Making the Case for Olin's involvement in K-12 Engineering Education

The case for improving STEM (science, technology, engineering, and math) education has been ongoing for over 15 years (Katehi et al., 2009). While strides have been made to redesign science and math education, very little has been done in engineering. However, many national boards including the National Academies of Engineering (NAE) and the U.S. Department of Education are looking to develop engineering in K-12 education (Kathei et al., 2009). Though core subjects do not change very often in education, in 2006 the state of Massachusetts added engineering to its curriculum frameworks, the state standards for subjects covered in education (Perova et al., 2009).

There are a number of reasons that national boards and industry have cited for moving engineering into K-12. First, it allows us to maintain a flow of students into the engineering "pipeline" (Katehi et al., 2009). Second, in a technology-driven world, technological literacy for all citizens is invaluable to progress (Katehi et al., 2009). Just as citizens should be able to read and write, they should have a basic understanding of how technology works, how it is designed, and how society and culture influences its development. Third, engineering design is an excellent tool for supporting student development of essential skills such as analytical thinking, communication, collaboration, and adaptability (Katehi et al., 2009). Fourth, engineering is an excellent vehicle for strengthening student understanding of science and math (Katehi et al., 2009).

However, the biggest problem facing engineering in the K-12 curriculum is a lack of professional training in engineering. Most teachers of engineering in K-12 have a technology or science education background, and very few have engineering degrees (Katehi et al., 2009). To help support engineering in K-12 classrooms, many colleges and universities have started outreach programs. These outreach programs take a variety of shapes. Programs can be faculty-run or student-run; volunteer or paid; part-time or full-time; and/or have students teach in classrooms or faculty train teachers in summer programs. Each type of program has made different impacts on their communities and students. Many of these outreach programs are run through engineering departments and collaborate with university education departments. All of these programs use hands-on learning and the engineering design process to motivate students.

Olin College is uniquely positioned for facilitating education outreach in order to meet the nation's goals. The college has an interest in bettering engineering education, and encouraging interdisciplinary studies and project-based learning methods. Students and faculty are involved in rigorous education research spanning many different areas. As a small school of roughly 300 students and 30 faculty outside the Boston area, Olin is capable of being involved with many different types of organizations (schools, museums, etc.). The college has started pursuing outreach program development through a STEM program with the Boston Metro West schools and through a service initiative, Engineering Discovery (as well as a handful of other programs including FIRST mentoring and the Society for Women Engineers middle school girls program). However, existing programs require support from the greater Olin community, in order to develop a large-scale operation that is sustainable beyond the four years of an undergraduate experience.

Olin College can create a sustainable program in education outreach, through on-campus and in-classroom programs facilitated by Olin undergraduates and mentored by Olin faculty. The curriculum we develop through this program can then be exported to other area schools and classrooms. This proposal aims to identify an outreach model appropriate for Olin, in order to meet nationwide goals for K-12 engineering education. In the following proposal, we will discuss the goals of engineering in K-12 education, the role existing outreach programs have played in K-12, and why Olin is the perfect new addition to the space.

Engineering in K-12 Education

Technological literacy and the engineering pipeline

In a world where technology plays an increasing role in our lives, technological literacy for all citizens is invaluable (Perova et al., 2009; Katehi et al., 2009; Sullivan et al., 1999). By understanding technology, citizens can make informed decisions about it and can readily understand their consumer impacts (Katehi et al., 2009).Unfortunately, most people think of technology in terms of its artifacts (e.g. cell phones and computers). Many do not understand how technology influences society or how it is developed (Katehi, 2009). In fact, there is a pervasive perception that engineers are not responsive to the needs of society and the economy (Katehi et al., 2009). This misunderstanding of the role of engineering in today's world directly affects the flow of engineering students in the pipeline.

Among educators and policy-makers, there is increasing concern regarding the matriculation of students into engineering fields. While the department of labor predicts over 50% increases in the STEM workforce, states are seeing a decline in the number of students graduating in engineering (Rockland et al., 2002). In addition, most students that enter engineering for college are strong students in math and science, but we need to attract a wider pool of students to fill the pipeline (Katehi et al., 2009).

Engineering education in K-12 curriculum allows us to generate an understanding of how engineering and technology influences social, economic and cultural systems (Sullivan et al., 1999; Katehi et al., 2009). It also allows us to generate an understanding of the subject at younger years to build a pipeline into engineering (Kimmel and Cano, 2001; Katehi et al., 2009).

Finally, engineering education allows us to move citizen perceptions of technology as artifacts to an understanding of process, ways-of-thinking, and capabilities (Perova et al., 2009).

Engineering as a classroom learning tool

Engineering education in K-12 curriculum is an excellent classroom tool. The engineering design process facilitates the development of important twenty-first century skills and opportunities to apply concepts from the other STEM subjects.

In 2006, the Harvard Change Leadership Group identified “The Global Achievement Gap” (Wagner, 2008). Students in the United States are struggling to develop skills that matter most for the twenty-first century. These survival skills, identified by the Harvard Change Leadership Group through interviews with educators and business leaders include:

1. Critical Thinking and Problem Solving
2. Collaboration
3. Agility and Adaptability
4. Initiative and Entrepreneurship
5. Effective Oral and Written Communication
6. Accessing and Analyzing Information
7. Curiosity and Imagination (Wagner, 2008)

In this new age of technology and rapid innovation, it is important for students to develop more active, analytical skills. The ability to approach problems creatively and to communicate and collaborate with others is invaluable to the twenty-first century attitudes in the workplace. Business leaders are calling for all employees, from those in upper management to those serving in the military, to acquire a new set of skills (Wagner, 2008).

The nature of the engineering design process can clearly motivate the development of Wagner’s survival skills. The design process requires students to brainstorm ideas and solutions, encourages students to find multiple solutions, facilitates iterative development, and calls for evaluation and optimization (Katehi et al., 2009). These steps require students to:

1. Think creatively about the subject
2. Analyze the situation and propose solutions
3. Adapt ideas to constraints
4. Work with teams collaboratively, and
5. Communicate ideas to peers.

Just through the nature of engineering design, six of Wagner's seven skills can be utilized. An instructor can easily adapt the lesson to include an "initiative and entrepreneurship" component by rephrasing problems in terms of addressing a societal need.

Engineering curriculum can also be a tool for contextualizing other subjects. Applying math and science to engineering problems can improve student comprehension in all areas. Some studies have shown that engineering education improved test scores in math and science (Katehi et al., 2009), though further research needs to be conducted. In addition, using subjects such as history to contextual technology advances, can give more meaning to the history lesson and a social context for engineering (Katehi et al., 2009).

Engineering education in K-12 is invaluable to the changing economy and technology-oriented society. Unfortunately, very few K-12 instructors are trained in engineering (Katehi et al., 2009). In addition, these more hands-on activities require smaller student-teacher ratios. Universities have started outreach programs over the past decade to provide the tools and support for K-12 educators to move forward on integrating engineering into the curriculum.

University K-12 Engineering Outreach Programs

Why University Outreach?

Over the past decade, curriculum standards across the nation have been changing to incorporate active learning methods. In 1996, the National Science Education Standards changed to encourage more inquiry-based approaches (Williams, 2002). In 2006, Massachusetts State added engineering to its K-12 Curriculum Standards. However, in a changing environment, teachers struggle to balance their time between meeting these new standards, developing new curriculum, attending district and state meetings, and creating units that appeal to a diversity of students (Swift and Watkins, 2004). To meet these challenges, schools have partnered with university outreach programs. Universities can provide the technical expertise for encouraging the educational reform that the national boards are seeking (Williams, 2002).

Program types

In 2002, the Science and Technology Policy Institute (STPI), funded by the NSF, conducted a lengthy investigation of the impacts of university outreach programs[1] (Williams, 2002). The STPI discovered over 200 university outreach programs as they began their investigation (Williams, 2002). These programs spanned several types: direct classroom enhancement programs, teacher-preparation programs, teacher-researcher programs, one remote classroom enhancement programs, and one instructional material development program (Williams, 2002). In the direct and teacher-preparation programs, science graduate and undergraduates work in classrooms with K-12 teachers to support them in STEM instruction (Williams, 2002). In the teacher-researcher program, teachers spend some time with graduate students conducting research and developing activities based on their experiences in the lab for the classroom (Williams, 2002). The graduate student serves as a resource for science knowledge and ideas. In the remote classroom program, scientists are paired with K-12 classrooms and answer questions students have about a topic via email (Williams, 2002). Finally, the materials development program, undergraduates create new curriculum to distribute to K-12 teachers

[1] While the STPI focuses on science outreach, the research outcomes are parallel to the impacts of engineering programs. Thus, we will treat the two STEM subjects similarly, while acknowledging that engineering outreach will differ due to the teacher's complete inexperience with the topic. The STPI discovered over 200 university outreach programs as they began their investigation (Williams, 2002). Ultimately, the researchers conducted 80+ interviews across eight outreach programs, choosing programs that had been in existence for more than five years (sustainable) and worked with underserved communities (Williams, 2002).

(Williams, 2002). In addition to the programs observed in the STPI study, there are many afterschool and summer university outreach programs and teacher-training programs.

Direct classroom enhancement programs (Formal learning environments)

Many programs focus on developing curriculum for the teacher's use (Carpinelli et al., 2004; Swift and Watkins, 2004; deGrazia et al., 2000; Rogers and Portsmore, 2004). Engineering curriculum can take two routes (Kimmel and Cano, 2001): 1) a complete engineering curriculum or 2) engineering lessons integrated into science and math units. The first approach is more feasible at middle school and high school levels where electives are offered (Kimmel and Cano, 2001), but this means only attracting students who are interested. The second allows for adaptation into classrooms for all students.

The University of Colorado Integrated Teaching and Learning (ITL) laboratory focuses on taking the second approach to curriculum development (Schaefer et al., 2003). The curriculum development process requires four individuals: an engineering student, a K-12 teacher, a university faculty, and outreach staff. The engineering student researches and develops engineering curriculum. The K-12 teacher provides the classroom experience expertise and works closely with the engineering student to develop activities. The university faculty reviews and provides technical expertise and support for the engineering student. Finally, the outreach staff coordinates and oversees the other interactions (Schaefer et al., 2003). ITL's research shows that the engineering student thrives when he or she is able to develop curriculum and present their units in class (deGrazia et al., 2000). Therefore, curriculum is designed, tested, reviewed and revised before considered complete. All individuals are paid for their support to the program (Schaefer et al., 2003).

Ideally, the curriculum activities are assistive for teachers and are guided by the teacher's expertise in working within a K-12 classroom (Swift and Watkins, 2004). These lessons should try to employ many of the senses, and tend to be hands-on (Swift and Watkins, 2004). The Tufts Center for Engineering Education Outreach (CEEO) took curriculum development a step further and developed the NXT LEGO robots as a tool for K-16 classrooms (Erwin et al., 2000). CEEO has shown students working with LEGOs as early as Kindergarten studying friction and as late as college building a CNC milling machine (Erwin et al., 2000).

The New Jersey Institute of Technology's (NJIT) Center for Pre-Engineering Instructional and Outreach Program is over 30 years old(Carpinelli et al., 2004). They develop curriculum for classrooms, either using curriculum from a national program, Project Lead the Way, or through curriculum integrated modules which use engineering to advance science and technology. In the Pre-Engineering Instructional teachers are brought on campus for three weeks, are trained by the program, and then work in afterschool programs during the year (Carpinelli et al., 2004).

The aforementioned programs typically employ engineering students. In contrast, the University of Colorado has also offered a service-learning course, the K-12 Engineering Outreach Corps, as an upper-level technical elective (Sullivan et al., 2005). In this 3-credit course, students teach engineering weekly in two classrooms in grades 3-6. Within the formal course, there are two university engineering instructors with experience working with K-12 students. The course meets three times a week, where students work on their own curriculum unit, have weekly discussions on pedagogy supported by literature, and practice teaching sessions. The students journal about their classroom experiences weekly and give presentations three times a semester (Sullivan et al., 2005). It's a great opportunity for students to apply their technical expertise to new problems, and survey feedback showed that students felt this was a rigorous technical elective (Sullivan et al., 2005). The biggest challenge for this course was finding a 5 hour open block in the students' schedules for teaching. In addition, some professors were not supportive of this course offering as a technical elective (Sullivan et al., 2005).

NSF offers a graduate student fellowship for employing students to work in K-12 classrooms during the year, NSF GK-12 program. Through this grant, CU-Boulder employs graduate students to spend 10 hours/week in classrooms. As engineers, they are role models for K-12 students and collaborators for teachers (deGrazia et al., 2004). The Tufts Student Teacher Outreach Mentorship Program (STOMP) pairs engineering students with K-12 teachers and classrooms. This program began through a small fund from the LLL foundation, though now is self-funded through paid Weekend Workshops (Portsmore et al., 2003). The mentor positions are paid, so that more students can devote time to their program (Cejka et al, 2005). STOMP is used as an opportunity to further curriculum development and the development of educational tools including the LEGO robots.

These programs are different examples of university outreach that directly enhance the classroom. They support teachers through curriculum development and technical training. They can support K-12 students directly through mentoring opportunities. These types of programs achieve the goals of many national organizations for bringing K-12 into the classroom.

Out-of-classroom activities (Informal learning environments)

Informal learning refers to activities that occur outside of school and are voluntary by nature (Hofstein and Rosenfeld, 1996). While in-classroom activities target all populations, these types of programs seem to enroll particular types of students. Students who enroll in voluntary science/engineering programs are typically ones who out-perform peers, are inquiry-oriented, and prefer student-centered activities (Hofstein and Rosenfeld, 1996). Many outreach programs, including the New Jersey Institute of Technology and University of Colorado at Boulder, offer these outside-of- school programs.

The ITL offers summer programs as an opportunity to train new university engineering students in teaching and allow the entire program to regroup (deGrazia et al., 2000). The ITL hosts programs at their campus to expose students to the collegiate environment. One successful program they have held is the Girls Embrace Technology (GET). They invite “techno-neutral” girls to participate, students who are highly motivated but would never consider a career in technology (Sullivan et al., 2003). GET is a six week summer internship, with a modest stipend of 80 dollars per week. The objective is to have high-school girls engage in a “job-like” experience, developing educational software for younger students on teams of four. In order to create a greater community support, parents are given a pre-orientation and invited to an exposition, EXPO, at the end of the summer (Sullivan et al., 2000). The assessment data from this program is overwhelming. Students in this program are given a pre-test and post-test with content knowledge questions in areas of programming structures, digital image file format, user interface design, etc. The overall scores of students went from 32% correct on the pre-test to 81% correct on the post-test (Sullivan et al., 2000).

The ITL also hosts the *Success Institute* for under-represented minority students in engineering. This is a 2-5 day on campus summer program for high school students. It is unique in that the program engages students, parents, and industry to create a meaningful engineering experience. While the students participate in activities, parents attend talks and discussions about how to best support their children in pursuing STEM careers. In addition, minorities from industry, conduct a panel to discuss their careers and “how they got where they are” (deGrazia, 2001). By hosting programs on campus, the ITL is able to take advantage of their lab spaces and design studios, for students to have a collegiate experience (deGrazia, 2001).

NJIT also hosts competitions and provide research opportunities on campus for students to have contact with the university experience. They host a Career Day on campus, inviting teachers and students to various engineering departments. The departments host lectures and demonstrations, providing an opportunity for local kids to gain exposure to college academics (Rockland et al., 2002). In addition, they have hosted a Women's Summer Engineering Career Exploration Program on campus, where female students reside in the dorms, and undertake an engineering design project and visit local engineering companies (Rockland et al., 2002).

While outreach programs predominantly focus on working in classrooms, many also have university-based experiences to expose students to higher education environments. In addition, the experience allows programs to train new outreach undergraduate students in working with younger students and regroup the entire team.

Impacts on K-12 students and teachers

The researchers found that the effects in classrooms from these outreach programs were motivational (Williams, 2002). Teachers noted attitude changes towards science among the students. Outreach programs show greater gains in technological literacy; students in a post-activity phase indicated that they "did not feel engineers spend most of their time with their computers" (Hynes, 2007). Female students also showed greater gains in feeling that engineering is useful to everyday life (Hynes, 2007). Student test scores tend to increase through participation of in-class outreach programs; a Tufts GK-12 program showed a jump from 72% to 93% on standardized test scores (Rushton et al., 2003).

In order to create more interest in engineering, outreach groups develop curriculum and programs with contextualized goals. Tufts creates situated robotics activities to attract women and minority students (Zeid et al, 2007). For example, a design challenge for developing assistive devices is appealing to these groups who enjoy helping others (Zeid et al, 2007). By appealing to student interests, engineering curriculum can motivate excitement.

Teachers in outreach programs have a lot more hands-on curriculum to work with. Teachers who were part of outreach training programs indicated more confidence in teaching engineering modules to their students, responding in a survey they “could teach the lessons tomorrow” or “glance at their notes first” (Carpinelli et al., 2003). They also enjoy the opportunity to collaborate with someone (Portsmore et al., 2003). The sheer presence of another individual in the classroom means a reduction in the student-to-teacher ratios (30:1 to 15:1), allowing for more flexibility (Williams, 2002). Teachers began teaching more STEM and start acting more as facilitators rather than lecturers (Williams, 2002).

Impacts on university students

University students that join outreach programs have many motivations. Many want to help children and get engineering into K-12 classrooms (Pickering et al., 2004, Cejka et al., 2005). Others believe in the value of citizenship (Cejka et al., 2005). These university students typically show an interest in education, but have no room for the courses, so they join outreach endeavors (Pickering et al., 2004). Many outreach programs consult with their university’s department of education in the development of material for the program (Williams, 2002). The interaction and impact of working with K-12 students keeps undergraduates returning to the program (Pickering et al., 2004).

Many studies have shown that outreach students feel more confident about their communication skills (Cejka et al., 2005; Gravel et al., 2005; Pickering et al., 2004; deGrazia et al., 2000). They develop a greater depth of subject knowledge by thinking about how to break it down for younger students (Williams, 2002). Students also develop a greater appreciation for educational resources (Williams, 2002; Cejka et al., 2005; Gravel et al., 2005, Kotys-Schwartz et al. 2005). Case studies show students have an increased desire to teach, and graduate students bring pedagogy from K-12 classrooms into undergraduate classrooms (Kotys-Schwartz et al., 2005). Interestingly, graduate students never mention compensation as a motivator for joining this program. However, undergraduate students frequently cite money as a motivator for working with an outreach program (Williams, 2002). In addition to this gain in communication, engineering outreach students are developing other critical skills. Gravel et al. showed that their students feel they have improved in their ability to work on teams as well as realize their personal strengths (2005).

Outreach programs also seem to attract and retain more females (Pickering et al., 2004). There are offshoot benefits for women in outreach programs. In general, women in engineering need applications and context for their work (Pickering et al., 2004).Outreach programs provide a social context for engineering. Teaching also allows women to overcome any intimidation they might generally feel in classrooms (Pickering et al., 2004). Students incorporate their coursework into their teaching, giving them another opportunity to understand the material. Women become more familiar and content with concepts, thus gaining confidence (Pickering et al., 2004). More rigorous investigation needs to be conducted, but the initial study finds that outreach can lead to minimizing attrition of female students.

Surprisingly, the biggest challenge faced by outreach groups is a lack of support from their university (Williams, 2002). Outside of the outreach program groups, there are few among the college faculty to support the group. They view the goals of these programs to counter the goals of the university programs. The question that is frequently raised by these skeptics (and congress) is: what is the long-term pay-off from getting students who don't plan to teach in K-12 classrooms? (Williams, 2002). However, the research presented in the previous paragraphs show that students gain valuable skills in communication and knowledge of material.

Characteristics of successful, sustainable outreach programs

The STPI investigation cited five major characteristics for a successful outreach program (Williams, 2002). They need shared vision: unite people of different backgrounds and inspire all involved with the project (Williams, 2002). The program needs personnel, "a champion", who is not afraid of breaking the norm and setting up the endeavor (usually a senior faculty who has nothing to lose) (Williams, 2002). Strategic planning and support infrastructure are critical to maintaining a sustainable program (Williams, 2002). Finally, locality was cited as a major characteristic –having students that can walk to their partner school allows for a stronger bond between the school and university (Williams, 2002).

In addition to the characteristics outlined by the STPI, many groups identify paid undergraduates is critical to a long-lasting program (Portsmore et al., 2003; Williams, 2002). The Tufts program had volunteers in an early version of the program, but struggled to keep students who held campus jobs. By creating campus-job positions, undergraduates can make a bigger time commitment, of roughly 6-8 hours per week, on outreach (Portsmore et al., 2003).

While many successful outreach programs are in place, Olin College is in a unique position for contributing to this space. The college's focus is on renovating engineering education. In the following section, we will discuss Olin's place in engineering education at the collegiate level and how these lessons can be taken into K-12 environments.

Olin College of Engineering and Education

In addition to identifying gaps in K-12 education, universities and national organizations have identified problems with undergraduate education. The environment for engineering has changed over the past couple decades, from defense to commercial competition (Prados, 1998). Today's engineers need to be trained in an active, project-based learning environment, which emphasizes the development of skills such as communication, design, collaboration, and an appreciation of multiple solutions (Prados, 1998). The Accreditation Board for Engineering and Technology (ABET) revised their accreditation criteria in "Engineering Criteria 2000" to include: "ability to communicate effectively", "ability to design a system, component, or process to define needs", and "motivation and ability to engage in lifelong learning" (Prados, 1998).

In response to calls for a better engineering program, the F.W. Olin Foundation donated over 300 million dollars in 1997 to start a new innovative college (Somerville et al., 2005). Located in Needham, MA, Olin College was founded with three aspirations:

> "1) the consideration of human and societal needs;
> 2) the creative design of engineering systems; and
> 3) the creation of value through entrepreneurial effort and philanthropy"(olin.edu, 2010)

In order to meet these aspirations, the community strives to discover and develop effective educational tools and tries to serve as a model for other institutions (olin.edu, 2010).

The Olin community has been working hard to explore new dimensions of engineering education and the impacts of curricular renovation on students. Where professors typically do not have an education background, much of the faculty at Olin are actively pursuing research and publishing in engineering education. The faculty have developed new curriculum and rigorously assessed new ideas. They collaborate with many universities across the country. In this section, we will discuss the role Olin has been taking in engineering education since its opening.

Curricular Innovation

As Olin developed its vision, the faculty put together a list of curricular goals in order to shape an Olin graduate. The goals for the curriculum include:

- Curriculum should motivate students to pursue lifelong learning
- Curriculum should have design throughout the four year program
- There should be a Senior Capstone program that is authentic
- Students learn to work as team members, individuals, and team leaders
- Students learn to communicate logically
- Students should gain global perspectives (Somerville et al., 2005)

The Olin curriculum has many distinguishing features. There is a focus on integration and coordination between subjects; this provides an opportunity for students to solve problems in a social context, develop communication skills, and practice lifelong learning skills (Somerville et al., 2005). The curriculum has an emphasis on engineering design, requiring all students spend between 20-60% of their time in a semester working on significant design projects (Kerns et al., 2005). Olin's goals for its students are similar to many of the identified twenty-first century skills.

Even before admission to the college, Olin strives to introduce students to active learning. During its prospective students' weekend, the admissions committee has seniors in high school engage in design challenges. In the 32nd ASEE/IEEE Frontiers in Education Conference, Frey, Horton and Somerville presented a team-based design activity for prospective students (2002). During the first two years of prospective student weekends, the faculty designed activities where students were challenged to build large (>5 feet) structures: towers and a cantilever system in the Babson College gym on teams of four (Frey et al., 2002). In the tower activity of 2001, the students were given the challenge of raising a flag as high as possible given the materials provided (Frey et al., 2002). In the cantilever activity, students were asked to maximize the horizontal distance of their system (Frey et al., 2002)

The faculty found that through these design challenges, students began to think creatively about how to use the materials provided to achieve their goal. Two examples of this creativity include using tissue crepe paper as suspension cords and designing a “scissors” mechanism to prop up a tower that is over 15 feet tall (Frey et al., 2002). By working on teams, students have the opportunity to work on critical skills such as: communication, team-work, and collaborative learning. In addition, the activity serves as a method to expose students to the types of teaching and learning methods that Olin uses (Frey et al., 2002).

This type of initial design challenge activity is similar to many K-12 classroom activities. The Tufts program has a classic module, “Build a Chair for Mr. Bear”, in which first and second graders are given a variety of materials and must build a sturdy structure for a teddy-bear to sit in (Rogers and Portsmore, 2004). These design challenges Olin students are engaged in are excellent ice breakers which can be adapted for students across many age groups.

Continuing into Olin’s curriculum, first-years are given the opportunity to study math, physics, and engineering within integrated course block (ICB). ICB emphasizes “fundamental and universal engineering ideas (e.g. effort and flow)” and engineering tools (e.g. numerical simulation and data acquisition)” (Somerville et al., 2005), and is taught by a multidisciplinary team. These ICBs provide the opportunity for students to connect their learning in STEM courses to the real world. The need for more integrated courses comes from rapidly changing science and technology in industry (Laughlin et al., 2007).

Olin faculty and students conducted research on these ICBs, studying student and faculty perceptions of integration in the curriculum. Laughlin et al. found that the stronger the relationship between the subjects, the more integration students perceived (2007). For example, if an equation learned was applied to a physics problem, students felt there was more integration. When Olin students were studying click beetles in an engineering design project and using click beetles in their physics and math problems, they felt that the ICB was truly integrated. Using a thematic project for the ICB creates a feeling of integration (Laughlin et al., 2007).

In addition, the dynamics between the teaching faculty (friendliness, coordination, and communication) affected how students perceived the integration of their courses and their enjoyment of the course. Having both professors present in class allows for natural collaboration; "[one professor] was talking about Ampere's Law then the other would jump up and be like, 'Hey, it's just like Green's Theorem', and do some math on the board …we [the students] called it 'Physulus'" (Laughlin et al., 2005). This type of dynamic excites students and encourages them to pay attention. In addition, Laughlin et al. studied the value of integration on students' learning. They found that integration contributes positively to the students' learning experience, providing relevance and application of math and physics principles to engineering design problems (Laughlin et al., 2005). In fact, most students in Laughlin et al.'s survey expressed the desire to see more applications as they were learning the disciplinary material (2005).

Canfield and Zastavker (2009) also investigated the roles of faculty conceptions of teaching in a first-year, small college math-physics program. The premise of their research was to determine how the previous experiences of the faculty shape a project-based learning course.

Typically, faculty enter academia with their pre-existing beliefs about teaching and learning, which are often resistant to change (Canfield and Zastavker, 2009). Here Olin examined the role faculty pre-conceptions take in the execution of a project based course. They found that while no faculty members felt their goals as an instructor was to impart information, many of them cited lecture as a useful tool for student learning. Surprisingly, faculty involved in team-teaching are still capable of maintaining “very different notions of how to educate students” (Canfield and Zastavker, 2009). In order to begin engineering education reform, faculty must make their teaching conceptions explicit and consider alternative conceptions of teaching and learning (Canfield and Zastavker, 2009). This research suggests that in team-teaching environments it is important to communicate ideas on pedagogy to create an experience that meets the goals of the program.

Integrating math, science, and engineering is the goal of many K-12 outreach programs. Tufts, CU-Boulder, and NJIT’s outreach programs develop curriculum that uses engineering design projects to span topics in mathematics and science. Olin College has previously conducted this work in its own classrooms, through the first-year ICB experience. Faculty continue to do research on the impacts of integrated coursework on students and their learning. The academic environment at Olin could be supportive for the development of K-12 engineering curriculum which integrates subjects from other disciplines.

Olin also places a great emphasis on design for its students; the undergraduates take about 16-20 credits of design before graduation (Somerville et al, 2005). In their first year, students enroll in Design Nature, focusing on design to prototype. In the second year, students take User-Oriented Collaborative Design (UOCD) where students develop concepts and models through interaction and collaboration with users. Finally, students take a design depth in a topic of their choice and take Senior Capstone as a culmination of conceptualizing and designing a prototype (Somerville et al., 2005).

Outreach programs employ engineering design in its activities for K-12. For example, the Tufts program has a module encouraging students to design assistive devices for handicapped individuals (Zeid et al, 2007). Students, especially underrepresented groups, appreciate engineering more given some social context (Zeid et al, 2007). Because Olin students undergo an intensive design program, they have a strong understanding of the full design process. They can use these experiences to create design activities for K-12 students. In fact, one Olin outreach program, the STEM academy, did develop a one-semester unit that paralleled the Design Nature experience.

Students at Olin also have the opportunity to take other innovative courses. The computer science (CS) faculty has tried to restructure typical computer science curriculum to have a smaller core (Downey and Stein, 2006). Olin emphasizes the context of problems and solutions, which is adapted into the CS curriculum. Software Design, the first core CS course, presents computation as an interactive process, with emphasis on incremental design. Students engage in a team project, designing a software system of their choice, learning how to program with others, where students learn how to communicate their work with others (Downey and Stein, 2006). Examples of final projects include educational software, networked video-games, file sharing systems, programs that analyze text, etc. The CS curriculum then advances into two other core subjects: Foundations of Computer Science and Software Systems, with emphasis on experimental design. The CS curriculum at Olin has a smaller footprint than most schools, which allows for students of other disciplines to gain skills in computation. For example, a computational biologist needs skills in both CS and biology (Downey and Stein, 2006).

Among high school students, girls have previously made up less than 20% of the population that takes the advanced placement (AP) exam in computer science (Sullivan et al., 2003). K-12 outreach strives to attract women into computer science by exposing them to the subject. The CU-Boulder GET program attracts "techno-neutral" women, to engage them in computer science. The GET program is similar to many of the goals of Olin's Software Design; the students work on teams to develop a software program that meets some design goal in order to learn essential programming concepts. Olin's commitment to contextualized CS learning is invaluable to the development of K-12 programs. Placing engineering in context is a primary goal for the national boards and department of education.

Perhaps the best documented curriculum innovation has been in Olin's materials science curriculum. In Olin's introductory materials science course, the faculty strive to foster creative processes and attitudes (Stolk, 2009). Stolk's introductory materials science course is broken up into three major phases, lasting 5 weeks each, and facilitating students' conceptual understanding through project work (2009). On the first day of class, students are greeted with a pile of random products (toys, appliances, etc.). They choose a product and a team, and spend the first 5 weeks studying the material properties of their product and consider it with regard to its application (Stolk, 2009). The common technical goal of "connecting structure and composition to properties and performance" ensures that students develop conceptual understanding of material science. In the second project, students explore metal alloys and processing techniques. In the final project, students study modern materials. In all three phases, students explore material science techniques and principles through their projects, using textbooks, references, faculty and staff expertise, and teaching assistants to gain new knowledge (Stolk, 2009). Olin curriculum survey results revealed that over 60% of students strongly agreed with the statement “this course helped me think creatively about the subject”. The other percentage selected “agreed”.

Olin continues to push the envelope on its material science courses. In order to understand the impacts of society on engineering, Martello and Stolk have developed an eight-credit course combining humanities and materials science, Paul Revere: Tough as Nails (2007). The goal of this course is to integrate the broader social, historical, and contextual impacts into technical subjects. Here, the professors begin the course by connecting the material culture of ancient societies with techniques and structure and properties. The middle of the course involves using Paul Revere’s records of metalworking activities to learn metallurgy. Finally, the course concludes with an exploration of modern materials (Martello and Stolk, 2007). This course sounds similar to the introductory course described in the previous paragraphs (Stolk, 2009), but here the work is contextualized against the backdrop of culture. In Olin curriculum surveys, the students were shown more strongly to agree with statements like “This course helped me to think creatively about the subject” and “this course stimulated my interest in the subject”, though further studies need to be conducted to analyze these findings (Martello and Stolk, 2007).

Many students do not understand the impacts of culture and society on engineering and innovation (Katehi et al., 2009). Martello and Stolk’s Paul Revere course is an incredible matching of history and technology. Students who undertake this course gain an appreciation for the impacts of culture on technology. Olin students, studying engineering in the context of history and engineering, can develop outreach programs that integrate subjects such as art and history to engineering.

Stolk, a current faculty member at Olin, has also co-authored other papers regarding conversion of traditional materials labs to project-based learning experiences at California

Polytechnic State University. At CalPoly, they have redesigned their courses to be project-based, going through an intensive redesign of the curriculum using design principles (Savage et al., 2007). In one course at California Polytechnic State University, the instructors developed sophomore and junior level courses where students use design problems to study materials science (Vanasupa et al., 2007). For example, a group of students needed to heat treat roller bearings for a particular application. Another team of students was asked to improve the design of a prosthetic device. The students were found to be extrinsically and intrinsically motivated to conduct the project work, and identified their peers as learning resources (Vanasupa et al., 2007). Students in the project-based courses at CalPoly identified themselves as more independent and self-reliant, capable of directing their learning (Savage et al., 2007). These types of activities at Olin can be adapted for K-12 environments, to encourage younger generations to become independent, active, and curious learners.

Olin is actively developing curriculum and analyzing its effects on students. The types of projects explored in this section could be adapted to meet the needs of K-12 classrooms. In addition to surveying students in innovative courses, Olin faculty and students conduct research on the impacts of courses on underrepresented groups. Currently much of this research has focused on gender.

Gender and Engineering

Olin College has a number of faculty that investigate the role of gender in engineering. As of 2001, women made up 57.4% of the college population, but only 20.1% of all bachelor’s degrees in engineering go to women (Zastavker, 2006). Olin faculty members investigate a wide number of factors that affect women in engineering. Professor Chachra and her colleagues have shown women are more aware of how an engineering task is situated, and show more engagement with courses and extracurricular activities (Kilgore et al., 2007). However, there appears to be a confidence gap in engineering projects, even among high-performing students (Chachra et al., 2009). By building reflection into coursework, such as portfolios or small group seminars, perhaps some of these perceptions can be mitigated (Chachra et al., 2009).

It is important to tailor courses to support women in engineering. Zastavker et al. studied the effects of project-based learning on first-years (2007). The results showed that both men and women find in-class group work helpful to their learning, with no statistical differences. Both genders also report that project-based learning connects course work to real life in meaningful ways, making learning more fun (Zastavker, 2007). Despite these similarities, women reported feeling “anxiety” and that the “courses were challenging”, more so than men. In contrast, more men than women reported feeling “bored” and “not challenged enough” (Zastavker, 2007). While project-based learning can be beneficial to both genders, care must be taken to avoid perceived differences (Zastavker, 2007).

Olin faculty and staff are rigorously investigating impacts on females in engineering courses. Similarly, many outreach programs are assessing their impacts on female students **(**Sullivan et al., 2009; Hynes, 2007). Olin can look to the research faculty are conducting in these areas as it develops an optimal program. In addition, the faculty and students who have experience conducting rigorous research in these areas can provide advice and support for developing assessment plans for our K-12 outreach programs. This personal strength allows us to evaluate and assess work internally.

Implications for K-12 engineering education work

Olin College is an education innovator. The community not only works to develop curriculum that meet the goals of national groups and industry, but also reflects on the impacts of these courses and learning environments on students. Much of the research conducted by Olin faculty and students is parallel to the work conducted by K-12 outreach programs.

Olin has a commitment to integrated coursework, design, and innovative coursework that contextualizes engineering against social and cultural constraints. This is precisely the type of curricular innovation that the national boards are looking for in K-12 education. It would be a natural transition for Olin to begin work in the K-12 environment, using our faculty experiences to conduct rigorous development and assessment of programs.

The Olin College curriculum encourages students to develop twenty-first century skills: critical thinking, collaboration, adaptability, initiative, communication, and imagination. In addition, some coursework is integrated with other subjects, contextualized against society, and there is significant emphasis on design. K-12 education is looking to improve these skills and introduce engineering with these methods. Olin College is in an ideal position for involvement in K-12 education.

Possible Models for Olin's Involvement in K-12 Education

Given Olin's dedication to innovative engineering education, the College is in a unique position to join the K-12 outreach efforts. Many model programs exist, spanning direct classroom enhancement, after-school programs, summer camps, and Saturday programs. Olin College students and faculty have run many different programs over the years, with some that have lasted multiple years. In this section we will explore Olin's outreach programs, and propose a sustainable model based on other established programs and consideration of Olin's resources in this area.

A quick view at Olin's involvement to date

Olin's education outreach initiatives have nominally been student-led. Over the past nine years, students have started or been a part of many endeavors: FIRST robotics, Society of Women in Engineering outreach programs, the STEM academy, and Olin Engineering Discovery. Many of these programs are characterized by volunteer endeavors. Some are supported by professional societies and others are independent initiatives.

FIRST robotics mentoring is a popular program at Olin. FIRST is a national competition that challenges high school students to design a LEGO robot to succeed in a variety of mechanical tasks. College students mentor these teams and are critical resources. Olin works with The Engineering School in Hyde Park, working with low-income students. Olin students commit to working nearly ten hours per week during the FIRST build season, January through March. The Olin volunteers give students advice on how to build their robot and how to program it. These undergraduates are a connection to the real engineering world. This has been an ongoing service project since Olin's inception, though commitment from Olin students has varied quite a bit.

The Society of Women Engineers (SWE) has been active in education outreach for several years. SWE students collaborate with a group based in Cambridge, the Science Club for Girls (SCGF), working with 7^{th} and 8^{th} grade students. Their partnership has been sustained over the years through the support of the SCGF director, Connie Chow, incidentally an Olin faculty member's spouse. The partnership began in fall 2007 and has lasted through the present (May 2010). In the past, roughly six Olin females would spend Saturday afternoons for three hours at an SCGF site in Newton, MA. However, the Saturday time made it difficult to attract the middle school students. In addition it was a significant time commitment for Olin students. This year, they changed their model to working with a local elementary school, Newman Elementary, which is less than a mile away from Olin's campus. As an afterschool program, five Olin students worked with 17 girls, weekly, with a low time commitment of roughly three hours. The SCGF partnership has been successful due to a few factors for success (as identified by the NSF study): a supportive partner, close proximity, and low time commitment. Because of Connie Chow's close relationship with Olin and role in outreach, it is easy to maintain a partnership and adapt to Olin student needs.

The STEM academy was a 2008-2009 program funded by the Regional Employment Board. Local high school students from MetroWest schools were bussed onto Olin's campus nearly every Saturday during the semester. The program planned to have high school students join in ninth grade and continue the program through their senior year. Approximately four Olin students developed and taught curriculum under the mentorship of engineering faculty. The students say that the work was the equivalent of a four-credit Olin course. They were compensated for the time spent teaching. This program ended last term due to a shortage of funding.

Olin Engineering Discovery is the longest-lasting education outreach program. This student organization's sole purpose is to bring engineering to K-12 students (typically targeting 4th and 5th graders but has worked with 1st-8th grade). It started as a service project by the inaugural class, where students worked with the Needham afterschool program, volunteering once a week at Hillside Elementary school. In fall 2007, Olin students reorganized the project to reach more students. With a team of roughly 15 Olin undergraduates, they re-designed curriculum and began new endeavors. The team spent a semester working with Trotter Elementary school in Dorchester, MA, a school where over 75% of students are eligible for free lunch. They started hosting on-campus Saturday events at Olin with the Needham community, raising 700 dollars per event. At present, Engineering Discovery runs a variety of programs: weekly visits to three classrooms at Stanley Elementary in Waltham through the Tufts STOMP program, semester Saturday Workshops at Olin with Needham students, and bi-weekly visits to the Needham Housing Authority. Next year, they hope to expand to a new partnership with the Spirit of Knowledge Charter School opening in Worcester, MA in September, 2010.

Engineering Discovery is a successful program that has sustainably grown over the past few years. Because it is a program striving to share Olin's goals with the local community, this proposal will focus on models for Olin to adopt through Engineering Discovery.

The pros and cons of different outreach program types

Most outreach programs focus on direct classroom enhancement models. Admittedly, the value of engaging with students in their classrooms is very high. The National Academies are interested in bringing engineering education into the curriculum (Katehi et al., 2009). The purpose of outreach is to provide the training and support for teachers to bring engineering into their classroom. The presence of an undergraduate in engineering brings the student-teacher class ratio down by 50%, making it possible to have more personal interaction for students. Also, the teacher gains confidence and curriculum for teaching engineering.

Through direct classroom enhancement programs, Olin students would have the opportunity to develop curriculum that can be used by teachers indefinitely, long after Olin students graduate or move to different schools. In addition, Olin undergraduates have continued first-hand interaction with younger students, allowing the opportunity to build trust and relationships. Finally, through working with an experienced teacher, Olin students can gain an appreciation for education that they can bring back to their college coursework.

If not in classrooms during the school day, an afterschool program model could be used. It still allows Olin undergraduates to work with a steady group of students and possibly have teacher support. However, afterschool programs have the disadvantage of largely targeting students who are already interested in engineering or are self-motivated

The biggest disadvantage for working anywhere off-campus from Olin is the time commitment. While Olin students can serve many local populations in the Needham-Wellesley area, low-income neighborhoods are further away, typically requiring a 30-60 minute drive each way. With a 1-2 hour commute and another 1-2 hours spent at the school, an Olin student needs 4 hours just to teach on any given day. It is difficult to find a continuous block of time of that size in the Olin schedule. Doing an afterschool program might have fewer conflicts with the Olin course schedule, allowing more Olin students to participate in outreach. However, 4 hours of teaching time, and another 3-5 for preparation, meetings, and supply acquisition, brings up an Olin undergraduate time commitment to 9 hours per week.

One way to alleviate the burdens of a large commitment is to offer a financial incentive. This year, over 100 students have held campus jobs, usually working between 3-10 hours a week. Offering undergraduates a salary allows more students to participate in the outreach program. Nearly every sustainable engineering outreach program pays its undergraduates and the NSF STPI study found that undergraduates consider the pay an enabling factor.

Incorporating in-classroom outreach into college coursework is also another method for bringing Olin students into classrooms. Similar to the CU-Boulder course, Olin could offer a technical engineering elective centered on topics in education with a core part of the course including student teaching. One benefit of this method would be that we don’t need money immediately. However, this model does not have enough support to encourage students to stay with the program beyond 1-2 semesters.

On campus programs are another option for Olin outreach efforts. Programs on campus give the opportunity to expose students to the collegiate environment. In addition, Olin can create programs with a heavier focus on engineering, facing fewer limitations on the subjects covered. Saturday programs at Olin are an excellent choice for fundraising efforts with the local community. Tufts offers Saturday programs for this purpose. However, a long-term Saturday program is not recommended. Engineering Discovery's experience shows that sports conflicts and travel logistics make it difficult to offer these types of programs to either affluent or low-income populations. A summer camp would be a great opportunity to reach students and get new Olin students involved with Engineering Discovery. While Olin students frequently keep internships during the summer, a one-week program either at the beginning or end of the summer could be feasible.

Other factors for success

In addition to selecting program types that maximize Olin student participation, it is important to gather additional support from Olin faculty and staff. Faculty involvement in engineering education outreach has been critical to long-lasting programs shown by CU-Boulder's ITL and the NSF report. At Olin, there are a number of professors conducting research and experimenting in engineering education. Their experience is beneficial to the design of new curriculum and programs. In addition, they have the capability and experience to pursue grants for innovative education projects, and the background for conducting research of outreach programs for evaluation. Evaluation is important for application for federal and industry grants.

Finally, professors are capable of carrying the program forward as Olin undergraduates are only around for four years.

Programs have also cited that staff/personnel are critical to maintaining the program. At Tufts, they employ graduate students as staff. CU-Boulder's ITL office has several staff members. These individuals take care of budget, finance, maintaining contacts with schools and officials, and monitoring grants and funding opportunities. Currently, Olin students try to cover all of these roles in Engineering Discovery, but usually lose track of these items when focusing on teaching. Hiring a staff member to take care of these logistics allows undergraduates to focus on their students. In addition, the staff member can continue sharing their experience with generations of Olin students, whereas an undergraduate leaves Olin within four years.

A Program for Olin

Olin's Engineering Discovery holds programs across many different program types. A combination of working within classrooms and hosting programs is the best way to reach a variety of K-12 students and include the most Olin students. Engineering Discovery has secured partnerships with area schools in Waltham and Worcester, MA. In addition, they are exploring the possibility of working locally with the Needham Public Schools. Finally, they plan to continue hosting Saturday workshops at Olin as a fundraising effort.

In addition, for a sustainable outreach program it is critical for Engineering Discovery to have faculty mentors and outreach program staff. This will facilitate the growth of the program for years to come. Faculty and outreach staff can help coordinate students, research and evaluate the success of programs, and apply for funding through industry and federal grants. With their support, this student organization can become an integral part of the Olin community.

Conclusions

Engineering in K-12 education has a variety of benefits for society. It exposes students to technology and gives them a better understanding of the influence society has upon its development. It exposes children to the subject, encouraging them to consider it as a career path. It is an excellent platform for integrating math and science topics into an application. Finally, the engineering design process facilitates the development of many critical 21st century skills. However, the current education system does not have the resources to integrate engineering into the curriculum.

Olin College, as an engineering education innovator, can provide the resources and expertise to develop a strong, sustainable outreach program. Their focus on design, project-based learning, and innovative coursework is well-matched with the goals of K-12 education. Through the help of faculty, staff, and undergraduates, Olin can provide the curriculum and expertise to meet the needs of K-12 students and teachers, both within local schools and on its college campus. In addition, outreach programs present the opportunity to build community relations and build industry partnerships. Olin College is capable of offering a sustainable K-12 outreach program for the community.

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