Improving Future Faculty with Graduate Engineering Education

Abstract

One of the major missing links in today’s graduate engineering curriculum is the lack of effective preparation of students who plan on entering into academia upon graduation. While classes exist to prepare future engineering faculty, these classes are often taught by current faculty members with limited breadth of experience in dealing with difficult students or difficult situations. Formal teaching methods are often not supplied – and practical experience is limited, often resulting in poor and ineffective communication between faculty and students.

This paper will address a potential solution towards preparing graduate students in becoming future engineering faculty. The paper will focus on several engineering graduate students who participated in a grant linking their education, research, and career development. The development of the graduate students in the program is rooted in a 20 hour a week commitment to develop and implement self-created, engineering and research related lessons in local high schools throughout the academic year. The paper will analyze the impact of the program’s required summer class, yearlong practicum classes, mentoring activities, and self-reflection on the individual graduate students’ ability to effectively communicate their research and lessons to the high school students.

The paper will use data collected throughout the previous year, from the summer instructional planning class, weekly graduate student reflections, weekly practicum classes, self-reflection notes from bi-weekly meetings with the high school teachers, meetings with the faculty mentors, and most importantly from data collected after several key major lessons taught by each graduate student at their locally assigned high schools.

Currently in its ninth year, program findings indicate that the experiences in this program have a positive effect on the communication abilities of the graduate students. In particular, the students’ ability to take their current research and effectively communicate it to high school students with limited technical knowledge and experiences will be showcased. The focus of this paper will be on the previous engineering graduate students, each assigned to a different school with diverse culture and economic backgrounds and each working with four different teachers in that school.

Project STEP Overview

Our project is currently in its ninth year of funding. Bringing well communicated engineering concepts, based on a city theme and graduate student research, into high school classrooms is the main focus of the project. The graduate students, called STEP Fellows, are the main focus of the grant. The STEP Fellows, 15 from 2006 to 2009, are trained to bring their complex graduate research to an understandable and interesting K-12 level. This process instills better communication skills in the STEP Fellows and breaks any reservations of working with the K-12 environment once employed as a university faculty member. On average the University of Cincinnati’s (UC) Project STEP partners with five high schools a year. At each high school we
place one graduate engineering student Fellow. Each Fellow works with four teachers at the school. Usually this means that one Fellows works with two mathematics teachers and two science teachers. Each Fellow creates and implements major lessons that span a few days to a few weeks for each teacher. All of the Fellow products (lesson plans, worksheets, pre/post tests, PowerPoints, posters, etc…) are available to the public on our website (www.eng.uc.edu/STEP click on lessons). A small sample of the 120 + lessons that have been created, implemented, and made available via the web include: Foul Water (environmental engineering), Computer Evolution (computer science engineering), Earthquakes (civil engineering), Food for Thought (chemical engineering), Polymers (materials engineering), Range of Motion (biomedical engineering), Blast Off (aeronautical engineering), Electromagnetic Induction (electrical engineering) and Car Design (mechanical engineering).

Although the chief goal of this project is to produce scientists, engineers, and secondary mathematics and science educators who are experienced in developing and implementing authentic educational practices, the secondary goal is to impact student learning by relating STEM content to urban city issues through the use of hands-on, technology-driven, inquiry-based projects that relate to the desired curriculum. Students need an understanding of STEM and the reasons to pursue STEM careers; over 3,000 students have been exposed to STEM lessons in the past three years with Project STEP. Teachers of these students are involved in this process as well, and 36 different teachers have participated in the STEP program between 2006 and 2009. Lastly, Project STEP focuses on the sustainability of the program itself. The university faculty participants, six primary investigators and four coordinators, play a large role in facilitating the promotion of community partnerships with teachers, K-12 students, and Fellows.

**Training of the Fellows**

Long term goals for our project include: 1) To train, energize, and sustain graduate engineering, math and science Fellows to effectively teach STEM skills to secondary school students; professional development of each Fellow that involves lesson observations, lesson plan documentation, and course mastery of instructional planning and practicum; 2) Develop hierarchical and expandable STEM lesson plans that explicitly connect key concepts at different grade levels; and enhance student learning in STEM disciplines that involves student activity feedback forms completed by students after each lesson or activity; and 3) Sustainability of the project that will plant the seeds of systemic change at the university and K-12 schools through synergistic partnerships that ensures the sustainability of the program beyond NSF funding.

These goals are met through graduate engineering Fellow training in the summer and during the academic year. Additionally, project teachers, university personnel, and Fellows interact during frequent meeting times and three major events during the year.

Our project’s objectives for the Fellows include: 1) Engage Fellows in productive and innovative instruction and activities to enable teaching STEM skills; 2) Connect education, research, and career development of Fellows; 3) Mentor Fellows in best teaching practices; 4) Provide practical teaching experience for Fellows; and 5) Fellows develop and deliver authentic high school learning activities. Figure 1 shows this process.

Our project’s objectives for the secondary teachers, students, and schools include: 1) Increase student learning and interest in science and mathematics; 2) Use hierarchical learning model to
connect concepts in curriculum; 3) Deliver hands-on inquiry activities in 9-12 grade science and math curricula; 4) Connect city problems with student learning to contextualize STEM education; 5) Integrate authentic STEM learning across grade levels, courses, and schools; 6) Incorporate hands-on examples of technology in teaching activities; 7) Incorporate computer-based learning in teaching activities; 8) Enable teacher use of multimedia/web resources for course design/delivery; 9) Create a scalable network of partners; 10) Enable STEM teachers to share research skills with classrooms and colleagues; 11) Implement changes in high schools and the community to sustain the program; 12) Implement changes at the university to sustain the program.

Figure 1: GK-12 Fellow Training Wheel

Evaluation Methods Based on Goals

In relation to goal 1 and Fellow training, Fellows are trained extensively throughout the year and each lesson that is produced, with intense K-12 teacher and university personnel input, is recorded and publicly accessible on a website. These recorded lessons are rated using the Revised Teaching Observation Protocol (RTOP). This protocol was developed as an observation instrument to provide a standardized means for detecting the degree to which K-12 classroom
instruction in mathematics is reformed. The developers did NOT presume that reformed instruction is necessarily quality instruction. The RTOP is divided into five categories: 1) Lesson Design and Implementation, 2) Content: Propositional Pedagogic Knowledge, 3) Content: Procedural Pedagogic Knowledge, 4) Classroom Culture: Communicative Interactions, 5) Classroom Culture: Student/teacher Relationships. The Psychometric properties of the RTOP include reliability, face validity, and construct validity. Summaries of these ratings and an overview from the observer are given to each Fellow so he/she can improve his/her next lesson. Fifteen observations are conducted by the end of May each year.

In relation to goal 2 and enhanced student learning, student learning is evaluated for each lesson via a pre- and post-test related to the content taught. These tests are distributed, collected, and analyzed by each Fellow. Student responses are shown in Figures 2 and 3.

<table>
<thead>
<tr>
<th>Prompt: Overall, I would rate this lesson as:</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>1</td>
<td>.3</td>
</tr>
<tr>
<td>Fair</td>
<td>9</td>
<td>2.5</td>
</tr>
<tr>
<td>Average</td>
<td>42</td>
<td>11.8</td>
</tr>
<tr>
<td>Good</td>
<td>171</td>
<td>48.2</td>
</tr>
<tr>
<td>Excellent</td>
<td>102</td>
<td>28.7</td>
</tr>
<tr>
<td>Total</td>
<td>325</td>
<td>91.5</td>
</tr>
</tbody>
</table>

Figure 2: 2008-2009 Student Activity Feedback Sheets - All Lessons - Interest

<table>
<thead>
<tr>
<th>Prompt: I learned a lot from this lesson</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>3</td>
<td>.8</td>
</tr>
<tr>
<td>Disagree</td>
<td>13</td>
<td>3.7</td>
</tr>
<tr>
<td>Neutral</td>
<td>74</td>
<td>20.8</td>
</tr>
<tr>
<td>Agree</td>
<td>163</td>
<td>45.9</td>
</tr>
<tr>
<td>Strongly Agree</td>
<td>100</td>
<td>28.2</td>
</tr>
<tr>
<td>Total</td>
<td>353</td>
<td>99.4</td>
</tr>
</tbody>
</table>

Figure 3: 2008-2009 Student Activity Feedback Sheets – All Lessons – Learning

In relation to goal 3 and sustainability of the project, data from Focus Groups with each constituent group (Fellows, teachers and PIs) are conducted annually. Each group will involve a different set of constituents. Event data from the Fellow Showcase is collected from K-12 teacher and PI attendees. Event data from the Technology Workshop is also collected from K-12 teacher and PI attendees. Event data from the Open House are collected from teachers, visitors, and the project oversight committee. The project oversight committee meets with the fellows, teachers, and PIs during the Open House as well as attends the presentations. This event occurs in April each year and data is incorporated into the final Evaluation Summary for the Project.
Important to note is that overall, this project is meeting all 3 goals. The Project Oversight Committee members gave the following very positive feedback at the April 2008 Project STEP Open House:

- **Great Job!** See comments throughout. I really believe the project could lend itself to add it to the research base.
- **The leadership for the STEP Fellows is very much in evidence.** The integration across each STEP team, K-16 is particularly noticeable. Finally, the learning outcomes for Fellows and K-12 and excellent modules and very accessible.
- **The STEP program has a well developed strategy to bring engineering to High school students.** The modules and lessons created by the Fellows program and to the teaching and learning of STEM disciplines. The enthusiasm that the Fellows expressed during their presentations demonstrated that the goals were met. The opportunity to travel and teach in Tanzania gave depth and breadth to the STEP experience. The lessons learned from this project should be modeled across all NSF GK12 Funded proposals.

**Challenges and Obstacles**

The major challenges of the Fellows include time management and successful implementation of teaching techniques. Our training program addresses both of these factors, and over the last three years there has been a decrease in Fellow anxiety due to time and teaching methods. Major challenges for K-12 teachers include time and including another teacher in the classroom. These challenges are addressed at our annual Showcase with encouraged questions and dialogue. Student challenges center on math and science concepts. Training of the Fellows highlights proven methods of student engagement for increased science, technology, engineering, and science impact.

**Fellow Highlight**

The wind blows, and the high school students are huddled together in one big group. The river that runs by their feet is cold and has not been warmed by the sun. The sun that should be shining is hiding behind clouds, and on any typical day in April it would be at least 70 °F. Today it’s only 45 °F. There are eighteen students standing in the cold, murky water of the Mill Creek Watershed in Cincinnati, Ohio. They are here collecting water samples to analyze, with the purpose of using both traditional and novel scientific methods to determine if this particular section of the Mill Creek is still contaminated. Mill Creek is considered an impaired watershed for many reasons: high nitrate, high phosphate, and high levels of fecal coliforms to name a few reasons. Fecal bacterial indicators, such as fecal coliforms indicate that there is a potential risk posed for human health. The problem is that simply measuring fecal coliforms or E. coli (traditional methods) does not tell the students from where the source of fecal contamination is coming. This is where the novel molecular methods come into play. Through the PhD work of one Civil and Environmental Engineering graduate student, NSF GK-12 Fellow One, novel bacteria were identified that are endemic to specific GI-tracts of certain animals (i.e there are groups of bacteria only found in the human gut, in the pig gut, in the cow gut, etc.). By using molecular methods, such as Polymerase Chain Reaction (PCR), the students can target the DNA of these bacteria and figure out what is contaminating the water. This method is also robust because it is fast, and within three hours the students can tell what type, if any, fecal
contamination there is in a water sample. This is exactly what the students did on that cold day, and they found that the Mill Creek water samples they analyzed were contaminated by human fecal pollution sources. They were disgusted, but empowered with a purpose.

Once the students identified the source of the contaminant they teamed up with watershed managers to create ideas to reduce the source of that fecal pollution using a best management practice. The partnership for this project is between Fellow One (GK-12 Fellow), the high school teacher, the high school students, the Mill Creek Watershed Restoration Program (MCRP), the program educator from MCRP, and a university faculty member. The collaboration comes full circle and demonstrates a true partnership. The method developed by Fellow One under the guidance of a faculty member was passed on to high school students and a high school teacher (who will do this again!) who will use the method to inform their watershed managers of potential causes for high fecal bacteria counts. These busy students collected water quality data such as nitrate, phosphate, pH, biological oxygen demand, turbidity and fecal coliforms, and they went a step further and identified the problem. Additionally, the data they collected goes into the MCRP database and is used to determine if the water quality in the watershed is getting better or worse over time. These students are scientists, doing scientific research, and they want to be doing this work. So, as the wind blows, it’s not just making students cold, it carries the promise of real solutions to a current problem. This is an authentic scenario of a community partnership that happened outside of Cincinnati, Ohio in April of 2009.

Gina Lamendella said, “When I began the NSF GK-12 STEP program, I knew that I would be the scientist/engineer coming into the classroom to inspire students about learning science, engineering, and math. What I didn’t realize was that the students would give me something I have been searching for during my entire graduate career: a reason for the countless, lonely hours spent in the laboratory, reading, and writing. While I understand my research has very important and tangible environmental impacts, I found myself still feeling something was missing in my scientific endeavors; sharing my research experience with the generation that will improve on it and carry it forward. I was excited by the fact that students at Norwood High School were eager to learn about my research, they understood my research, and realized the positive impacts of conducting scientific research.” This type of learning, not acquired in a classroom setting, is invaluable for future faculty.

**Fellow Feedback Data**

Fellows are at the heart of Project STEP. A review of the survey reflections submitted by 12 of the 15 past STEP Fellows from 2006 to 2009 elucidates the role of the university graduate student in the STEP program. Each Fellow stands in a unique position as a kind of pivot point among high school and university educators, high school students, and the university research environment. Effects of the experience, voiced through the mouths of the participants, range from purposeful enthusiasm to the need for resolution. For most of the Fellows, STEP is an “eye-opener” into teaching, and most (67%) Fellows state that they want to teach at some level in the future. One Fellow states that STEP “help[s] me see and understand realities of teaching.” STEP has an overall positive effect on the majority (70%) of Fellows based on the online survey as shown in Figure 4. The STEP Fellows show a better understanding for GK-12 everyday teacher challenges and student interactions. The overwhelming majority of Fellows found the STEP experience directly influenced their ability to manage time, their verbal communication and
presentation skills, and their career goals. This 80% felt that the STEP program highly influenced their understanding of the K-12 environment in tandem with their confidence in teaching in general. Interestingly, two inquiries into STEP program influence turned up very different results: ability to complete lab work and understanding of collegiate teaching. In two cases, Fellows report no affect on their ability to complete lab work and in another the Fellow states that her understanding of collegiate teaching was unaffected. Despite some of these differences, positive comments regarding STEP abound. For example, a Fellow states, “Being with the students has been great!” The Fellows also participate in the following three main events during the academic year to promote STEP community awareness and effective communication skills: UC Fellow Showcase, UC Fellow Technology Workshop, and the UC STEP Open House. It is no secret that, for the Fellow, the STEP program comprises an exciting, extreme immersion into a different environment, an opportunity to connect the distinct worlds of secondary school and the university at many levels. At the same time, it is quite clear that most Fellows (75%) exit this experience more sensitive to the needs of GK-12 teachers and learners, more likely to assume both roles in the future. Since Fellows, or future university faculty, recount empathy for teachers, compassion for learners, and interest in the learning process, this program has affected the outlook of future STEM professors on teaching and learning and thus ensures sustainability of Project STEP.

Challenges

One aspect of the program that needs further attention is the influence that STEP has on the Fellows’ research. There is a broad agreement among seven of the twelve responding Fellows (58%) that the STEP program requires more time and effort than initially anticipated. Specifically, time management is one of the biggest obstacles that the Fellows face. Four Fellows (33%) agree that STEP does not leave them enough time to focus on their research and related lab work. One Fellow stated that, “STEP broke my time available for my own studies and research into little... chunks.” According to the survey, the STEP Fellowship takes priority in time management and further focus on graduate research can come only when STEP work is finished. Although time is an important topic in the survey, it is also shown that STEP helps the Fellows manage time more efficiently, based on the 87% rating (Figure 4).

![Figure 4: Project STEP influence on STEP Fellows](image-url)
Additionally, it has been a challenge to link the Fellows' research with specific content in the course curriculum maps provided by the secondary teachers before the academic year begins. A real key to sustainability of the program may be the ease of integrating lessons and mini-activities into the school district-required course content.

Lastly, wording in the student activity feedback form may lead to multiple interpretations. This is a concern. For example, “this lesson increased my interest in studying engineering,” may be answered as ‘neutral’ or ‘not at all’ by a student who was already very interested in engineering.

**Impact of Training**

One of the most difficult interactions to measure, the impact of formal training on the Fellows, is done somewhat informally. During the Fellows initial summer instruction period they are given small scale teaching assignments (10-15 minute lessons) in order to familiarize them with the classroom atmosphere. The instructor gauges their effectiveness in communication and informally interviews the Fellows to assess their comfort and confidence. Further training is applied to the students based off of perceived weakness from both instructor and Fellows. After the initial summer instruction, it becomes difficult to differentiate the impact of the weekly practicum course and the weekly in-class experience, as the source of Fellow development. Our current model uses the practicum class as a way to discuss major occurrences within specific Fellow classrooms, and using them as learning opportunities for all the Fellows. Since no formal method exists to judge the impact, we rely solely on the feedback of our Fellows. What follows is a response from one of the Fellow which is typically of the other Fellows as well. "Coming into the STEP project I had significant experience interacting with K-12 youth, but more in one-day outreach activities - I was completely lacking in any real ability to effectively interact in a class setting. Being able to slowly transition into an educator role during summer was crucial in being able to hit the ground running the very first week of school - I didn't just sit in the back of class and observe - I was able to provide real engineering and scientific connections as well as fundamental support in all my classes (Physical Science, Geometry, AP Biology and AP Calculus). While training during summer seemed long the end benefit to myself, my teachers and our students well outweighed the upfront time commitment."

**Conclusion**

Through both the data and the testimonials, from Fellows and K-12 students and teachers, we have established a baseline of the STEP Fellows improvement in their ability to communicate engineering content. Our findings indicate that our Fellows’ increase in communicative abilities is due to their constant interactions with current faculty and staff as well as their weekly integration in K-12 classrooms. In order to further strengthen our findings, we recommend a comparison of teaching evaluations of Project STEP alumni currently in faculty positions with other new faculty members.

**Acknowledgement**

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