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Engineering Visiting Fellows: A modular, low-cost model for scalable, university-facilitated international K-12 partnerships in engineering education

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Abstract

A grand challenge in the global engineering community is the recruitment and retention of students. Previous research in engineering education has shown that pre-college exposure to engineering plays an integral part in student self-selection of engineering as a course of study at the university level. Presented in this work is an international program which seeks to attract talented students through the use of NSF GK12 Engineering Visiting Fellows and cross-cultural, hands-on problem based design projects. In this two-year study, 5 separate projects are carried out involving 690 students split between urban high schools in the United States and partner secondary schools in Kenya. Quantitative and qualitative analysis is carried out using surveys developed by a third party program evaluator. The outcomes of the program in achieving student engineering self-efficacy, interest in engineering careers, and awareness of global engineering challenges through cross-cultural communication are evaluated in the context of program cost and overall impact. Future expansion plans of this pilot project are also presented.

1. Introduction

The engineering community in many nations across the world is struggling to attract and retain students. This is a concern because a lack of qualified engineers in society creates long-term structural inabilities to address the challenges both developed and developing societies are facing.[1, 2] Research has shown that exposure to engineering and engineering concepts at the K-12 level greatly increases student interest, knowledge and retention in engineering fields.[3-5] This project seeks to create such exposure for secondary school students globally. In this work, a scalable, modular, low-cost model project is presented in which engineering graduate students act as NSF-sponsored 'Visiting Fellows' bringing the National Academy of Engineering's Grand Challenges for Engineering (Table I) concurrently into two different classroom contexts: an inner-city American partner school and a partner school in Kenya.

Table I - The National Academy of Engineering Grand Challenges for Engineering

Make solar energy economical	*Provide energy from fusion*
Develop carbon sequestration methods	*Manage the nitrogen cycle*
Provide access to clean water	*Restore and improve urban infrastructure*
Advance health informatics	*Reverse-engineer the brain*
Prevent nuclear terror	*Secure cyberspace*
Enhance virtual reality	*Advance personalized learning*
Engineer the tools of scientific discovery	*Engineer better medicines*

The role of the Visiting Fellow is to prepare both classrooms for long-term international partnership in secondary engineering education. A partnership is developed by having each Visiting Fellow distill her Ph.D.-level research in engineering into tangible, curriculum-integrated content for the high school classroom with the assistance of participating science teachers. This classroom content is turned into a hands-on, problem based engineering design project that emphasizes the global nature of one or more of the NAE Grand Challenges. The NAE Grand Challenges have been shown in previous research to be an effective contextualization tool in the K-12 environment.[4]

In this implementation, the visiting fellows were participants in a larger, multi-year NSF GK12 grant. The fellows visited a classroom in Philadelphia regularly and adapted their projects into two-week intensives. The fellows then traveled to Kenya, where they helped and trained teachers to implement the design project in a two-week intensive. A fundamental tenet to each design project was the use of online communication (videoconferencing, teleconferencing, e-mail, and/or social networking) between both students and teachers from different cultures in performing background research, carrying out the engineering design process and delivering final design project content. The relationship developed between teachers and the use of online communication enables the project to continue long-term and at low cost.

2. Methodology

This project was carried out over a period of two years. In the first year, a single Visiting Fellow successfully piloted the 2 week intensive in a rural Kenyan school. In the second year, 5 Visiting Fellows and 2 evaluators participated in a scaling of the Visiting Fellows Program. A total of 690 students and 12 teachers at 4 secondary schools in the US and Kenya participated in the interschool partnership. However, as this project seeks to examine the efficacy of the two week visiting scholar intensive and not the year-long GK12 program (results from this program are reported in other works [6-8]), the results from the schools in Kenya (304 participants) are the focus of the data reported here.

All students participated in one of five different individual projects developed by an NSF GK12 Fellow. Depending on the needs of each school, projects were run either daily after school or within science classrooms. The five individual projects developed and implemented are:

Your Hand in the Future - Technology in Music and Entertainment
The music, arts and entertainment community deeply depend on the expertise of many types of engineers to create, produce and perform their art through the use of many technologies. In this project students participate in a set of hands-on activities on password protection and cyber security, sound effects and sound processing, and microphone and speaker construction.

Your Hand in the Future - Light, Photography and Remote Sensing
Whether it be for the purpose of creating art of the protection of the world's nuclear arsenals, light and photography are universal technologies. Multiple types of engineers are necessary to create even the simplest cameras. In this project, students participate in a set of hands-on activities that help the students to understand the basic nature of light, polarization in photography, infrared photography, and remote sensing through the use of holographic optoelectronic nanocomposites.

Designing Health Clinics for Your Partner Classroom
In both developing and developed countries there is a great challenge and need for properly functioning, well-designed health clinics. The needs of each culture and location are,

however, unique to the local environment. In this projects, two schools from different cultures partner together. The students perform research on and at local health clinics and relay this information to a partner school on another continent. After learning from the other culture, students on one continent are tasked with designing a health clinic for the partner school.

Biowall Design: Enhancing Urban Infrastructure through the use of Biowalls
As cities grow larger and the share of world population living in cities continues to rise, there is an ever-increasing demand for methods of integrating green spaces into urban infrastructure. One such method is to use bio-walls, which are vertical structures comprised of plants and organic matter. Biowalls have been proven to enhance indoor air quality, improve aesthetics, and passively filter building water supplies. In this project/competition, student groups design and construct their own biowalls for the school.

Biofiltration: Using locally grown plants to filter polluted water supplies
A grand global challenge is the need for clean local water. This projects aims to help students understand the role that locally grown plants can play in the filtration of numerous harmful water source pollutants. In this hands-on design competition, groups of students research the biofiltration capabilities local plants and the pollutants found in local water supplies. Student groups then design, build and test a biofiltration structure comprise of local biological matter and capable of filtering local contaminated water supplies.

Each one of the project topics demonstrates the expertise of a different Ph.D. Candidate in various fields of engineering. The two Your Hand in the Future projects were piloted with students in back-to-back years of the program in the same classrooms to demonstrate the potential for long-term continuity. The purpose of these projects was to introduce students to engineering, the engineering design process, the various fields of engineering, and the real-world applicability of traditional science principles through engineering and technology.

In addition to the engineering context of the classroom activities, the program also sought to promote cross-cultural communication and an understanding of the global nature of the world's grand challenges. Depending on the communications resources available, multiple methods were used for implementation of cultural exchange. In schools with sufficient technology and bandwidth, multiple live video-casts were carried out in which groups of students communicated about their research and their hands on projects. Some time was also given for cultural Q&A, such as questions about food, music, and lifestyle. In schools where connectivity and technology are a problem, classrooms would pre-record answers to a set of seed questions concerning their projects and culture. These pre-recorded videos were shown in the partner class and each class had an opportunity to provide a video response. Students were also encouraged to use moderated twitter and e-mail to share in their research where the technology was available.

One good example of the integration of culture into a project is in the "Health Clinic Design Project," in which students in rural Kenya traveled to local health clinics to do hands-on research. They relayed this research to their colleagues in the United States, who helped to design a health clinic for Kenya. Meanwhile, students in the United States had done research on American health clinics and relayed this information to the Kenyan students, who subsequently designs a health clinic to meet the demands of urban America. The "Technology in Music and

Entertainment Project" allowed students to learn about and share different music styles as they built homemade speakers out of locally available materials. The Light, Photography and Remote Sensing project allowed students to share their own photographic images of their schools and lessons learned digitally. Both the Biowall and Water Filtration projects allowed groups of students from the schools to share about the challenge of access to clean water from the cultural perspectives of a rural Kenyan and urban American environment.

2.1 Program Metrics

Quantitative and qualitative assessment is carried out in order to examine the efficacy of the program in [1] encouraging students to pursue engineering, [2] increasing student knowledge of engineering, [3] increasing awareness of the real-world applicability of the curriculum and [4] increasing awareness of global challenges and culture. A program-specific free response and Likert-based assessment tool is administered by a third party evaluator associated with the underlying NSF GK12 grant. The longevity of the program is explored using interviews with teachers and administrators, and the overall cost of the program is examined in the context of outcomes.

3. Results and Discussion

Student responses to the program as a whole (Figure 1) demonstrate the overwhelmingly positive results seen both quantitatively and qualitatively. 98.2% of participants agreed or strongly agreed both in the utility of the program and its ability to enhance their awareness of global engineering challenges. In the words of one student, "my favorite part of the program was getting to interact with trained scholars and also them helping me to expand my understanding of engineering." A majority of the students agree with this sentiment, since 97.1% of program participants stated that they believed that the program increased both their interest in and understanding of engineering.

More detailed student responses about interests in engineering are shown in Figure 2 and Table II. In these results, it can be seen that students were exposed to and engaged in learning about engineering. Before participating in the program, 46.5% of students listed engineering as on of their top 2 career fields of interest. After the program, this had increased to 71.9% of all participants amongst the same group of students.

Students were not only interested in engineering, but also became better versed in the various fields of engineering. Prior to participating in the program nearly half of the students participating had little or no experience with engineering. Over 90% of participants were only familiar with the fields of civil, mechanical and electrical engineering (as these are the traditionally predominating fields in Kenyan culture). By the end of the program, only 15.6% of participants still demonstrated a lack of knowledge about the various fields of engineering based on the same set of free response questions. One student said that, "I have come to see engineering as a means of improving every aspect of physical life. Before, I viewed engineering as useful for only a few aspects of physical life such as infrastructure." Another student stated that the program "enabled me to broaden my view of engineering," while yet another student said "[the program] has made me to change my perspective of engineering very completely."

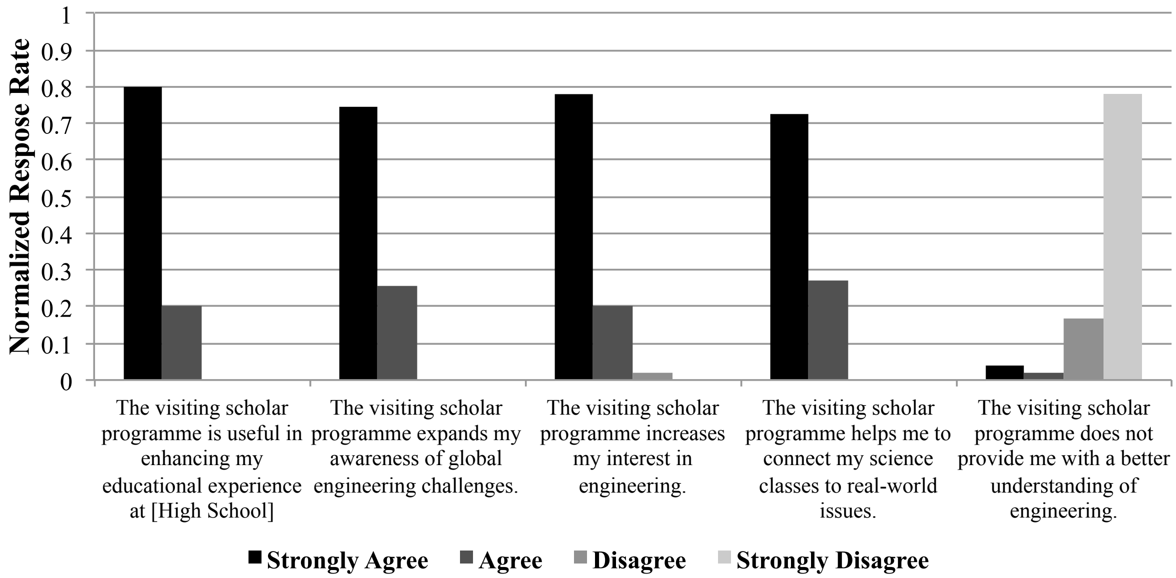

Figure 1 - Student perceptions on aspects of the Engineering Visiting Fellows program. The normalized response rate is graphed as a function of student responses to individual Likert-based questions.

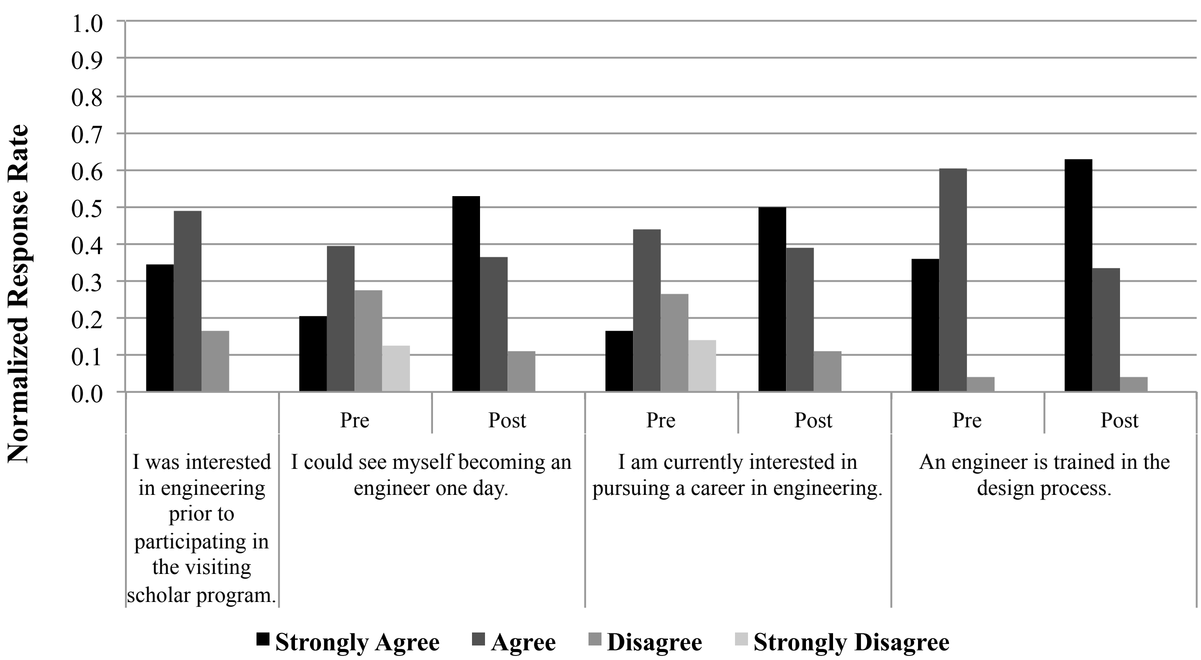

Figure 2 - Student perceptions on Engineering. The normalized response rate is graphed as a function of student responses to individual Likert-based questions.

Table II - Student Responses to Free Response Questions

Select up to two career fields you are most interested in pursuing academically and professionally.	Before Program	After Program
Engineering	46.5%	71.9%
Information & Communications Technology	42.6%	34.4%
Architecture	16.3%	12.5%
Business & Finance	24.9%	15.6%
Healthcare	18.6%	21.9%
Scientific Research	6.7%	8.3%
Other	17.0%	9.4%
What is the highest level of education you plan to pursue?	**Before Program**	**After Program**
Doctorate	46.5%	65.6%
Masters	26.7%	31.3%
Bachelor's	22.5%	3.1%
High School Diploma	4.3%	0.0%
What does an Engineer Do?	**Before Program**	**After Program**
Solid Grasp of Engineering	14.6%	31.3%
Some Understanding of Engineering	36.6%	53.1%
Little or No Understanding of Engineering	48.8%	15.6%
What was your favorite aspect of the NSF Visiting Scholar program?		
Videoconferencing with American Students	19.4%	
Hands-on Project Experience	54.8%	
Experience Researching for Project	22.6%	
The Visiting Fellows	3.2%	

Figure 3 shows the student responses in relation to their individual projects both before and after participating in the 2 week Engineering Visiting Fellow Program. In this data, a marked growth in student self-efficacy in the individual program topics is clearly demonstrated. After two weeks of hands-on activities, students felt confident in their ability to share their projects with their peers. They expressed an ability to relate their projects to the real world, to the classroom, and to engineering. In fact, 77.4% of the students who participated in the visiting fellows program stated in a free response that their favorite aspect of the two weeks was either research for or execution of the projects.

Hands-on, problem-based activities are nearly unheard of in Kenyan education, as nearly all learning is lecture style with some step-by-step laboratory work. As a result, these projects posed an educational paradigm shift for the students. In interviews, teachers also agreed that this pedagogical approach was more engaging and largely unknown to them in their educational training. There were only insignificant differences in student outcomes between the five projects implemented. Consequently, it becomes clear from the aggregate that using hands-on activities is a particularly effective pedagogical method for engaging students in engineering in Kenyan culture, and in any educational culture where lecture and memorization are the dominant pedagogical techniques. The exact content of the individual projects appears to be less important than the delivery method.

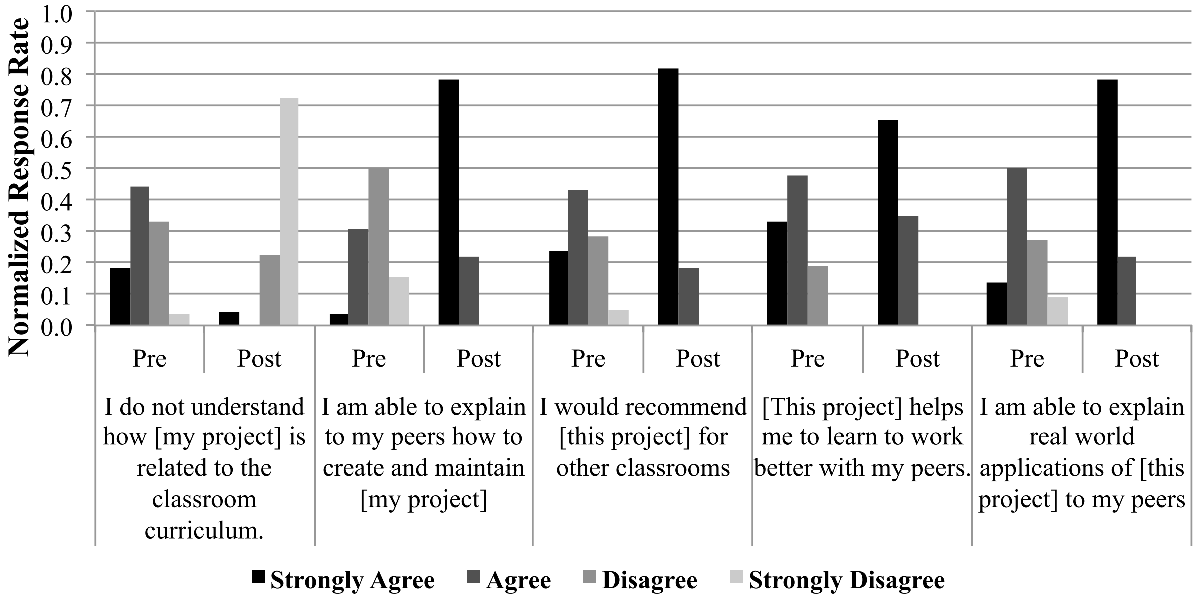

Figure 3 - Student responses to project-specific questions. The normalized response rate is graphed as a function of student responses to individual Likert-based questions.

Student cultural sharing, while not a quantifiable outcome, certainly received much interest and attention from the students, and in particular from the teacher interviews. 19.4% of all student participants listed their cross-cultural communication as their favorite aspect of the project. This is a direct result of only one of the partner schools having sufficient internet bandwidth and technology to support live videoconferencing. While over half of all students at other locations mentioned the importance of the cross-cultural sharing elements, the overall effect of the hands-on, tangible design projects has a greater impact. However, every Kenyan teacher interviewed mentioned the importance of the international nature of the project as fundamental to the education of their students.

As mentioned earlier in the paper, this work has been carried out in a manner designed to be scalable at relatively low cost. The total costs for the 1st year international pilot program (1 Fellow, 3.5 weeks) was $4,500, while the second year's scaled up program (5 fellows & 2 evaluators, 3.5 weeks) was $23,000. In total, the program has worked directly with over 300 direct project participants and 1,500 total students in Kenya over two years for under $28,000. Costs are kept low by having fellows participate in homestays or staying on school campuses. Such arrangements also dramatically enhance cross-cultural sharing both for the hosting schools and for the visiting fellows.

4. Conclusion and Continuing Work

Presented in this work is a method for engaging high school students in engineering globally through cross-cultural partnerships facilitated by an Engineering Visiting Fellow. In this project, 5 NSF GK12 Graduate Fellows in Engineering facilitated partnerships between secondary schools in a major American metropolitan city and in an Kenyan country. Quantitative and qualitative outcomes of the two week intensives in Kenya have been reported here. The

Engineering Visiting Fellows program has demonstrated dramatic increases in student awareness and interest in engineering, with 71.9% of all participants indicating an interest in pursuing engineering after participating. For under $28,000, a pilot and expansion of the program were run over a period of two years that reached over 1,500 total students, including over 300 who participated in targeted engineering design projects. Evidence of cross-cultural experiences is shown in student, teacher and fellow qualitative outcomes.

All current participating schools have indicated a strong desire to continue participation in the program, and over a dozen other schools have requested future partnership opportunities. In the coming years, the program plans to send 10 NSF GK12 fellows annually to 5 secondary partner schools in Kenya for the next 3 years. Post-secondary outcomes of previous program participants will be investigated in this work.

5. Acknowledgements

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