AC 2011-664: A REPORT ON A GK-12 PROGRAM: ENGINEERING AS A CONTEXTUAL VEHICLE FOR MATH AND SCIENCE EDUCATION

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A report on a GK-12 program: engineering as a contextual vehicle for math and science education

Abstract

This work reports on the cumulative results of a four year NSF GK-12 program that partnered Drexel University with the School District of Philadelphia. The premise of the program was to place GK-12 fellows in school classrooms to benefit the fellows, teachers, and students. The specific goals of the program were to improve the teaching, communication, and team skills of the GK-12 fellows, provide mentoring experiences for the GK-12 fellows, provide content enhancement for the GK-12 teachers, enrich and excite the science and math learning experiences of middle grade students, and to further strengthen the relationship between our university and the school district. The strategy for accomplishing this was the development of a unique presentation model that uses engineering in context and examples of engineering in the world around us as a vehicle through which to integrate and enrich the teaching of science and mathematics while embedding feedback and interactive processes by which the fellows, teachers, and students communicate shared experiences. The school students and GK-12 teachers gain an appreciation for the science and mathematics concepts in an applied, real world context while the GK-12 fellows become knowledgeable in pedagogy through direct application of their technical/scientific expertise in the context of the classroom setting, interaction with the teacher, mentoring students, and building their personal teaching and confidence. Thus the GK-12 fellows, teacher, and middle grade students all “learn-by-doing”.

Throughout its four year existence, our GK-12 program has impacted a large number of fellows, teachers and students. In total twenty one fellows partnered with twenty teachers from ten different public schools to impact over 1500 students. The student population was composed of primarily minority and low-income students. The fellows have developed more than 250 engineering based modules that are available for public access. To assess the effectiveness of the program, the fellows, teachers, and students were monitored throughout the school year. The fellows completed multiple surveys and wrote weekly reflection journals. The students were surveyed at the beginning and end of the year, while the teachers completed mid and end of year surveys. Evaluations of all three populations showed positive outcomes. The fellows developed their communication skills in the classroom and gained experience communicating their research to a non-specialized audience; the teachers reported their partner fellow as being a valuable asset to the classroom in a number of ways; and the students showed an increase in their knowledge of engineering, as well as their math and science skills.

In essence, our GK-12 program has been a true asset to the participating schools, classrooms, teachers, and fellows. It enriched education, utilized higher order thinking processes, incorporated technology and investigation, and created an environment where students work together to explore complex science concepts in a fun and exciting way. The teachers benefited by having a true expert in the classroom that implemented engineering modules and exposed the students to experiences they would not otherwise receive. Finally, the fellows developed as teachers, mentors, communicators and built partnerships with public school teachers and students.

Introduction

While the U.S. has long been regarded as one of the global leaders in engineering, recently engineering education in the U.S. has come under fire. In 2003, 46% of master's degrees and 57% of doctoral degrees were awarded to foreign nationals[1]. This problem will only continue to grow as a majority of U.S. children have not received significant education in engineering[2]. In order to strengthen the science, technology, math, and engineering (STEM) future of the U.S. the NSF GK-12 program funds graduate fellows in STEM fields to bring their knowledge and expertise into K-12 education. The purpose of the program is to benefit the graduate students as well as the K-12 education system collaborating with the GK-12 fellows[3]. The fellows gain valuable experience teaching in a K-12 classroom, communicating their research to a non-expert audience, and collaborating with a diverse team. Meanwhile, the collaborating teachers gain professional development opportunities and the K-12 students are instructed in STEM related topics that otherwise would not be taught. Furthermore the graduate school and local school districts have the opportunity to build a lasting partnership that can benefit both parties in the future.

This work reports on the cumulative results of a four year NSF GK-12 program, from 2006 to 2010, which partnered Drexel University with the School District of Philadelphia. Our GK-12 program paired graduate fellows with middle school teachers from the Philadelphia School District. The graduate fellows then spent ten hours a week teaching with their partnered teacher in the classroom. The fellows applied their expertise in engineering to develop lesson plans that use engineering as a contextual vehicle to teach math and science. Over the course of our program, the GK-12 fellows have developed more than 250 engineering based modules that are available for public access. Our GK-12 project aimed to benefit the GK-12 fellows, the GK-12 teachers, and the middle school students. In total, our program directly impacted twenty one fellows, twenty teachers, and over 1500 students. The student population was composed of primarily minority and low-income students. We have previously reported on the impact our program had on the students, as well as the effectiveness of specific modules[4-9]. Here we will give an overview of our GK-12 project, describe the methodology used to evaluate our program, and finally discuss the results.

Project Summary

During the four years of our GK-12 project, we sought to achieve four specific goals:

- Improve the teaching, communication, and team skills of the GK-12 fellows
- Provide mentoring experiences for the GK-12 fellows
- Provide content enhancement for the GK-12 teachers
- Enrich and excite the science and math learning experiences of the students
- Further strengthen the partnerships between our university and the local school district.

The project aimed to achieve these goals by employing engineering as a contextual vehicle for math and science education. Specifically, we developed a presentation model that used engineering in context and examples of real world engineering to integrate science and math education while ensuring constant interaction and feedback between the teachers, fellows, and students[10,11]. The fellows became regular members of the classroom and were directly involved in classroom instruction, curriculum development, student mentoring, as well as other school related activities. The teachers and students gain an appreciation for real world, engineering, applications of curricular math and science concepts while the fellows become knowledgeable in pedagogy through direct application of their technical expertise in the context of the classroom setting. In this way, the fellows, teachers, and students all participate in experiential learning. The fellows were chosen through an application process. The criteria for selection included academic standing, recommendations from their mentors and/or other faculty members, experience in working with students and teachers, ability to relate basic mathematical and scientific concepts through simple technological examples, interpersonal team skills, and leadership potential. These characteristics were measured through a paper application packet as well as an interview. The teachers were required to fill out an application and submit a personal statement. The teachers were required to be: a math or science teacher, committed to enhancing the level of science and math education in their school, effective communicators and collaborators, and open to innovative teaching techniques.

Each year of the program began with a two week summer training workshop for the teachers and fellows. The workshop enabled the fellows and teachers to form working relationships. The fellows learned about the teachers' school and the curriculum they teach, while the teachers were introduced to graduate life at the university and each fellow's research field. In addition, a faculty member from our education department instructed the fellows on pedagogy and lesson planning. Examples of some of the topics covered in this instruction include Bloom's taxonomy[12] and backward design lesson planning[13]. By the end of the summer workshop, each fellow had been paired with a teacher and together they had begun to plan lessons for the upcoming school year. Once the school year began, the fellows and teachers continued to collaborate to design new lesson plans, including activities that were based directly on the fellows' research. In addition to lesson planning, the fellows spent on average 10 hours a week working in the classroom.

Over the four year existence of the GK-12 program, we have impacted approximately 1500 middle school students, 19 teachers, and 21 graduate fellows. The middle school students impacted by the program were approximately 97% underrepresented minorities and 90% came from low income families. The fellows represent a diverse group; the fellows were 43% female, 14% African American, and 10% Hispanic. Additionally, the fellows came from the College of Arts and Sciences, the School of Biomedical Engineering, Science, and Health Systems, as well as all six departments in the College of Engineering. The fellows have written over 250 lesson plans in the TeachEngineering format[14]. The vast majority of these lessons are hands-on exercises or experiments, which vary from being math or science lessons highlighting an engineering application to full engineering design activities. One lesson was also selected as a finalist for the Premier Curriculum Award for K-12 Engineering. All of the lesson materials are freely accessible at our GK-12 website, http://www.http://gk12.coe.drexel.edu/.

The lessons developed by the fellows span a broad range of topics and methods. Some lessons are experiments or activities that are directly connected to the middle school curriculum while other lessons can be used as standalone activities. For example, our website contains lessons covering topics such as exponential decay, the metric system, surface area, as well as many other topics tied directly to the standard curriculum. There are also lessons covering topics like sound insulation and robotics that are not normally included in the curriculum. The lessons can be found through our GK-12 website by searching for key words or browsing. In addition, each lesson contains a list of the Pennsylvania Math and Science standards[15] covered in the lesson. This way, teachers are able to easily find engineering lessons that tie into their normal curriculum. Most of the lessons were designed for middle school students, but many lessons contain modifications for higher or lower grade levels. We have previously reported on the effectiveness and impact of individual lesson plans[5-9].

Many of the fellows have chosen to participate in additional activities with their students outside of math and science classes. For example, the fellows have acted as mentors to students for the Sea Perch program[16], the BEST robotics competition[17], the academic quiz bowl team[18], and the local science fair[19]. The fellows have also brought students to our university to see cutting edge research laboratories and to participate in hands-on activities with equipment and materials not available at their school.

Evaluation Methodology

The assessment data concerning the GK-12 fellows was measured by an external evaluator who has extensive experience in evaluating educational programs. The GK-12 fellows, middle school teachers, and middle school students were all assessed to determine the program's impact. The evaluation was done through observation, and specialized data collection, as well as traditional surveying. A combination of formative and summative evaluations was completed; formative analysis was used to enhance the program's performance while summative analysis to measure the final impact of the program. The evaluation methods used consisted of both qualitative and quantitative methods. The qualitative methods included observations, open-ended surveys, structured discussions, informal interviews, and peer evaluations. Quantitative data was collected using paper-based surveys employing a Likert scale of 1-4 with 4 being the highest. The middle school students involved in the program were given a survey at the beginning of the school year and one at the end. The surveys consisted of both open and closed ended questions which examined the student's knowledge, interest, and attitude toward engineering. The details of the students' evaluation were previously reported by Mitchell-Blackwood et al.[4]

The fellows were assessed informally throughout the existence of the program. These assessments consisted of bi-monthly meetings as well as weekly reflection journals. The meetings enabled the program coordinators and external evaluator to hear firsthand accounts of each fellow's classroom experience. In addition, the reflection journals contained more detailed accounts of classroom experiences and the fellows' self-evaluations. Finally, the external evaluator visited a number of classrooms to observe the fellows' interactions with the teachers and students during the second half of the school year. These assessment techniques consisted of anecdotes and personal observations; the only quantitative data gathered concerning the fellows' performance came from surveys completed by the teachers.

The teachers completed a survey at the mid-point and at the end of the school year. The teachers were asked to assess their perceptions of the benefits of the program to themselves, their class, and the fellow. The questions and results are shown in table 1. In addition the teachers were asked to give comments describing their general experience in the program.

Results

The results of the surveys given to the middle school students were previously reported by Mitchell-Blackwood et al. and the full details can be seen there[4]. In summary, the survey showed the students gained a greater understanding of engineering and more students were able to correctly identify engineers as designers and problem solvers at the end of the school year. The external evaluator's anecdotal findings demonstrated positive outcomes for the fellows and corresponding classrooms. The evaluator found from observation and conversations with teachers and students that the fellows were admired and welcomed in every classroom they worked in. The fellows formed close working relationships with the teachers and students often recognized the fellows as expert scientists. The evaluator observed the fellows capable of leading the classroom and "possessing an apparent enthusiasm for learning, solid content knowledge, and respect for everyone".

Ten teachers during the last two years of the program were given a survey at the middle of the academic year and at the end of the year. The survey consisted of 18 questions employing a Likert scale of 1-4 with 4 being the highest, as well as free response comment section. The results of the survey and select comments are shown below.

Table 1: Teacher Survey Results

	Mid-Year	**End of Year**	
Questions pertaining to Fellow as team partner:	**Mean**	**Mean**	**Change**
1) How successful is your Fellow at exposing students to engineering principles in a lesson plan(s)	3.9	4.0	2.6%
2) How successful is your Fellow at leading students through the lesson plan process	3.6	3.7	2.7%
3) How successful is your Fellow at engaging the class in discussions	3.3	3.8	**15%**
4) How successful is your Fellow at classroom management	3.4	3.3	-2.9%
5) How skilled is your Fellow at helping you find resources to use in a unit plan	3.9	4.0	2.6%
6) Overall, how effective is your Fellow in facilitating your experience in infusing engineering principles into the curriculum	3.9	4.0	2.6%
Questions pertaining to the impact of the program on participating teacher:			
7) Has the program helped in preparing you to implement methods of teaching that emphasize independent work by students that incorporate engineering principles	3.5	3.8	8.6%
8) Has the program helped you to integrate educational technology into the grade or subject you teach	3.4	3.8	11.8%
9) Has the program helped you to support your students in using technology in their schoolwork	3.0	3.8	**26.7%**
10) Has the program helped you to integrate technology into your	3.0	3.7	**23.3%**

teaching			
11) Has the program helped you to integrate engineering principles into lessons	3.4	3.8	11.8%
12) Has the program helped you to provide useful new ideas for teaching strategies to apply with your students	3.5	3.8	8.6%
13) Has the program led you to collaborate with other teachers not part of GK-12	3.0	3.0	~0~
Questions pertaining to the impact of the program on middle-school students:			
14) Has the program had a positive impact on your students' understanding of what an engineer or scientist does	3.5	4.0	**14.3%**
15) Has the program had a positive impact on the learning of mathematics and/or science on your students	3.9	4.0	2.6%
16) Has the program (and by inference the GK-12 Fellow's participation with you) had a positive impact on the study habits of your students	3.4	3.3	-2.9%
17) Have you seen an improvement in benchmark scores since the beginning of the year	2.9	3.3	**13.8%**
18) **Have you seen an increase in student interest to attend college**	2.3	3.3	**43.5%**

Teacher Comments about Program Experience

"Overall, I would like to sincerely thank you for allowing me to be a part of this program. It has proven to be invaluable for me, school and the students. I had not really thought about the engineering aspect of the science, because my focus was based on the inquiry. However, I see the necessity of integrating inquiry with the engineering and math."

"The moderate effect of the use of technology is not the result of the program of the Fellow, it is the lack of classroom computer access."

"The benchmark scores for the students have been in the 75 – 85 percent range all year. They are far above the District average and the highest in the school."

"There has been a tremendous increase in student interest to attend college. Kids feel very motivated to become an engineer because they "learned more and understood more". They felt more associated with engineering especially because the GK-12 fellow."

"Engineering plays a major role in my classroom since I teach robotics; however, I don't possess an academic engineering background. Being able to effectively relay the principle/concepts of engineering to my students was always a concern for me. Having an engineer in the classroom helped me fill in the gaps and make better cross-discipline (S.T.E.M.) connections through the lessons we developed."

“My Fellow was very successful at exposing the students to engineering principles. Throughout the year, students were constantly reminded of the connection between science activities and experiments to the profession of engineering.”

“Overall, the GK program and my Fellow were instrumental in increasing students’ knowledge of science and engineering. I learned a lot about how to teach science and incorporate what scientists and engineers do. This is the first year we didn’t have a science teacher and each teacher is responsible for teacher science. I didn’t realize how unprepared I would have been had it not been for the GK 12 program and the Fellow.”

“I believe very strongly the students would not have done nearly as well on the benchmarks had it not been for the GK12 program and the Fellow. Next year I will be confident in teaching science. I will also be instrumental in assisting another teacher with our science curriculum.”

“The professional development I received along with the students’ newly acquired knowledge about scientists and engineers are invaluable. We have gained increased interest and respect for these fields that were intimidating in the past. Thank you for this rewarding experience.”

“I have gained so much knowledge from my participation and my Fellow. I feel this is a very valuable program for teachers and students and that with continued support in the classroom, teachers can prepare students beginning in middle school for careers in science and engineering by getting them excited about science and math through interesting hands on activities as well as specific instruction in science, math and technology and engineering principles.”

Discussion

The data gathered by the external evaluator shows positive outcomes across all three populations, teachers, fellows, and students. The fellows received high scores when the teachers were asked to rate the fellows’ abilities in the classroom. In the time between the middle of the school year and the end, the fellows improved greatly in their ability to engage the class in discussions. The lowest score the fellows received was in their classroom management abilities. This is most likely due to the absence of instruction in classroom management strategies during the summer training workshop. The teachers also reported that the fellows were able to impact the students’ knowledge of engineering. The students were not the only ones affected by the engineering education brought to the classroom by the fellows, as the teachers also gained valuable knowledge of engineering. The teachers were given concrete examples of how their usual math and science curriculum relates to the real world.

Another area where the teachers benefited from having the fellow in the classroom is in utilizing technology in instruction. The fellows were more technologically literate and thus were able to plan and implement lessons using technology that the middle school teachers would not normally be able to use. Some of these lessons that had a strong technological component were previously described by Brown et al.[7] and Cathell et al.[8] Lessons that include technological components are important not only because they expose students to equipment and methods often used by engineers, but also because technology education is required by our state’s core curriculum standards[14]. The lessons developed by the fellows improved students’ understanding of the math and science core curriculum standards and was demonstrated in the students' increase in benchmark scores. The benchmark exams are statewide standardized tests designed to measure the students' understanding of the core curriculum standards. There are a number of factors that may have resulted in the increase of the students' benchmark scores. The fellows noticed the students were more engaged during class time due to the hands-on activities. Each of these activities was designed to cover specific state standards, which the benchmark exams test. In addition, the presence of another adult and content expert in the classroom allowed for more individual attention for students with questions. Finally, the teachers' abilities improved even when the fellow was not present in the classroom. One of the largest impacts of the program is that the teachers have gained educational techniques that will continue even after the fellows have left the classroom. Multiple teachers noted how they will be better equipped to teach science and math in the future due to the collaboration with the fellow.

The teachers indicated that the fellows gained in their ability to engage the class in a discussion. This result supports a previous evaluation of GK-12 fellows by Mitchell et al.[20] In their report, the fellows self-reported an increase in communication and instruction skills. The fellows in the Mitchell study indicated that their improved instructional skills were due to their increased ability to communicate their knowledge in language the students could understand. The teachers in our study confirmed this result by indicating an increase in the fellows' communication ability as the year went on.

The largest change in the program's impact from the middle of the school year to the end of the school year was in the students' interest in attending college. This is an interesting result as increasing students' interest in college was not one of our goals and the fellows were not instructed to explicitly promote attending college. One possible explanation is that having recognized the fellows as expert scientists who graduated college, the students were able to see the opportunities available to expert scientists and engineers from the lessons brought to the class by the fellows.

Many of the changes in the fellows' impact from the middle of the academic year to the end of the year can be attributed to the experience gained by the fellows during the first months. As the fellows spent more time in the classroom they became more skilled in pedagogy and lesson planning. The bi-monthly meeting contributed to this effect as the fellows were able to collaborate on lessons and discuss teaching techniques that succeeded and failed. The meetings were integral to the development of the fellows into effective teachers. The reflection journals also allowed the fellows to focus on their successes and failures in the classroom in order to improve their classroom skills. However, the external evaluator suggested that the reflection journals be more of a space for structured feedback rather than free response. This would allow the fellows to be more invested and focused in their reflections. The evaluator suggested than in addition to a free response area, the reflection journal would prompt the fellows to answer questions like "what have I done to engage my collaborating teacher and students in STEM topics?"

Another suggestion made by the evaluator was to have some kind of rotation of fellows between classrooms. The program did a good job of exposing students to engineering, but the students were limited to seeing one discipline of engineering. The students would benefit more from seeing the different kinds of engineering. Another suggestion was to introduce the students to engineers working in industry so the students are not just exposed to the academic, research based, side of engineering.

Overall the evaluation indicates our GK-12 project has had the following effects:

- Benchmark scores have increased far above the district average and highest in the school for the GK-12 class
- There is an increase in student interest in attending college
- The fellows aided the unprepared science teacher and built their science confidence as they approached new challenges
- The fellows became more skilled in engaging the students in discussion
- The program has led to a large increase in the use of and the integration of technology into schoolwork
- Our website contains over 250 engineering modules that are available freely to the public

Conclusion

In this work we have given a summary and evaluation results of our four year GK-12 project. Our project aimed to benefit graduate fellows, middle school teachers, and middle school students by using engineering as a contextual vehicle to teach math and science concepts. The results gathered shows that we succeeded in all of these aims. The graduate fellows became more skilled teachers in the classrooms and gained valuable experience communicating their research to a diverse audience. The middle school teachers learned how to integrate engineering and technology into their lessons in addition to having assistance from a content expert in the classroom. The middle school students were exposed to engineering and technology they would otherwise not have the opportunity to see. The students also scored better on standardized tests and became more interested in attending college after their experience in the GK-12 program.

Our GK-12 program can be used as a model for integrating graduate level engineering education with K-12 education. The immersion of graduate fellows into K-12 classrooms resulted in significant benefits to all parties. Programs that encourage students to become engineers are important to ensure the U.S. is competitive in the now global field of engineering. Our GK-12 program not only encourages students to become engineers, but also stresses the importance of engineering education to the graduate fellows and teachers. The effects of the program on all three populations, the fellows, teachers, and students, ensure that the benefits of the program will not end at its completion. In the future, fellows will have a greater appreciation for engineering education, the teachers will understand the importance of engineering and pass it on to their students, and the students are more likely to attend college. Our GK-12 program is a model of a valuable asset in the struggle to enhance the status of engineering in the U.S.

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