

A Model STEM Team Collaboration: Four Schools for WIE

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Abstract--Recognizing the need for both technological literacy and a more diverse pool of students in technical fields, universities, companies, and professional organizations (such as the Society of Women Engineers) have developed “outreach” programs to local school districts to address the pre-college pipeline issue. These groups have often worked alongside each other, but with little guidance on how to maximize the effects of the interaction between academia and industry in K-12 settings. In 2002, Northeastern University (NU), Boston University (BU), Tufts University and Worcester Polytechnic Institute (WPI) began a collaboration to test a new model for outreach under the “Four Schools for Women in Engineering” program. Along with their evaluation partner, the Wellesley Centers for Women, the collaboration created the concept of a Science, Technology, Engineering and Mathematics Team, or “STEM Team”. This paper will present the final evaluation data from the three year NSF funded project, along with a discussion of how others can implement STEM teams and learn from our work.

Introduction

Numerous initiatives have tackled the problem of encouraging women and underrepresented minorities to enter the field of engineering both at the college and pre-college level (Anderson-Rowland et al., 1999; Davis & Rosser, 1996; Knight & Cunningham, 2004). Even after years of attention, women earn only about 20% of engineering bachelor’s degrees (Gibbons, 2002). This small number has been attributed to different issues including students’ images of and stereotypes about science, math, and engineering (Frehill, 1997; Margolis & Fisher, 2002), the influence of parents (Lee, 1990), friends (Clewell, Anderson, & Thorpe, 1992), teachers, and guidance counselors (Clewell, Anderson, & Thorpe, 1992; Ware, Steckler, & Leserman, 1985).

Middle school has been identified as a critical time for students, especially girls, in their decisions about their future plans. Middle school girls report more math anxiety and plan to take fewer math courses than their male counterparts (Brush, 1985). Girls’ confidence in their abilities and their interest in math and science erode significantly by the eighth grade (Campbell, Jolly, Hoey, & Perlman, 2002). Exposing students to math and science is important both in creating well-informed citizens and in allowing students to choose scientific and technical careers when they go to college (Evans, 1995). The middle school years are an important time to address and improve all students’ attitudes towards math, science and engineering.

Research has revealed strategies to encourage girls to persist in science, math and engineering. Positive role models can change students’ attitudes about technical fields (Evans, 1995). Classroom practices such as using real world and holistic examples in science and math classes

(Margolis & Fisher, 2002; Rosser, 1990), and restructuring classroom settings to make them more inclusive have also helped maintain interest among female and minority students.

Existing Outreach Models

Many university-based programs have developed outreach efforts to introduce K-12 students to STEM careers (Knight & Cunningham, 2004). These programs have taken many different forms; some partnerships involve bringing university students to K-12 classrooms as presenters (Coyle, Jamieson, & Sommers, 1997; Koehler & Burke, 1996; Ross & Bayles, 2003), while others involve longer term collaboration between students and teachers (Pratt & Skaggs, 1989; Trautmann, 2005; Williams, 2002). Industry partners have also engaged in outreach activities by volunteering directly through their companies and events such as “National Engineers Week.” Industry and academia share the common goal of increasing the number of scientists and engineers. The STEM Team model for outreach builds on these past models by linking industry, academia and K-12 schools together into a unified team.

The STEM Team Model

One of the goals of the Four Schools for WIE project was to use the Massachusetts framework requirements to infuse the curriculum with gender- neutral modules and activities that focus on engineering and technology while providing students with appealing role models and activities that are age appropriate and gender inclusive. Each of the partner engineering institutions – Northeastern, WPI, Boston University, and Tufts University – organized one STEM team composed of:

- Co-PI from the partner institution
- Engineering faculty member from the partner institution
- Graduate and /or undergraduate engineering students.
- Professional engineers: alumnae and/or corporate partner employee
- Two middle school teachers (one per participating middle school classroom)

The Principal and Co-Principal Investigators from each participating partner were responsible for leading their institution’s primarily female STEM team. The faculty member from each institution functioned as the team’s co-leader. Graduate and undergraduate students, as well as professional women engineers were role models and provided engineering expertise in the classroom. Classroom teachers from participating middle schools were integral to team activities often leading engineering activities in their classes with the assistance of the other STEM team members.

Each STEM Team worked together to select and develop a unit in a different area:

1. Northeastern University: chemical engineering – to use the 8 step engineering design process to experiment with methods to concentrate orange juice.
2. Boston University: genetics – to illustrate DNA as building blocks to code genetic traits.
3. Tufts University: computer science – to use binary numbers to introduce the language of computers.
4. WPI: biomedical engineering and materials science – to explore, through the engineering design process, the creation of different solutions involving orthopedic casts.

Past papers have described specifics about the activities that were developed (Knight, Wong, Browning, & Ingraham, 2004; Sontgerath et al., 2004; Ziemer, Carter, & Leventman, 2004) and

detailed description of two of the activities in the STEM Team Manual appear in a later section of this paper.

Evaluation

Although many outreach programs exist, few programs have gathered rigorous evaluation data to support their efforts (Mervis, 2004). Evaluation was a major component of the STEM Team project from its inception, including the development of a tool to assess students' attitudes towards math, science and engineering. Although data was collected from control and experimental classrooms, we decided not to use the data from the control classrooms, because student experiences outside the classroom could not be factored out.

Evaluation Results

The evaluation was designed and undertaken by two researchers from the Wellesley Centers for Women. It focused on how teachers and STEM team members experienced the program and the impact of the intervention on student attitudes.

1. Teacher Outcomes

In a paper and pencil survey with open-ended questions, teachers were asked to reflect on the benefits of the project, the effectiveness of the STEM Teams and for their recommendations for additional training, support, STEM Team composition and curricular changes. Teachers reported that exposure to expertise from actual engineers, graduate and undergraduate students, and industry representatives coupled with the training that was an integral part of this intervention were helpful both in their understanding of engineering and in how to teach this subject effectively. Teachers highlighted the following benefits for their students: exposure to role models, glimpses into the real world of work for engineers, and a curriculum that made it possible for all students to achieve up to a benchmark of proficiency rather than a competitive classroom environment where only a few students are engaged in the projects.

2. Impact on STEM Team Members

Each STEM Team was composed of a coordinator, teachers, faculty members, undergraduate and graduate students, and industry representatives. STEM Team members reported having benefited from the regular meetings that served to keep the teams focused and remarked on the synergy generated by the diversity in team membership. The ability to expose middle school students to a wide variety of practicing engineers was also mentioned as a strength of the program. Several respondents recognized the value of having undergraduate students in the classroom, which not only made some projects possible but was also key for establishing good rapport with the 8th grade students. Some team members also noted the challenges of recruiting and training undergraduates for the classroom. All in all, the study showed that it is feasible to bring together individuals from different domains to work together toward enhancing the teaching of STEM fields, especially the new engineering strand.

3. Impact on Students

Methods. The evaluation design involved comparing answers students gave to the same questionnaire administered in the beginning of the school year (pre-test) and then at the end of the school year (post-test). A total of 436 students on whom we had pre-tests completed the post-

test survey and these students form the basis of the study group for the final data analysis (the retention rate was 88%). Questionnaires were administered by the STEM Team coordinators during the science class period. Most students were able to complete the questionnaire within 20 minutes. The students ranged in age from 11 to 16; the mean age was 13.41. All students were in the 8th grade. The overall distribution of gender was 51.4% male and 48.6% female. The largest racial/ethnic group of surveyed students was Caucasian (42%), followed by Asian/Asian decent (18%), Black/African descent (17%), Latino (10%), Other (7%), and Biracial/Multi-Ethnic (6%). The racial/ethnic distribution of the student sample reflected that of the seven middle schools that participated in the study.

We examined the impact of the intervention on individual students using regression analyses which yield information on what variables best predict whether a student's scores will increase or decrease. The independent variables in the regression analyses included a three-point response to how interesting the students found the activities on engineering in their science class, students' scores on the three attitude surveys and selected STEM-related careers obtained *before* the intervention, and the pre-post differences on all the attitude and career variables. The rationale for including pre-intervention scores for predicting pre-post differences was to examine whether positive or less positive attitudes toward STEM fields and careers students reported before the intervention made a difference in how much pre-post change occurred. In other words, on a 5-point scale, if a student moved from a pre-intervention score of 3 to a post-intervention score of 5, the meaning of the 2 point pre-post difference may be different from a 2 point difference obtained when a student moved from a pre score of 1 to a post score of 3. Analyses were conducted separately for boys and girls because of the possibility that a different set of predictors might be operating for boys than for girls, which would not be captured by including sex of student as a dummy variable in the equations.

Results. The results in Table 1 show that for each pre-post difference score in attitudes toward engineering, math, and science the most powerful predictor is a student's pre-test attitude toward the same STEM field before the intervention. The negative sign of the *beta* coefficient suggests that students who started out with high attitude scores, ended up not changing much and students with low pre-test attitude scores had large difference scores indicating greater change from the pre-test to the post-test.

It is of interest to note that among boys, a positive pre-post difference score in attitudes toward engineering is additionally predicted by 1) finding the intervention classes interesting, 2) having a positive attitude toward mathematics before the intervention, and 3) having more positive attitudes toward math after the intervention. These three variables together explain 27% of the observed differences in male students' pre-post difference scores in attitudes toward engineering. A similar amount of variance is explained in the observed differences in male students' pre-post difference scores in attitudes toward math and science (24% and 27%, respectively). Finding the class interesting makes a difference for science but not for math. Having an initial positive attitude toward math before the intervention contributes to predicting the pre-post difference in attitudes toward science, but an initial positive attitude toward science does not appear to be important for a larger positive difference score on math attitudes. This finding that an initial positive attitude toward mathematics makes 8th grade boys more open to developing positive attitudes toward science but not the other way around, suggests that mathematics is the more

basic of the STEM fields. If the student likes math, the student will like science after the intervention, but if the student likes science initially, that initial positive attitude is not likely to generalize to liking math later.

Table 1. Regression analyses predicting difference scores in attitudes toward STEM fields among **boys**, expressed in standardized regression coefficient, *beta*.

<i>N</i> =195 Predictor Variables	Pre-Post Difference In Attitudes toward Engineering <i>beta</i>	Pre-Post Difference In Attitudes toward Math <i>beta</i>	Pre-Post Difference In Attitudes toward Science <i>beta</i>
Interesting class	.139*	-.007	.141*
Pre Attitude toward Engineering	-.475***	.220*	.051
Pre Attitude toward Math	.155*	-.497***	.319***
Pre Attitude toward Science	.011	.049	-.454***
Pre-post Difference in Engineering	-	.238***	.139
Pre-post Difference In Math	.227**	-	.138
Pre-post Difference In Science	.137	.143	-
Variance Explained (R²)	27%	24%	27%

* $p < .05$; ** $p < .01$; *** $p < .001$

Predicting the girls' change in attitudes toward STEM fields from before to after the intervention follows a similar pattern of *beta* coefficients, with the initial attitude scores showing the largest negative effects (see Table 2). Finding the intervention classes interesting appears to make a big difference in developing more positive attitudes toward engineering after the intervention, but does not appear to impact changes in attitudes toward math or science. The most remarkable finding in the girls' results is that the predictor variables in the regression analysis explains fully 41% of the observed differences in female students' pre-post difference scores in attitudes toward engineering. The comparisons of variance explained (R^2) in Tables 1 and 2 and in Tables 3 and 4 show that the intervention had a greater impact on female students' attitudes toward engineering as a field of study as well as choosing engineering as a career than it did on male students' attitudes. For example, the variables examined explained only 27% of the variance in the pre-post difference in attitudes toward engineering among boys while it explained 41% of the variance in girls' pre-post difference in attitudes toward engineering and 32% versus 41% in boys and girls pre-post difference scores in attitudes toward engineering as a career.¹ The same set of variables explained relatively similar amounts of variance among boys and girls in science and mathematics as fields of study and science- and math-related careers. We interpret this

¹ Comparison of variance explained in analyses that use the same variables is a more powerful indicator of effect size than a significant difference statistic obtained using analysis of variance techniques (Valentine & Cooper, 2003).

finding to mean that the intervention had a more powerful effect on girls' attitudes toward engineering than it did on their attitudes toward math and science. Moreover, the intervention had a more powerful impact in terms of changing girls' attitudes than boys' attitudes toward engineering.

Table 2. Regression analyses predicting difference scores in attitudes toward STEM fields among **girls**, expressed in standardized regression coefficient, *beta*.

N=197 Predictor Variables	Pre-Post Difference In Attitudes toward Engineering <i>beta</i>	Pre-Post Difference In Attitudes toward Math <i>beta</i>	Pre-Post Difference In Attitudes toward Science <i>beta</i>
Interesting class	.312***	.002	.105
Pre Attitude toward Engineering	-.567***	.223*	.287***
Pre Attitude toward Math	.203*	-.384***	-.090
Pre Attitude toward Science	.109	-.059	-.294***
Pre-post Difference in Engineering	-	.289***	.330***
Pre-post Difference In Math	.214**	-	.057
Pre-post Difference In Science	.245***	.057	-
Variance Explained (R²)	41%	21%	20%

*p<.05; **p<.01; *** p<.001

In Tables 3 and 4 the results of the regression analyses predicting changes in students' interest in STEM careers is presented. For both boys (Table 3) and girls (Table 4) the most influential predictor is having a *less positive* attitude toward the career in the pre-test, as indicated by high but negative *beta* coefficients. We believe that similar to the difference scores in attitudes toward STEM fields, this pattern of results is brought about by students starting out with low scores benefited more from the intervention. However, the impact of the intervention is not likely to be as strong as the magnitude of the *beta* coefficients would suggest because of the methodological bias (Anderson-Rowland et al., 1999; Knight & Cunningham, 2004).

Table 3. Regression analyses predicting difference scores in interest in STEM careers among **boys**, expressed in standardized regression coefficient, *beta*.

<i>N</i> =189	Pre-Post Difference In Engineer <i>Beta</i>	Pre-Post Difference In Chemist <i>Beta</i>	Pre-Post Difference In Biologist <i>Beta</i>
Predictor Variables			
Interesting class	.230***	.052	-.025
Pre-post Difference in Engineering	.196*	.065	.031
Pre-post Difference In Math	.140*	-.065	-.064
Pre-post Difference In Science	-.108	.145*	.261***
Pre-Engineer	-.495***		
Pre-Chemist		-.499***	
Pre-Biologist			-.403***
Variance Explained (R²)	32%	28%	28%

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 4. Regression analyses predicting difference scores in interest in STEM careers among **girls**, expressed in standardized regression coefficient, *beta*.

<i>N</i> =188	Pre-Post Difference In Engineer <i>Beta</i>	Pre-Post Difference In Chemist <i>Beta</i>	Pre-Post Difference In Biologist <i>Beta</i>
Predictor Variables			
Interesting class	.150*	.038	.019
Pre-post Difference in Engineering	.231***	.031	.009
Pre-post Difference In Math	.009	.012	
Pre-post Difference In Science	.233***	.303***	.153*
Pre-Engineer	-.561***		
Pre-Chemist		-.450***	
Pre-Biologist			-.482***
Variance Explained (R²)	41%	26%	27%

* $p < .05$; ** $p < .01$; *** $p < .001$

Summary and Conclusions

Taken together, the results show that both male and female students who started out with lower positive attitudes toward both STEM fields and STEM careers made more gains after the intervention than students who started out with more positive attitudes. Also, the intervention

had a greater impact on female students' attitudes toward engineering as a field of study as well as choosing engineering as a career than it did on male students' attitudes.

The evaluation shows that:

- More girls reported they would consider engineering and chemistry as a career after the intervention than did boys;
- Individual-level impact of the intervention on girls' attitudes toward engineering both as a field of study and as a career was larger than its impact on boys' attitudes;
- Among both girls and boys, students who showed the most positive change relative to where they started out in the beginning of the academic year, are those who had relatively less positive attitudes toward STEM fields and careers.

Limitations of the Evaluation

A shortcoming of the evaluation is that it did not allow for longitudinal tracking of the students who participated in the intervention. We cannot answer the question of what happens to these students as they continue on to high school. Do they, in fact, take more courses in math, science and technology and at higher levels (advanced placement)? How do their ideas regarding potential careers change over time? Without the ability to follow these young people beyond 8th grade, we cannot assess the full impact of the Four Schools for WIE curriculum. In addition, without true control groups using random assignment, we cannot definitively attribute change to the efficacy of the curriculum. A further weakness of the present study is that it did not allow for an estimation of the school and teacher effects as contexts for the intervention. This is a particularly important point to examine in future studies because girls appeared to be more influenced by the school/teacher context regarding engineering than were boys.

Dissemination Products and Guidelines for Replicating this Model

The STEM Team model is a highly replicable, low-cost intervention system. The regular presence of competent female role models in middle school classrooms have a positive impact on the gender-related images that all students, both male and female, have about engineers. The presence of the female members of the STEM Team in the classroom demonstrates to girls and boys that “women do engineering.” Engineering student involvement injected considerable energy into the classroom. Their closeness in age to the middle school students made them role models. Pre-college students can be introduced to a wide variety of engineering disciplines by selecting female undergraduate engineering students from a variety of majors (including electrical, mechanical, computer, civil, chemical and) with success in their academic program to work in classrooms. Involving engineering faculty and practicing engineers gave students a glimpse into potential career paths after college. Involving teachers as active participants in the development and delivery ensured that the activities were well matched to the curriculum, appropriate for eighth grade students, and gave teachers the opportunity to interact as active team members.

The *Growing a STEM Team!* Manual, DVD, and website are resources for those who are interested in replicating some or all of the STEM Team model in order to conduct gender equitable outreach to K-12 classrooms. A brief description of the dissemination products follows.

Manual

The STEM Team at Worcester Polytechnic Institute took the lead on writing the STEM Team Manual, with input from the partners at the other institutions. The manual consists of:

- Background information about gender issues in engineering
- How to create a STEM Team partnership between students, faculty, teachers and industry
- Description of program evaluation
- Description of the development of units
- Classroom tested units
- Appendices (Letters, Evaluation Instruments)

The manual also details the process by which the STEM Teams were formed, and describes how the teams collaborated to develop the activities. In addition to describing the overall process, the manual gives detailed information about each step, including schedules for the initial workshop and subsequent follow up workshops, sample letters for potential STEM Team participants, and instruments for program evaluation to facilitate replication of program activities in other locations.

The curriculum units in the manual were written and submitted by each individual team using a standard template similar to the FOSS Science kits. The classroom-tested engineering activities are designed for 8th grade middle school students and include “The Great Orange Juice Squeeze”, “Binary in a Box”, “Solar Houses” and “Bridges Connecting the World.” Each unit was co-developed by the STEM Team, tested in the classroom and revised at least once before being included in the manual.

Two Sample Activity Descriptions

The “*Wacky Shoe Design*” activity engages students in an engineering design project. Students decide on a special activity that they would like to perform, and then must design a shoe to help them perform this function. They will determine what special features the shoe will have and what materials they will need to create the shoe. After designing the shoe, they will depict it in a sketch, and then create a prototype of the shoe with the provided materials. After the shoes have been completed, the students test their shoes and evaluate the need for redesign.

The “*Great Orange Squeeze*” presents the students with the challenge of converting oranges in Florida to good-tasting, healthy orange juice for the Boston Public School system breakfast program at a cost of \$0.25 per 8-ounce glass. The module is divided into 6 interactive activities that require students to use both science and engineering concepts to solve the challenge. The students investigate different forms of heat transfer to discover how they work, and then choose one method of heat transfer to manufacture their concentrated orange juice. They design a concentration process through a flowsheet communication activity, experimental trials, and redesign. A variety of simple design materials lead to different distillation apparatus. The students also design different processing variables, which influence the taste and vitamin C content of the juice, such as the time of boiling and amount of fresh juice to add at the end. At the end of the module, students determine the taste, vitamin C content, and cost of their orange juice, and see how well their process solution meets the challenge.

Website

From the onset of the project, there was consensus that an online presence and tool for collaboration and communication would be valuable. An easy to remember URL of www.stemteams.org was selected. The website has morphed over the years from a general information site to a collaboration tool to a dissemination venue. The initial role for the website was for general information for the public with relevant NSF program information, recognition of all stakeholders, and administrative contact information. The site was extended to have tools to share and disseminate CORE-STEM-team (administration) and University-STEM-team (faculty, teachers, students, and industry) activities. A consumer-off-the-shelf product (Webboard) was chosen to allow this collaboration.

During the last phase of the project, the website was modified once again to serve as a dissemination tool. The dissemination plan included a WEPAN workshop to solicit feedback about the manual in spring of 2005, an email campaign to WIE Program directors and members of the “Programs for Gender Equity” listserv in the summer of 2005, and an email campaign to technical and scientific companies on the *Working Mother’s* Top 100 companies for women list in fall of 2005. Website visitors from the campaign were able to sign up for a free copy of the STEM manual through a web based survey powered by *Survey Monkey*. A request for follow up information will also be made via email. We expect the site to be maintained for another 2 to 3 years, at a minimum, to allow people to download the PDF files of the manual as well as to see updates and the final program evaluation.

DVD

A DVD was produced by Boston University’s Media Group/BU Productions during the third year. It documents the experience of students and teachers in the participating middle schools with a focus on the experience with and effects of STEM Team exposure. It also includes live demonstrations of classroom curricula activities, tips, and interviews with key STEM Team members reflecting on the experiences from the project. The intended audience is teachers, professional engineers and university faculty and out reach coordinators that are interested in enriching K-12 school curricula.

The combination of the STEM Team DVD and a CD of the manual can be ordered from the website (www.stemteams.org). The manual can also be downloaded as a .pdf file from the website.

Conclusion

The Four Schools for WIE program was successful in increasing teachers’ confidence and capacity to teach engineering in their classrooms, an impact which will have a long term effect on the classrooms and schools in which we worked. Participation in the program was correlated with an improvement in students’ attitudes towards science, but not in mathematics or engineering. Since all of the activities were presented in science classes, this could be evidence of a positive association between science and the project, although we did not collect the data to confirm that assertion. The results suggest that the program affected girls more than boys in two ways: first, more girls reported that they would consider engineering and chemistry as a career after the intervention than did boys, second, the individual-level impact of the intervention on girls’ attitudes towards engineering as a field of study or potential career was larger than its impact on boys’ attitudes. The greatest gains in attitude for both boys and girls were among

students who had less positive attitudes initially towards STEM Careers, suggesting that a program such as the Four Schools for WIE Program may help “level the playing field” for students who have limited contact with STEM role models.

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