12-2011

Enriching Science and Math through Engineering

Adrienne Redmond
Oklahoma State University, adrienne.redmond@okstate.edu

Julie Thomas
Oklahoma State University, julie.thomas@unl.edu

Karen High
Oklahoma State University, karen.high@okstate.edu

Margaret Scott
Oklahoma State University

Pat Jordan
Oklahoma State University

See next page for additional authors

Authors
Adrienne Redmond, Julie Thomas, Karen High, Margaret Scott, Pat Jordan, and Jean Dockers

Published in *School Science and Mathematics* 111:8 (December 2011), pp. 399–408; doi: 10.1111/j.1949-8594.2011.00105.x

Published online December 5, 2011.

Enriching Science and Math through Engineering

Adrienne Redmond, Julie Thomas, Karen High, Margaret Scott,

Pat Jordan, and Jean Dockers

Oklahoma State University

Abstract

This case study reviewed the collaborative efforts of university engineers, teacher educators, and middle school teachers to advance sixth- and seventh-grade students' learning through a series of project-based engineering activities. This two-year project enriched regular school curricula by introducing real-world applications of science and mathematics concepts that expanded opportunities for creativity and problem-solving, introduced problem-based learning, and provided after-school programming (for girls only) led by engineering students from the local university. This engineering education initiative showed significant impact on students' (1) confidence in science and mathematics; (2) effort toward science and mathematics; (3) awareness of engineering; and (4) interest in engineering as a potential career. With regard to gender, there were no significant differences between boys' and girls' responses. The girls' confidence in their own skills and potential, however, was significantly more positive than the boys' confidence in the girls. These results gave rise to new questions regarding mentor/mentee relationships and the overall effect of "girls only" mentoring.

Introduction

In this case study research, a group of middle school teachers and administrators partnered with university engineers and teacher educators to advance sixth- and seventh-grade students' learning through a series of project-based engineering activities. This two-year project was designed to enrich regular school curricula by introducing problem-based learning that purposefully integrated engineering with science and mathematics. We wondered if we could positively impact students' interests and attitudes in science and mathematics and encourage engineering as a career option through these combined efforts.

Literature Review

We initiated this research with enthusiasm for learning how engineering lessons and activities might increase middle schoolers' motivation and interest in science, mathematics, and engineering careers. It is well documented that middle schoolers have already begun to develop dispositions toward mathematics, science, and engineering (Eccles & Midgley, 1989; Mooney & Laubach, 2002; Ryan & Patrick, 2001).We knew too, that in this period of early adolescence, students either begin to develop strong academic habits or they begin to struggle in school (Ryan & Patrick).

Developing Confidence and Positive Attitudes

Some students, at or near middle school age, develop anxiety or aversion to mathematics, believing that only certain students can be good at mathematics and that no amount of effort can make a difference for those who are not good at mathematics (Schoenfeld, 1992; Stodolsky, Salk, & Glaessner, 1991). Students' developing notions that their own difficulties with science or mathematics are due to a lack of ability undermine their motivation and can lead to anxiety (Ryan & Patrick, 2001). Supportive teachers can help reduce anxiety and successfully motivate middle school students to learn mathematics and science. Teachers' encouragement and support can lead to students' increased interest and enjoyment in school work, enhanced academic self-image, and greater expectancies for school success (Ryan & Patrick).

Integrated Learning

The construct of integrated teaching and learning arises from the constructivist learning theory (Bruner, 1977; Dewey, 1966; Piaget, 1973), which suggests that linked or connected learning experiences enhance the learning overall. This teaching for understanding involves teachers as facilitators, students as active learners, and construction of knowledge rather than simple absorption of facts (Berlin, 1989, 1990; Furner & Kumar, 2007; McKinney, 1993). Mathematics can enable students to achieve a deeper understanding of science concepts by providing ways to quantify and explain science relationships. Science activities, illustrating mathematics concepts, can provide relevancy and motivation for learning mathematics (Berlin, 1994; McBride & Silverman, 1991). Further, Berlin (1994) found that students greatly enjoy integrated lessons but that teachers, administrators, and parents worry whether students are really learning or simply playing. Barab (1999) found that high school students showed higher interest in integrated classroom activities, and their problem-solving, cooperative group skills increased. Jacobs (1989) reported links between integrated curriculum, higher attendance, and better attitudes toward school.

Advantages of Engineering Curricula

Engineering curricula provide a vehicle for integrating science and mathematics—and a context for the relevance and application of science and mathematics (Sullivan et al., 2005). Engineering education bridges classroom lessons to real-world experiences through concrete applications (Iversen, Kalyandurg, & de Lapeyrouse, n.d.). Given that women and minority populations are underrepresented in engineering professions and that engineering degree enrollments are flat, there is grave concern for the general public's limited awareness of engineers and their roles in creating new technologies that improve our quality of life (Sullivan et al.). Certainly, engineering education in middle school can serve to introduce engineering as a viable career option.

Brophy, Klein, Portsmore, and Rogers (2008) reviewed 25 promising models of P-12 engineering education. They found that engineering education can be integrated into curricula to increase a wide range of knowledge and skills in science, technology, engineering, and mathematics (STEM). They raised concern regarding classroom teachers' knowledge of engineering and institutional challenges such as high-stakes assessments.

Encouraging Girls in Science, Mathematics, and Engineering

Although women make up nearly half of the U.S. workforce, they make up only 26% of the STEM workforce (Halpern et al., 2007). Research and intervention projects since the American Association of University Women (AAUW) Educational Foundation's (1992) report *How Schools Shortchange Girls* have indicated patterns of progress in improved instruction and innovative learning opportunities for girls (AAUW, 2004). Still, many bright students, particularly women and minorities, choose not to pursue engineering careers (Mooney & Laubach, 2002).

Recent researchers point to some new understandings about gender and STEM. Fouad (2008) tracked middle school girls through high school and college. She reported that self-confidence instilled by parents and teachers had greater impact on girls' learning in science and mathematics than girls' initial interests. Dweck (2007) reported on interventions that shrink gender differences in mathematics. She found that teachers' messages about developing ones' intellectual ability (to counter students' perception of intellectual ability as a gift) not only served to alleviate girls' vulnerability but increased student performance overall.

In summary, research suggests the importance of encouraging middle schoolers' (boys' and girls') confidence and attitudes toward science and mathematics. Integrated science and mathematics instruction, combining both concrete and abstract learning opportunities, can provide a motivational context for learning. Engineering curricula, linked to appropriately integrated science and mathematics content, both motivates student learning and introduces career options. Girls at the middle level are in particular need of STEM learning support.

Methodology

In this study, we explored the overall impact of a two-year engineering enrichment project in a middle school. Students' possible involvement included *Get a Grip* lessons during a regular school day (boys and girls) and an after-school mentoring (girls only). Our specific questions included the following:

1. Did the *Get a Grip* integrated engineering curriculum or after-school mentoring influence middle level students' ideas and attitudes toward science, mathematics, and engineering?
2. Did the project's effect differ between boys and girls?

Research Design

This research followed sequential explanatory mixed methods design (Creswell & Plano-Clark, 2007) with a greater focus on the quantitative data (QUAN → qual). According to this design, researchers gathered qualitative data to explain or elaborate on the quantitative findings collected in the first phase of the study. The quantitative data were expected to provide generalizable results, while the qualitative data would help describe our quantitative results.

First, the quantitative survey instruments collected mathematics (Middle School Mathematics Attitude Survey [MSMAS]) and science (Middle School Science Attitude Survey [MSSAS]) attitudes of sixth- and seventh-grade students. These pre/postsurveys measured changes in students' mathematics and science confidence, value of mathematics and science, and knowledge/interest in engineering over the two-year project.

In the qualitative phase, an interview protocol prompted the lead teachers to describe their experiences and observations relative to the *Get a Grip* lessons and after-school mentoring program. The protocol encouraged lead teachers to reflect on notable changes in students' behaviors (both in the classroom and in after-school mentoring) and/or attitudes toward science or mathematics.

Research Participants

Participants included sixth- and seventh-grade students (N = 1,287) and 12 teachers (representing three core teaching teams) from an Oklahoma middle school. There were approximately 757 students (78% Caucasian, 9% African American, 3% Asian, 3% Hispanic, and 6% Native American) enrolled in this middle school during each year of this project, and 32% of the student body were eligible for free and reduced lunches. Eighty-one percent of the sixth-grade students and 90% of the seventh-grade students scored at the satisfactory level or above on the state assessments in mathematics in 2006–2007 (science exams are not yet required). In 2007, nearly 40% of seventh graders scored at the advanced level in mathematics compared with 22% statewide.

All 12 of the sixth- and seventh-grade teachers (language arts, social studies, mathematics, and science) led *Get a Grip* lesson activities related to their own core content. Two science teachers from this group (one sixth-grade teacher and one seventh-grade teacher) led the afterschool mentoring program along with university faculty and students. (These two teachers are identified throughout the remainder of this report as the *lead teachers*.) All 12 project teachers followed standards-based curriculum and regularly participated in district-wide professional development days (five per year). The lead teachers (one early-career and one experienced teacher) also attend annual state and national science conferences and help lead engineering summer camps for middle level students.

Treatment

An interdisciplinary research group (consisting of an engineering professor, female engineering students, science education faculty, and mathematics education faculty at a large Oklahoma university) organized an engineering enrichment project to positively affect students' attitudes toward science, mathematics, and engineering career awareness. In order to accomplish these goals, the research team implemented two related interventions over two years. Table 1 lists the total interventions. The control group did not participate in any of these engineering enrichment activities.

Table 1. Assigned Abbreviations for the Possible Engineering Interventions

Intervention	Abbreviation
Get a Grip activity in the classroom, one year	ENG^1
Get a Grip activity in the classroom, two years	ENG^2
Get a Grip activity in the classroom and after-school mentoring	ENG^m

In the Curriculum Integration Project, core teams taught an integrated thematic unit entitled *Get a Grip* (aligned with both the *National Science Education Standards* [National Research Council, 1996] and the *Benchmarks for Science Literacy* [American Association for the Advancement of Science, 1993] and originally developed at Northwestern University and funded by the National Science Foundation). *Get a Grip* (Olds, Harrell, and Valente, 2006) would familiarize middle school students with engineering as a career and encourage students to make connections between science concepts while completing a real-world engineering task. In this design process, students designed and developed a prosthetic arm (from common materials) to help a 12-year-old Afghani girl eat and carry water from a nearby river to her home. (For more information on the structure of the unit, visit http://www.ideanet.org/get-agrip/Sci_Scope_Nov_2006_Reprint.pdf.) Most of the eight core *Get a Grip* lessons in the unit correlated with district objectives for language arts, reading, mathematics, and social studies. The unit was taught in May of each year. Some adaptations were introduced in seventh grade as some of the students (ENG^2) had participated in *Get a Grip* during their sixth-grade year (ENG^1).

An after-school mentoring program organized weekly sessions (28 sessions per year) for sixth- and seventh-grade girls (N = 43 including 17 sixth graders and 26 seventh graders). The lead teachers explained that the girls who self-selected into this mentoring group were not the most popular girls or the real social leaders. Rather, it was the girls "who care about their grades and want to do well and they look at this as a way to do that." There were also "quite a few girls" who signed up because "they're not in dance and don't have a lot of money to do all the other things." Female mentors (two lead teachers and 10 engineering students) led activities that introduced engineering design processes and engineering career awareness to the girls. Mentoring activities encouraged the girls to find creative ways to solve real-world problems (such as saving penguins from global warming, managing and improving the water quality of an Amazon community, and designing electric, robotic cars).

Instrumentation

Quantitative survey data from the MSMAS and the MSSAS measured pre/post attitudes and interests of the sixth- and seventh-grade students. Qualitative interview data (transcribed and coded) recorded reflective observations of the lead teachers who helped with after-school mentoring.

The MSMAS and MSSAS survey instruments were developed from the Modified Fennema-Sherman Attitude Survey (Doepken, Lawsky, & Padwa, 1993) and from the Adventure in Engineering Survey (Mooney & Laubach, 2002). The *Fennema-Sherman Attitude Survey* has been used in numerous studies to measure students' attitudes toward mathematics. The original Modified Fennema-Sherman Attitude Survey (Doepken et al.) consisted of four subscales: (1) mathematics confidence; (2) usefulness of mathematics; (3) mathematics as a male-dominated subject; and (4) mathematics teacher perceptions. Doepken et al. further modified the survey instrument to measure science attitudes as well. Their Modified Fennema-Sherman Science Attitude Scale consisted of four subscales: (1) science confidence; (2) usefulness of science; (3) science as a male-dominated subject; and (4) science teacher perceptions (Doepken et al.).

Further adaptations of the MSMAS and MSSAS used in this study involved the addition of questions adapted from the *Adventure in Engineering Survey* (Mooney & Laubach, 2002). For example, (1) Girls could be a successful engineer; and (2) I am interested in pursuing a career in engineering. Other questions were developed by the research team. A sample question (developed by the research team) was, "How much effort do you typically put into your work for this mathematics/science class?"

Our MSMAS and the MSSAS instruments consisted of 19 questions in a four-point Likert type format (with A indicating strong agreement with the statement and D indicating strong disagreement) and a 20th question on effort. Three questions were negatively worded questions and reverse coded for analysis. In order to determine the internal consistency of the different subscales within the MSMAS and the MSSAS, a Cronbach's alpha was calculated; however, caution should be used when interpreting the results because some portions were too limited for reliability calculation to be meaningful. Table 2 shows the calculated alpha for each administration of the MSMAS and MSSAS. The instrument was moderately consistent for mathematics and science confidence and value but not consistent for parent/teacher expectations toward mathematics/science or for gender-related questions in mathematics/science.

Table 2. Cronbach's Alpha Scores on Four Subscales of MSMAS and MSSAS

	Confidence		Value		P/T Expect		Gender	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Sixth grade MSMAS	.737	.731	.706	.764	.476	.492	.377	.361
Seventh grade MSMAS	.726	.808	.737	.744	.614	.531	.349	.405
Sixth grade MSSAS	.689	.683	.778	.694	.576	.501	.289	.387
Seventh grade MSSAS	.661	.649	.755	.785	.589	.619	.356	.348

Data Analysis

To analyze the quantitative data, we ran a Mann-Whitney *U* for independent comparisons and a Wilcoxon-*T* for the paired comparisons. The Mann-Whitney *U* is the nonparametric counterpart of the independent samples *t*-test; the Wilcoxon-*T* is the nonparametric counterpart for paired samples *t*-test. These nonparametric statistical tests are useful if you have a small sample size or a non-normal distribution (Siegel & Castellan, 1988). To determine the probability that they would reject a false null hypothesis, researchers conducted power analyses (Cohen, 1989). The power analyses was conducted using G*Power (Buchner, Erdfelder, & Faul, 2009) and showed a power very close to 1 (.89–.99) for all statistical tests.

Qualitative data (narrative interviews) were transcribed, coded, and analyzed by comparative analysis. Results were organized into themes as guided by this analysis. Verification of truth was ensured by the detailed research plan, triangulation of data, member checks, and detailed descriptions of our experience and understanding (Spradley, 1980). According to Yin (1994, p. 25), such a case study component allows research to "explain causal links in real-life interventions that are too complex for the survey or experimental strategies."

Research Results

Our results suggest that this engineering project positively influenced middle level students' ideas and attitudes toward science, mathematics, and engineering. The mathematics confidence (p = .000), value of mathematics (p = 000), and advantage of effort put forth in mathematics class (.000) of the students in the experimental group were significantly higher than the control group (see Table 3). The experimental group of sixth graders also indicated enhanced expectations of girls' mathematics ability compared with the control group (p = .000).

Table 3. Control Versus Experimental Comparisons

	Sixth Grade		Seventh Grade	
Control-Experimental Comparisons	*Z*	*P* Value	*Z*	*P* Value
Science confidence	–.229	.819	–10.222	.000*
Value of science	–11.624	.000*	–7.014	.000*
Girls smart enough to do science	–1.145	.252	–4.154	.000*
Effort in science	–6.226	.000*	–9.228	.000*
Mathematics confidence	–14.341	.000*	–10.068	.000*
Value of mathematics	–19.101	.000*	–15.008	.000*
Girls smart enough to do math	–19.482	.000*	–1.110	.267
Effort in mathematics	–5.410	.000*	–3.901	.000*
Know what an engineer is	–13.386	.000*	–13.020	.000*
Interest in engineering as a career	–7.747	.000	–10.160	.000*
I could be a good engineer	–.256	.798	–.990	.322
Girls can be an engineer	–.038	.970	–.340	.734

Note: *indicates significance at p = .000.

The experimental group of sixth and seventh graders demonstrated significantly higher value of science (p = .000) and advantage of putting forth effort in science class (p = .000) than the control group. Although there were no significant differences between the sixth-grade control and experimental groups on the science confidence questions, the science confidence of the seventh graders that participated in the *Get a Grip* intervention was higher (p = .000) than the control group. Both the sixth- and seventh-grade experimental groups identified a significantly increased knowledge of engineering (p = .000) and increased interest in pursuing engineering (p = .000) when compared with the control group (see Table 3).

Narrative data supported these survey results. One lead teacher noted the surprising leadership of a seventh-grade girl who arranged for a community volunteer to bring a prosthetic limb demonstration into the classroom. As this teacher explained, "The seventh graders were the ones who got up and taught the lesson." This teacher is passionate about the meaning this integrated lesson had for her students:

> When they read the story about the boy who lost his leg, and now we're building an arm for a girl who lost hers, I think they see a purpose behind what they're doing. They're trying to do a good job because they know what they do is going to impact somebody's life and I think that's what's missing in schools—especially science classes. They do all these [other] labs and they're not connected to anything that has personal value to them.

Gender and Mathematics Comparisons

There were no significant gender differences in confidence or value of mathematics for sixth-grade participants (see Table 4). However, there were significant gender differences in seventh-grade mathematics confidence. The seventh-grade girls reported higher mathematics confidence than the boys reported after two years of intervention (p = .047).

Table 4. Gender and Mathematics Comparisons

	Sixth Grade Results				Seventh Grade Results			
	Mean				Mean			
	M	F	Z	*P* Value	M	F	Z	*P* Value
Mathematics confidence	9.50	3.168	–1.871	.061	12.09	11.87	–1.986	.047*
Value of mathematics	6.19	2.389	–1.244	.214	8.21	8.14	–.344	.731
Teachers interested in mathematics	2.02	.851	–1.063	.288	2.31	2.19	–1.095	.273
Girls just as good as boys at math	1.26	.588	–3.602	.000*	1.39	1.17	–3.628	.000*
Teachers encourage mathematics	2.40	.970	–.580	.562	2.55	2.45	–.647	518
Girls—math popular	3.07	.808	–2.239	.025*	3.31	3.36	–.602	.547
Girls smart enough to do math	1.40	.689	–2.594	.009*	1.40	1.32	–1.967	.049*
Effort in mathematics	4.18	1.01	–1.123	.261	3.68	4.05	–2.810	.005*

Note: *A low score indicates a higher rate of agreement and a higher score indicates a lower rate of agreement.

There were significant differences regarding perceptions of girls' ability to do well in mathematics (sixth grade, p = .009; seventh grade, p = .049) and girls' ability to do as well as boys in mathematics (p = .000).

Gender and Science Comparisons

These results indicate that there were no significant gender differences in science value or confidence for sixth- or seventh-grade participants (see Table 5). Sixth and seventh grade responses showed a similar pattern (in the gender differences) regarding perceptions of girls' ability to do well in science and girls' ability to do as well as boys in science. The mean scores for all groups were high, but girls were more likely to believe that girls were "just as good" as boys in science (sixth grade, p = .015; seventh grade, p = .000). Similarly, when asked whether girls could be "just as good" at science as boys and whether girls were "smart enough to do science," the boys' and girls' responses were significantly different (p = .000). The girls were more likely to agree with this statement than the male participants.

Table 5. Gender and Science Comparisons

	Sixth Grade Results				Seventh Grade Results			
	Mean				Mean			
	M	F	*Z*	*P* Value	M	F	*Z*	*P* Value
Science confidence	9.15	9.13	–.788	.431	9.89	9.93	–.225	.822
Value of science	8.37	8.36	–.322	.747	8.80	8.79	–.212	.832
Teachers interested in science	2.28	2.44	–1.297	.195	2.28	2.11	–1.683	.092
Girls just as good as boys at science	1.29	1.15	–3.559	.000*	1.48	1.12	–5.495	.000
Teachers encourage science	2.72	2.63	–.649	.516	2.55	2.45	–.920	.358
Girls—science popular	3.23	3.34	–1.472	.141	3.24	3.32	–1.002	.317
Girls smart enough to do science	1.35	1.23	–2.439	.015*	1.60	1.29	–3.677	.000
Effort in science	3.93	4.02	–.493	.622	3.53	4.03	–3.993	.000

Note: * indicates significance at p = .000.

Gender and Engineering Comparisons

There were significant differences in boys' and girls' understanding, interest in engineering careers, and their expected engineering abilities (see Table 6). Boys were more likely than girls to agree they knew "what an engineer does" (sixth grade, p = .000; seventh grade, p = .001). Similarly, the boys were more likely than the girls to be interested in pursuing engineering as a career (p = .000). The boys were also more likely to agree that they could be a successful engineer (sixth grade, p = .003; seventh grade, p = .000). Girls were more likely than the boys to agree that "girls could be successful engineer" (p = .000).

Table 6. Gender and Engineering Comparisons

	Sixth Grade Results				Seventh Grade Results			
	Mean				Mean			
	M	F	*Z*	*P* Value	M	F	*Z*	*P* Value
Know what an engineer is	1.69	2.13	–3.628	.000*	1.84	2.23	–3.459	.001*
Interest in engineering as a career	2.70	3.23	–3.862	.000*	2.82	3.24	–3.802	.000*
I could be a good engineer	1.84	2.14	–3.006	.003*	1.82	2.26	–3.992	.000*
Girls can be an engineer	1.62	1.26	–3.792	.000*	1.60	1.34	–3.624	.000*

Note: * indicates significance at $p = .000$.

Gender and Mentoring Comparisons

Sixth-grade girls who participated in the mentoring program had higher science confidence and greater interest in pursuing a career in engineering than those girls who did not participate in the mentoring program (see Table 7). The seventh-grade girls who participated in the mentoring program rated the value of science significantly higher than those girls who did not participate in the after-school mentoring program. There were, however, no significant mathematics attitude differences between the girls who participated in the mentoring program and the girls who did not participate in the program. This implies that the mentoring had more of an impact on science attitudes than mathematics attitudes.

Table 7. Gender and Mentoring Comparisons

	Sixth Grade		Seventh Grade	
Girls with Mentoring	*Z*	*P* Value	*Z*	*P* Value
Mathematics confidence	–.593	.554	–.767	.443
Value of mathematics	–1.369	.171	–.353	.724
Girls smart enough to do math	–.958	.338	.000	1.000
Effort in mathematics	–.071	.943	–.179	.858
Science confidence	–2.242	.025*	–1.745	.081
Value of science	–.568	.570	–2.035	.042*
Girls smart enough to do science	–1.069	.285	–.331	.741
Effort in science	–1.060	.289	–1.068	.286
Know what an engineer is	–.659	.510	–1.367	.172
Interest in engineering as a career	–2.555	.011*	–.736	.462
I could be a good engineer	–.873	.383	–.173	.862
Girls can be an engineer	–1.265	.206	–2.735	.006*

Note: *indicates significance at $p = .000$.

The lead teachers who helped with the after-school mentoring program strongly believed the program made a difference for girls in a variety of ways. For one thing, this after-school program allowed these teachers to notice the different behaviors between in school and after-school. As one teacher explained,

> These girls are much more quiet in the classroom but, . . . when they get to the after-school program, they're more in a leadership role (they're kind of forced to be in that role) and they've really stepped up to it. They're [creating] their own ideas and I think it helps them realize they do have valid ideas.

Lead teachers also noted that the mentoring girls took on a "team mentality" as girls who shared similar goals. Particularly, among the sixth-grade girls, these teachers observed new confidence in the classroom. It was not so much that these female students began asking higher level questions in class, but rather, they began asking more questions in general and, "I think they feel they can solve problems better now."

One of these lead teachers noted the importance of the college mentors. Asked to think about why the college students were so important—was it that they were engineering students or because they were also girls, this teacher explained,

> I think it's because they're female, college students. I think [our girls] look up to them. I think a lot of [our] girls didn't know what engineering was, so I don't think that was an important factor in whether or not they signed up. I think it was more that they were going to get to work with college girls.

It was the mathematics in these after-school engineering activities that most challenged these girls. As the lead teachers explained, "Math is the one [thing] they're afraid of." Lead teachers noted the girls' reluctance in mathematics. They especially remembered one mentoring session when they were working particularly hard with one group of girls who repeatedly sighed, "The math is just too hard. I just can't do it." With continued coaching, the girls actually solved the problem and one girl burst out enthusiastically, "Wow! We really rocked that math!"

Conclusion

This study provides important results related to improving science and mathematics instruction and engineering career awareness with middle level students. Taken together, this data show that the *Get a Grip* engineering curricula seemed to have a significant impact on all middle school students' (1) confidence in science and mathematics; (2) effort toward mathematics and science; (3) awareness of engineering; and (4) interest in engineering as a potential career. However, for those students who participated in the *Get a Grip* program over two years (ENG^2), there appeared to be no additional benefit except in mathematics confidence. Students who had *Get a Grip* in both sixth and seventh grades demonstrated significantly higher mathematics confidence when compared with the students who only had one experience with *Get a Grip* in seventh grade.

The lead teachers, who had been involved in the program for both years, may have positively influenced these students as they are invested in this engineering initiative and share similar philosophical confidence about how integrated lesson activities increase middle school students' motivation and interests toward science and mathematics, as well as deepen their understanding of science and mathematics concepts.

With regard to gender questions, we noted difference between boys' and girls' ideas about whether girls were "just as good as boys in science and math" and whether girls were "smart enough to do science and mathematics." The girls' belief in their own skills and potential was significantly more positive than the boys' belief in the girls. This seems to point to the fact that *Get a Grip* improved the girls' confidence in themselves, while the boys held to more stereotypical beliefs of girls' abilities. Certainly, the data on the after-school mentoring program for girls pointed to sixth graders' significantly greater science confidence and interest in pursuing an engineering career and seventh graders' significantly greater value of science compared with those sixth- and seventh-grade girls who did not participate in the mentoring program.

Discussion

This engineering education initiative resulted in significant impact on students' (1) confidence in science and mathematics; (2) effort toward science and mathematics; (3) awareness of engineering; and (4) interest in engineering as a potential career. With regard to gender, there were no significant differences between boys' and girls' responses. The girls' confidence in their own skills and potential, however, was significantly more positive than the boys' confidence in the girls.

Why were the boys not as confident about the girls' skills and potential in science, mathematics, and engineering? Researchers can explain *what* gender schema children learn from birth, there is much to learn about *how* children learn about gender. We know parents (Jacobs, Davis-Kean, Bleeker, Eccles, & Malanchuk, 2005) and teachers (Demmert, 2001) have a large impact on children's developing perceptions of self-competence. Fouad (2009) confirmed girls' feelings of self-confidence, instilled by parents and supported by teachers, are a precursor to girls' interests in science and math. This research points to the prevailing gender stereotype held by middle school boys—an influence not referenced in current research literature. While these research results are conclusive about the positive effect on the girls' gender schema, we are concerned that the boys' perceptions may serve to confound the beneficial effects of such an engineering project effort as this. Perhaps we need to give special attention to the boys as well as the girls.

Our mixed methodology research design allowed us to review some interesting differences in the results. For example, there were varied results with the second year data (ENG^2) suggesting that our survey instrument may not have been sensitive enough to gather subtle differences. Certainly, the qualitative data helped to elicit descriptions of the mentored girls' (ENG^m) increased leadership and confidence that was not identified in the survey.

We noted that the mentored girls (ENG^m) showed significantly improved confidence in science—but not so with mathematics confidence. While we have no conclusive explanation for this outcome, we cannot help noting that the two lead teachers were science teachers. Perhaps, too, the after-school mathematics problems were too challenging. As Dweck

(2007) reported, girls seem to lose confidence in the face of obstacles. As Dweck explained, girls may have similar abilities as boys, but a difference in coping skills causes girls to wonder about their ability when they are demoralized by challenging problems.

Lastly, we noted two unexpected disappointments with regard to this engineering enrichment project. First, the *Get a Grip* unit was taught in May—after completion of the mandated state tests in April. This was a purposeful decision by the teaching teams. By their reasoning, they needed to spend class time building reading, writing, and mathematics skills that would be tested in late April. Although the teachers found benefit in the *Get a Grip* unit, they clearly did not trust this integrated instruction as adequate preparation for high-stakes tests. Future research needs to address these teachers' concerns about clear incorporation of tested skills as component to integrated instruction.

Get a Grip was but one unit of integrated science and mathematics instruction with an engineering focus. Our original plan included a professional development component that would help all 12 middle school teachers identify the engineering principles and activities inherent in their current curriculum. It was further expected that engineering professors and their graduate students from the local university would provide middle school teachers with training and support in identifying and refining lessons that could become project-based activities and incorporate engineering principles. Unfortunately, this project component was unrealized because of limited professional development funding.

As Brophy et al. (2008) suggested, further research is needed to better understand the policy issues related to teacher professional development and curricular change and that includes engineering education. What are the institutional factors that inhibit the mainstreaming of engineering education and how can they be resolved? How can engineers (with domain knowledge) best help teachers (with pedagogical knowledge) blend engineering education into the traditional school curricula?

Limitations

These mentoring results (ENG^m) could be skewed by self-selection of the participants. As well, given the unequal number of participants in the study groups, one could argue that we would have had more difficulty reaching any data significance. Certainly, more in-depth studies would need to be conducted to determine the actual cause of the elevated beliefs in mathematics effort and "knowledge of an engineer" questions. However, it is highly likely that the students who participated in both interventions had more exposure to engineering concepts, faculty, and mentors, and thus became more aware of engineering careers. We are interested in learning more about the mentoring experience, the motivations of both the college students and the middle school girls, and how one group impacts the other.

To some degree, our study was limited by the instrumentation we chose, the number of after-school mentoring participants, and unexpected limitations in professional development opportunities. We initially chose to use the Modified Fennema-Sherman Attitude Survey (Doepken et al., 1993) and added questions that seemed relative. After conducting a Cronbach's alpha, we realized that our instrument was not consistent for parent/teacher expectations or gender-related questions. Because of this inconsistency, we had to run an analysis on several questions individually that increased the chance of Type 1 errors. We later found the Hirsch, Carpinelli, Kimmel, Rockland, and Bloom, J. (2007), a newly developed survey to measure attitudes toward science, math, and engineering that might be more appropriate for use in future studies.

References

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

American Association of University Women (AAUW). (2004). Under the microscope: A decade of gender equity projects in the sciences. Washington, DC: Author. Available on AAUW Web site. Retrieved November 4, 2011, from http://www.aauw.org/learn/research/upload/underthemicroscope.pdf

American Association of University Women Educational Foundation. (1992). *How schools shortchange girls: The AAUW report*. Washington, DC: Author.

Barab, S. A. (1999). Ecologizing instruction through integrated units. *Middle School Journal*, *30*(8), 21–28.

Berlin, D. F. (1989). The integration of science and mathematics: Exploring the literature. *School Science and Mathematics*, *89*(1), 73–80.

Berlin, D. F. (1990). Science and mathematics integration: Current status and future directions. SSMILES. *School Science and Mathematics*, *90*(3), 254–257.

Berlin, D. F. (1994). The integration of science and mathematics education: Highlights from NSF/SSMA Wingspread Conference Plenary Papers. *School Science and Mathematics*, *94*(1), 32–35.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P–12 classrooms. *Journal of Engineering Education*, *97*(3): 369–387.

Bruner, J. (1977). *The process of education*. Cambridge: Harvard University Press.

Buchner, A., Erdfelder, E., & Faul, F. (2009). G*Power Program. User's Guide available from Institut Für Experimentelle Psychologie Web site. Retrieved November 4, 2011, from http://www.psycho.uniduesseldorf.de/aap/projects/gpower/how_to_use_gpower.html

Cohen, J. (1989). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Creswell, J., & Plano-Clark, V. L. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage Publications Inc.

Demmert, W. G. (2001). *Improving academic performance among Native American students: A review of the research literature*. Charleston, WV: Eric Clearinghouse on Rural Education and Small Schools. Available on the ERIC Clearinghouse Website. Retrieved November 4, 2011, from http://www.eric.ed.gov/PDFS/ED463917.pdf

Dewey, J. (1966). *Democracy and education*. New York: Free Press.

Doepken, D., Lawsky, E., & Padwa, L. (1993). *Modified Fennema-Sherman Attitude Scale*. Retrieved August 16, 2006, from http://www.woodrow.org/teachers/math/gender/08scale.html

Dweck, C. S. (2007). Is math a gift? Beliefs that put females at risk. In S. J. Ceci, & W. M. Williams (Eds.), *Why aren't more women in science? Top researchers debate the evidence* (pp. 47–55). Washington, DC: American Psychological Association.

Eccles, J. S., & Midgley, C. (1989). Stage-environment fit: Developmentally appropriate classrooms for young adolescents. In C. Ames & R. Ames (Eds.), *Research on motivation in education*: *Vol. 3* (pp. 139–186). New York: Academic Press.

Fouad, N. (2008, September 8). Tracking the reasons many girls avoid science and math. *Eureka Alert*. Retrieved May 20, 2011, from http://www.eurekalert.org/pub_releases/2008-09/uow–ttr090508.php

Furner, J. M., & Kumar, D. D. (2007). The mathematics and science integration argument: A stand for teacher education. *Eurasia Journal of Mathematics, Science & Technology Education*, *3*(3), 185–189.

Halpern, D., Benbow, C., Geary, D. C., Gur, R., Hyde, J., & Gernsbacher, M. A. (2007). Sex, math and scientific achievement: Why do men dominate the fields of science, engineering and mathematics? Available on the *Scientific American Mind* Website. Retrieved November 4, 2001, from http://www.scientificamerican.com/article.cfm?id=sex-math-andscientific-achievement

Hirsch, L., Carpinelli, J. D., Kimmel, H., Rockland, R., & Bloom, J. (2007) *The differential effects of pre-engineering curricula on middle school students' attitudes to knowledge of engineering careers*. Paper presented at the 37th Annual ASEE/IEE Frontiers in Education Conference, Milwaukee, WI.

Iversen, E., Kalyandurg, C., & de Lapeyrouse, S. (n.d.). Why K–12 engineering? A publication of the ASEE Engineering K–12 Center. Retrieved November 4, 2011, from http://blue.utb.edu/engineering/pdf-files/Why_K12

Jacobs, H. H. (1989). *Interdisciplinary curriculum: Design and implementation*. Alexandria, VA: Association for Supervision and Curriculum Development.

Jacobs, J. E., Davis-Kean, P., Bleeker, M., Eccles, J. S., & Malanchuk, O. (2005). "I can, but I don't want to": The impact of parents, interests, and activities on gender differences in math. In A. M. Gallagher & J. C. Kaufman (Eds.), *Gender differences in mathematics: An integrative psychological approach* (pp. 246–263). New York: Cambridge University Press.

McBride, J. W. & Silverman, F. L. (1991). Integrating elementary/middle school science and mathematics. *School Science and Mathematics*, *91*(7), 285–292.

McKinney, K. (1993). *Improving math and science teaching: A report on the secretary's conference on improving mathematics and science teaching and instructional resources* (Office of Educational Research and Improvement Publication No. 065-000-00547-6). Washington, DC: U.S. Government Printing Office.

Mooney, M. A., & Laubach, T. A. (2002). Adventure engineering: A design centered, inquiry based approach to middle grade science and mathematics education. *Journal of Engineering Education*, *91*(3), 309–318.

National Research Council (NRC). (1996). *National science education standards*. Washington, DC: National Academy Press.

Olds, S. A., Harrell, D. A., & Valente, M. E. (2006). Get a grip! A middle school engineering challenge. *Science Scope*, *30*(3), 21–25.

Piaget, J. (1973). *To understand is to invent*. New York: Grossman.

Ryan, A. M., & Patrick, H. (2001). The classroom social environment and changes in adolescents' motivation and engagement during middle school. *American Educational Research Journal*, *38*(2), 437–460.

Schoenfeld, A. (1992). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 334–370). New York: MacMillan.

Siegel, S., & Castellan, N. J. (1988). *Nonparametric statistics for the behavioral sciences* (3rd ed.). New York: Wiley.

Spradley, J. P. (1980). *Participant observation*. Orlando, FL: Harcourt Brace Jovanovich College Publishers.

Stodolsky, S. S., Salk, S., & Glaessner, B. (1991). Student views about learning math and social studies. *American Educational Research Journal*, *28*, 89–116.

Sullivan, J. F., Cyr, M. N., Mooney, M. A., Reitsma, R. F., Shaw, N. C., Schaefer-Zarske, M., et al. (2005). The TeachEngineering digital library: Engineering comes alive for K–12 youth. Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition. Available from the American Society for Engineering Education Web site. Retrieved November 4, 2011, from http://k12division.asee.org/resources/

Yin, R. (1994). *Case study research: Design and methods* (2nd ed.). Thousand Oaks, CA: Sage Publishing.