Girls in Engineering, Mathematics and Science, GEMS: A science outreach program for middle-school female students.

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Introduction

There is a recognized shortage of domestic-born scientific and technical expertise in the United States. This personnel deficiency is compounded by stricter immigration laws, which can prevent foreign-born science, math and technology majors from remaining in the U.S. even if their degrees were earned in U.S. institutions. The technical personnel shortage will affect the United States' ability to maintain its position as a world leader in scientific and technological developments (Chemical and Engineering News, 2008; Lubinski & Benbow, 2007). It is also recognized that women are under-represented in many fields of science, mathematics and technology) and the scientific personnel shortage could be alleviated by increasing the number of females entering technical fields (Lee & Schreiber, 1999; Marra, Peterson, & Britsch, 2008; Burke, 2007; Carlson, 2006; Thom, 2001). Figure 1 compares the percentages of females graduating with bachelor degrees in science and technology fields from U.S. universities (Hill, C., Corbett, C., & St. Rose, A., 2010).

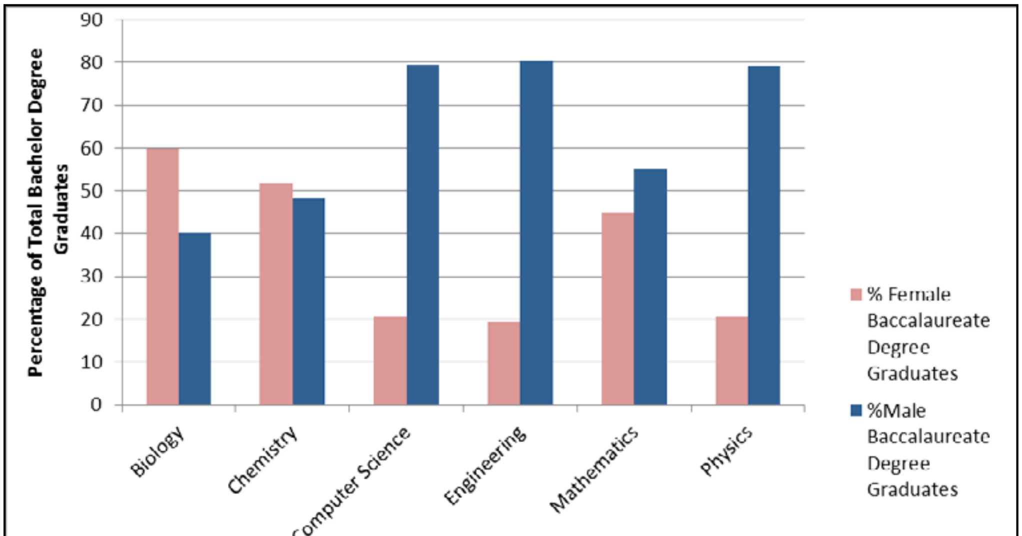

Fig. 1. Percent of female and male graduating with bchelor degrees from science, mathematics and engineering programs from U.S. universities.

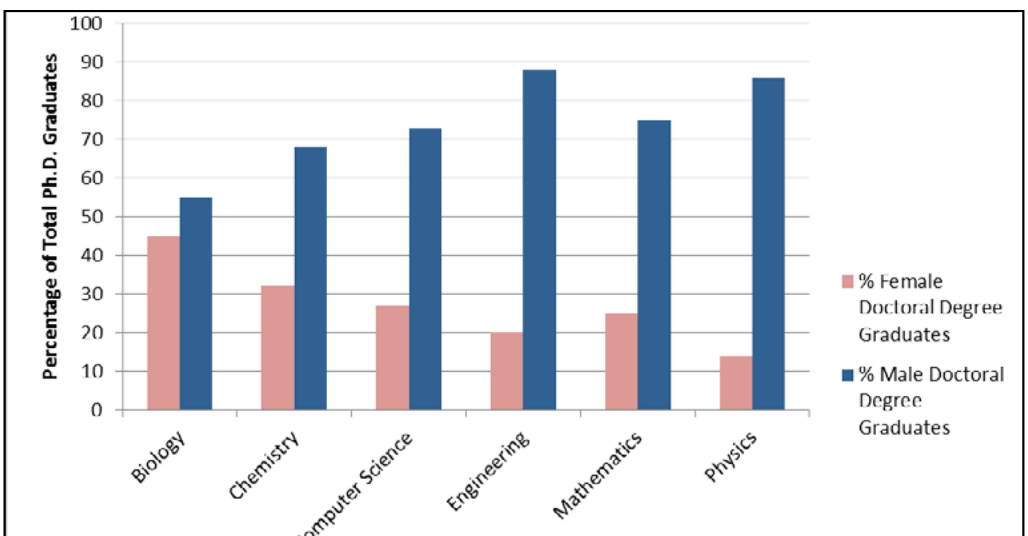

Fig. 2. Percent of female and male graduating with Ph.D. degrees from science, mathematics and engineering programs from U.S. universities.

Percentages of females receiving terminal degrees in fields of science and technology from U.S. universities are shown in Figure 2 (Hill, C., Corbett, C., & St. Rose, A., 2010; Chemical and Engineering News, 2009; Marra, Peterson & Britsch, 2008).

These percentages indicate that there is an untapped pool of human resources. In earlier grades, girls performance on standardized science and mathematics tests indicate scores are equivalent to those of male students, however, girls' scores decrease relative to boys' scores in later grades (Trends in International Mathematics and Science Study TIMSS, 2007). This difference is small and appears to be correctable rather than genetic as female students in other countries, such as Japan or Singapore, score higher than American male students (Valian, 2007; Trends in International Mathematics and Science Study TIMSS, 2007).

Lack of understanding in science and mathematics adversely affects society, not only by contributing to deficiencies in technical and scientific personnel, but also by citizens making uninformed decisions. A scientifically-literate person is familiar with nature, understands some important scientific principles, can problem-solve and interpret information in a scientific manner, recognizes the connection between mathematics, science and technology, understands that science has limitations, and uses scientific knowledge to influence human needs (Kesidou & Koppal, 2004; Rutherford & Ahigren, 1991). A lack of scientific and mathematical understanding affects decisions made by voters and consumers, leading to wasted money, and policies that may adversely impact society, industry, the economy and the environment.

Some authors have listed possible causes for the decrease in scientific and mathematical achievement including non-optimal learning conditions, negative stereotypes regarding inherent ability fear of being labeled "different" and fear of failure (Hyde, 2007). Multiple authors have described university outreach programs and activities which provide science and math experiences for K-12 students such as summer science camps, analytical chemistry experiments, forensic science cases, physical science experiments, engineering classroom activities, inquiry-based activities, and packaged engineering curriculum (Bachman et al., 2008; Robbins & Schoenfisch, 2005; McDonald, Sneddon, & Darbeau, 2008; Lee & Schreiber, 1999; Rogers & Portsmore, 2004; Perrin, 2004; Reid & Feldhaus, 2007).

Our personal experiences as female scientists and students led to the development of "Girls in Engineering, Mathematics, and Science (GEMS)," a series of science and math workshops which offer hands-on activities to middle-school female students. GEMS has a dual mission: to increase interest in science and math potentially encouraging more female students to enter these fields as a career, and to encourage a sufficient interest in science and math to enable them to be better informed citizens. The authors did not have opportunities offered to male peers, which encouraged interest in science or math and there were very few female scientists or science and math professors to serve as role models and mentors. Additionally, it was sometimes intimidating to be the only female student in a science or math class consisting of mostly male students. These experiences in our academic histories encouraged us to improve the situation for young female students. Similar programs have been implemented at other universities in the United States (Wilson, 2005; Zappas, 2008). GEMS workshops are presented by an all-female staff of faculty acting as activity designers and mentors, and use female undergraduate and graduate students as teaching assistants. Middle-school students, which start at grade six, were selected as the target participants for GEMS in order to improve familiarity and pique student interest in science before they entered the eighth grade. Studies indicate there are no statistically significant differences in male/female science scores for students at the level of fourth grade. However, boys' scores are approximately 12 percent higher than girls when the students are tested at the eighth grade level (Trends in International Mathematics and Science Study TIMSS, 2007).

The all-female environment of GEMS allows the participants to act freely without having to worry about being perceived as too intelligent, therefore as "different" by male students. This environment permits participants opportunities to state opinions and handle materials during the activities, without competition from boys who may be more assertive. Additionally, by using all females in the program, the participants meet women scientists who are successful role models in their fields. All GEMS activities are hands-on, active learning experiences created to enhance interest and facilitate retention of information. Gender-specific, active learning environments have been recommended by other educators as a means to optimize girls' interest in science and mathematics (Thom, 2001). The middle school students are exposed to a variety of fields in science and mathematics, with activities in chemistry, biology, astronomy, mathematics, civil engineering, bioengineering and more. Surveys evaluating student interest in GEMS indicated that the students enjoyed the activities, even though most had attended the event because of teacher or parental influence rather than personal interest. The results of the surveys are presented in a later section.

Implementation of GEMS Activities

Middle school students are generally recruited from public middle schools in a two-county region, however, some GEMS events have been held for private organizations, such as the Girl Scouts and alternative schools. Student recruitment depends on stipulations required by the grants funding each event. The GEMS events are publicized using brochures distributed to the public schools and private organizations. Information is also relayed in meetings between the GEMS directors, school district science coordinators, teachers, principals and Girl Scout leaders.

Additionally, information is posted on a website reaching students who were not enrolled in public schools, such as home-schooled students or those enrolled in private schools. Busses have been provided for targeted groups, such as schools with a high minority population. Minority student participation has increased by providing transportation and the busses are funded either by the school districts or with grants. Some of the grants have been directed at minority or economically disadvantaged students, with more than 80 percent of the GEMS participants being from these populations for events funded by these grants. Additionally, the school districts have provided extra assistance in ensuring these targeted groups have been able to attend GEMS by promotion within the classrooms and by sending teachers with groups of the students to the GEMS events.

Most workshops are held on Saturday mornings and include two sets of activities with each set being approximately two hours long. A maximum of 100 students are registered for each event and divided evenly into two groups for the activities. Students rotate between the two activity sets at the end of the two-hour period. The students are allowed some flexibility in the group to which they are assigned. They are permitted to be in the same group as one or two friends, but if a large number of students are from the same middle school, then they are split into opposite groups to allow them to meet girls from other schools. This increases their opportunity to meet people from diverse backgrounds with different perspectives. A brief 10-minute introduction starts the GEMS event, usually with a comical method of catching their attention, such as one of the co-directors dressed in a lab coat, with wild hair imitating Einstein and a false nose with lab glasses. The co-director asks the girls if this is what a scientist looked like and most children respond affirmatively. She then removes the costume and asks the students if they would recognize her as a scientist if they saw her in the mall and most of the middle-school students say no. The co-director then introduces the students to the GEMS mentors and teaching assistants to allow the children to see real scientists who do not look like the odd stereotypes depicted on television. The co-director emphasizes that not only could scientists be female, but are not "nerdy".

The teaching assistants are specially selected for several traits: excellence in their scientific discipline, patient and empathic personalities, interest in mentoring and teaching younger girls, and diverse ethnic backgrounds. The teaching assistants are the activity leaders, working closely with the middle school students leading them through the activities. The teaching assistants have varied backgrounds with economic diversity, ethnic diversity and diversity in their STEM majors. TAs with majors in biology, chemistry, engineering and education participate: both undergraduate and graduate students have assisted in the GEMS program. Undergraduate TAs range from freshman students to seniors and all TAs have been excellent role models for the younger students.

All TAs are trained approximately one week before the day of the GEMS event. The faculty member leading the science or math activity meets with the TAs and lets them perform the activity. There is a discussion on safety issues, experimental procedures and possible errors and also general information is relayed on how to "teach" the middle school students using active learning and guided inquiry methodology. Although some of the TAs have tutored other students one-on-one, it is often the first time that they have had to direct groups of people and so effective group management is also discussed. The ratio of middle school students in groups to TAs or faculty members is 9:1 or smaller, with the students divided into smaller groups of approximately nine students to enhance the opportunity for individual work and greater hands-on

Middle school district	Total students	Females	White	Black	Hispanic	Asian, Other	American Indian	Economically Needy
Collier	9025	4401	3856	442	3717	1010	23	5270
Lee	18209	8956	9267	2714	5279	949	38	12928
Totals	27324	13357	13123	3156	8996	1959	61	18198
Percent of total		48.9%	48.0%	11.6%	32.9%	7.2%	0.2%	66.6%

Table 1. District school board of Collier county and Lee county middle schools 2010-11 population statistics

participation. The TAs are also given general information on assisting with registration and activity set-up and disassembly during their training session.

After the middle school students rotate through the two activities, the program concludes with a brief discussion of their thoughts on the science and activities experienced during the day, completion of a program evaluation, and distribution of a small gift such as a tee shirt or a stuffed animal mascot. A slide show of pictures taken of the middle school students during the GEMS activities is displayed continuously during the conclusion.

The activity sets are usually stand-alone activities, such as ecological observations around university wetlands, but occasionally part of a greater theme (such as a forensic mystery case). With the direct hands-on approach to activities, the GEMS program may lead more girls to enter applied science careers, such as civil engineering, bioengineering, environmental engineering and careers in the fields of natural science, such as biology, chemistry and physics, or simply take a greater interest in science and math as it affects their daily lives. Depending on the grant funds available and the specific activity, supplies are purchased from chemical and biological suppliers, grocery stores, or borrowed from the university equipment.

In addition to the students, middle school teachers from the local two-county area are invited to take part in the GEMS events. This provides the participating science teachers availability of resources on campus, meeting faculty and professionals with the university, and taking part in activities that they can take back to their home schools to implement. Most of the middle school teachers who have attended have also been female with perhaps two male teachers attending during the 3-year period of the GEMS program. Partnerships have been formed with teachers from several middle schools, including two schools with a high percentage of Hispanic and African-American students who have limited exposure to higher education. The majority of the GEMS participants are middle-school girls, grades six through eight in Lee County and Collier County. The students come from the 13,357 girls in the 27 public middle schools in these counties. Diversity information was not specifically gathered for the GEMS participants, but the public schools have more than a 52 percent under-represented student population that includes schools with a minority enrollment of 97 percent. Table 1 shows the diversity information for middle school students in our local two-county region.

The GEMS program is free to all middle-school participants and is mostly grant-funded. The participants are accepted on a first-come-first-serve basis. To accommodate a maximum number of students per school for each event, schools are invited on a rotating basis. The same GEMS activities are repeated on multiple Saturdays during a school year so that all local schools are invited by the end of the academic year. Information on the types of science activities is deliberately not provided so that students would not pre-judge based on a negative preconceived idea of the subject matter. A week-long summer workshop has also been offered, consisting of the same format, offering two activities per day.

Table 2 lists the science, engineering and mathematics activities offered during the first three years of the GEMS program. Since science and mathematics are often inseparable, math was imbedded in many of the science and engineering activities. A variety of scientific topics were offered, to allow the GEMS participants to experience multiple

Field of Study	GEMS Activities
Civil engineering	Design and testing water filtration systems using gravel and soil beds
	Design and testing of earthen walls
	Design and testing of catapults
	Testing properties of adhesive strength
Bioengineering	Design and testing of heart valves
	Design and testing of bicycle helmets
Astronomy	Star studies and grouping galaxies
	Space shuttle engineer presentation
Mathematics	Measurements using the metric system
Chemistry	pH measurements
	Thin layer chromatography of pain killers
Forensic chemistry	Chemical analysis of “gun powder”
	Chemical detection of “blood stains”
	“Blood” typing
	Paper chromatography of inks
Forensic mathematics	Fingerprint pattern matching
Forensic biology	DNA electrophoresis
Biology	Dissection of rats and comparative anatomy
	The heart
	The senses and dissection of bovine eyeballs
	Human anatomy and physiology: pulse, blood pressure, skeletal structures
Molecular biology	DNA modeling and gel electrophoresis
	Extraction of wheat germ DNA
Environmental science	Exploration of local wetlands

Table 2. Fields of science and technology addressed in GEMS activities.

fields of science since some participants may be interested in one field as opposed to other fields. The topics were usually not connected, but deliberately mixed to illustrate the diversity of science.

Procedures and details of the activities are not included in this manuscript since the focus is on the use of the GEMS program to increase interest in science and math. The week-long summer program had an extra feature, concluding with a female space shuttle engineer from NASA as an invited speaker. She showed the students a short film about the space program which included brief interviews with many female scientists and astronauts. She also gave the students NASA souvenirs and answered their many questions about the space program and what education is needed to participate in the space program.

Students wear appropriate safety equipment for each activity, such as safety glasses and laboratory gloves. Most activities were especially selected or designed to minimize hazards and for activities in which chemicals may be more hazardous (i.e. gunpowder test) the teaching assistants handled the chemicals. No participant was forced to perform an activity to which they objected. For example, some students preferred not to participate in the rat dissection so were given alternate activities.

Assessment of Student Interest in Science Before and After GEMS

Quantitative measures of interest are obtained by a program evaluation which asks questions concerning program format and interest in the specific activities. Questions and answer choices included on a typical survey are listed in Table 3. Question 6, which asks about the specific activity, varied depending on which activities were offered during the semester. There is a separate question for each activity, so the total number of questions is usually greater than six.

Question	Possible Answers
1. Who encouraged you to attend the GEMS program?	a. Myself b. Teacher c. Parent d. Friend
2. How interested were you in science before attending the GEMS program?	a. Very interested b. Somewhat interested c. Slightly interested d. Not interested
3. Are you more excited about science after attending the GEMS program?	a. Very interested b. Somewhat interested c. Slightly interested d. Not interested
4. Would you participate in another GEMS program?	a. Yes b. No c. Maybe
5. Would you recommend the GEMS program to friends?	a. Yes b No
6. Did you enjoy the activity?	a. Yes b. No c. It was okay

Table 3. Questions and answers on a typical GEMS evaluation survey.

Participants can select more than one answer for Question 1 since they may have received encouragement from several sources and so the percentage of total responses is greater than 100 percent. They are also encouraged to write comments. Results for Questions 1 through 5 are presented in Table 4 and are taken from a population of 679 respondents over a period of three years. Percentages for Questions 2 through 5 may be slightly different than 100 percent because of participants' occasionally not answering one of the questions or number rounding.

An interesting observation was that teacher encouragement was the leading factor for proving an impetus for the students to attend GEMS and was a much greater influence than parental encouragement. We recently have started giving the middle school teachers a brief electronically delivered PowerPoint presentation which explains the GEMS mission and rallies interest in the GEMS activities. The teachers have told us this presentation is very effective and has a side effect of catching the interest of their male students who also want a science outreach program. We also volunteer to personally speak to the students and provide science demonstrations if the teachers think that will encourage enthusiasm for attending GEMS.

Figure 3 shows the interest in science before and after the participants attend the GEMS program. Survey results for Question 2, "how interested were you in science before attending the GEMS program," is depicted in blue while the response to Question 3, "are you more excited about science after attending the GEMS program," are shown in red. The percentages for each response category are average percentages for 532 respondents during the period of 2006 to 2009. The data shows that participant interest in science and math increase on average by 35 percent after attending a GEMS event.

Table 5 gives the survey results for each GEMS event. The percentage of participants who answered choices a, b, c, or d, or Questions 2 and 3 of the GEMS survey are listed. There does not appear to be a trend or correlation to the types of activities. For example, the same GEMS activities were offered to different groups of students in October 2006 and March 2007, however increased interest in science was 37.5 percent in March as compared to 27 percent in October.

Evaluation comments have been overwhelmingly favorable. For example, participants have drawn smiling faces or exclaimed they "loved the dissection" or "loved the ecology field exploration." Somewhat surprisingly given the general "fear" of mathematics, only positive comments were written regarding the metric measurement activity. An important critical comment was that some participants felt there is insufficient time allotted to complete activities which involve considerable problem-solving efforts, such as bioengineering.

Observations of the participants during one of the engineering exercises (heart valve design) indicated the students were initially hesitant to start the design process. They wanted to be told exactly what to do rather than proceed and possibly fail. This be-

Question	Answers	% of total participants
1. Who encouraged you to attend the GEMS program?	a. myself	36.2
	b. teacher	43
	c. parent	17.2
	d. friend	17.4
2. How interested were you in science before attending the GEMS program?	a. very interested	39.9
	b. somewhat interested	42.6
	c. slightly interested	13.1
	d. not interested	0
3. Are you more excited about science after attending the GEMS program?	a. very interested	72.2
	b. somewhat interested	22.2
	c. slightly interested	5.0
	d. not interested	0
4. Would you participate in another GEMS program?	a. yes	80.6
	b. no	1.1
	c. maybe	18.3
5. Would you recommend the GEMS program to friends?	a. yes	97.6
	b. no	2.1
	c. maybe	0

Table 4. GEMS participant survey results for questions 1-5.

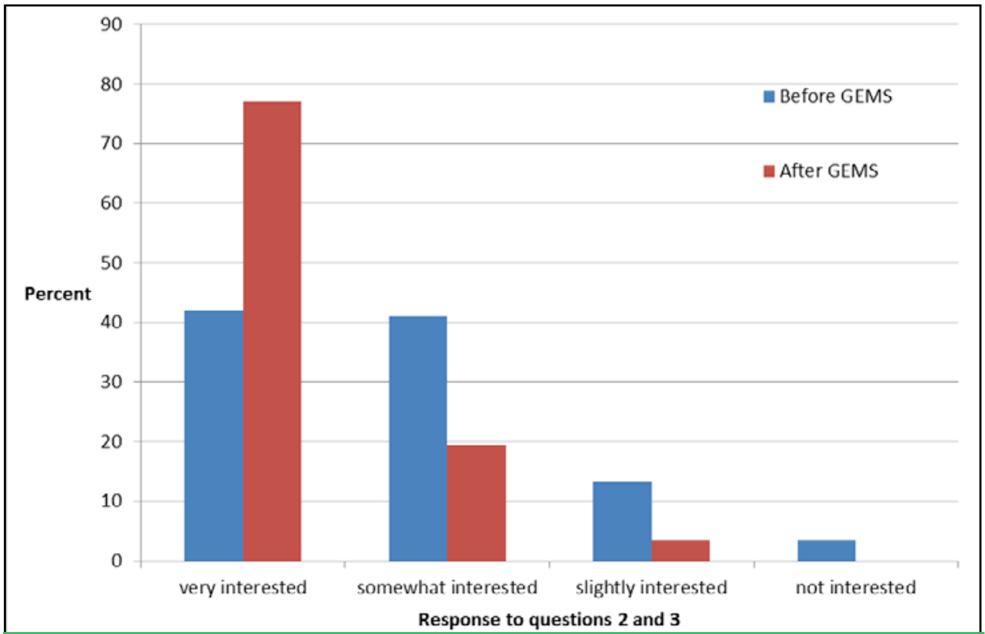

Fig. 3. Survey results for questions 2 and 3 indicating participant interest in science before and after attending a GEMS event.

havior correlates with findings by other researchers, which girls tend to lose confidence and cope less well than boys when giving confusing tasks (Dweck, 2007). However, the students soon realized if their initial valve design did not work, they could determine the point of failure and try something different. It was an important learning experience for the students to realize that science and technology do not usually succeed on the first try, but there is no stigma attached to the failure. Development of a self-confident attitude that encourages girls to risk failure is crucial to success in science and mathematics (Dean & Fleckenstein, 2007).

Conclusions

GEMS as an outreach program provides additional learning experiences beyond the classroom. The GEMS program gives the students an introduction to many fields of science, engineering and math, and it provides exposure to the world of higher education. Many of the students become comfortable with the university after only one day at GEMS and express a desire to attend the university after finishing high school. Students coming from distant counties were delighted with the wetland ecological activity, which they had not experienced in their agricultural community.

Another positive outcome of GEMS is the establishment of stronger relations between GEMS faculty and local middle school teachers. Several teachers have attended multiple events, brought back activities to their classrooms, and expressed a desire to partner with us in more outreach projects. Some of these teachers have returned to our university with their AP science students to participate in experiments and activities outside of GEMS. Other local middle school students worked under the direction of university environmental science faculty conducting field work analyzing a local lake that is highly polluted from agricultural chemicals. As demonstrated by the GEMS surveys, teacher partnerships are also crucial for motivating the students to attend the GEMS events. GEMS is also viewed favorably by parents and organizations in the local communities and local news media have helped encourage interest with articles describing the program. We were invited to conduct a special GEMS event for local Girl Scout troops which brought approximately 80 Girl Scouts from a two-county region and now are asked annually to provide a special Girl Scout GEMS event. We have also been asked to partner with Rookery Bay National Estuarine Preserve and conduct a GEMS event at that site. GEMS has also positively affected the TAs with some of them realizing that they enjoyed teach-

Event Date	Q2 A	Q2 B	Q2 C	Q2 D	Q3 A	Q3 B	Q3 C	Q3 D
Oct 2006	46.1	34.6	11.5	7.7	73.1	19.2	7.7	0
Mar 2006	45.8	41.7	8.3	4.2	83.3	16.7	0	0
Oct 2007	42.6	40.4	14.9	2.1	78.7	21.3	0	0
Feb 2008	40	42.2	15.6	2.2	88.9	8.9	2.2	0
Mar 2008	37.2	41	19.2	2.6	74.4	17.9	7.7	0
Jun 2008	46.4	44.9	5.8	2.6	87	11.6	1.4	0
Oct 2008	36.9	41.5	18.5	3.1	64.6	33.9	1.5	0
Nov 2008	34.2	46.8	13.9	5.1	74.7	21.5	3.8	0
Feb 2009	53.3	32	9.3	5.3	73.0	20.3	6.7	0

Table 5. Percentage of students showing increased interest in science and math after each GEMS event.

ing and working with the younger participants. It also benefits the TAs by increasing their understanding of science when they explain science and math to the middle school students. Additionally, they gain confidence by learning activities outside of their major fields of study. Overall, GEMS provides a rich learning experience for all involved.

The GEMS science and mathematics outreach program provides hands-on activities in which middle school female students become immersed into laboratory and field experiences and interact with female mentors and role models. The program stimulates interest in science, mathematics and higher education, and also introduces the participants to potential career opportunities.

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Terry Dubetz recently retired as an associate professor of chemistry at Florida Gulf Coast University but will continue teaching on a half-time schedule. She teaches Analytical Chemistry, Instrumental Analysis and General Chemistry. She was co-director of GEMS, with Jo Ann Wilson from its start in 2006 to 2011. Science education has been a special interest during her career.

Jo Ann Wilson is a professor of biology at Florida Gulf Coast University. In this capacity she also serves as the director for pre-medical professional programs. In 2006 Dr. Wilson and Dr. Terry Dubetz developed Girls in Engineering, Math and Science (GEMS) to promote science education to regional middle-school girls. The GEMS program is grant supported and most recently by NASA Florida Space Grant Consortium. GEMS has provided science activities to more than 1500 girls since 2006.