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# Girls Engaged in Mathematics and Science (GEMS): Building Awareness and Interest in STEM Careers through Robotics

**Charlease Kelly-Jackson, Ed.D.**
Kennesaw State University
Kennesaw, Georgia, USA

***Abstract*— The Girls Engaged in Mathematics and Science (GEMS) Summer Program was designed to increase upper elementary girls' awareness of science, technology, engineering, and mathematics (STEM) careers and nurture a lifelong interest in STEM subjects. The program served twenty-one rising 4th and 5th grade girls from an urban and underserved elementary school in the Southeastern region of the United States. The curriculum was based on a problem-based learning approach, which involved an engineering design model and LEGO Robotics Construction Kits. Participants were assessed using the STEM Semantics Survey and the Career Interest Questionnaire, which serve as major indicators for perceptions of STEM disciplines and careers [33]. Survey and questionnaire data revealed an increase in students' awareness of and interest in STEM related fields. According to focus group data, the planning and implementation of the program were effective.**

***Keywords—Robotics; Science, Technology, Engineering, and Mathematics (STEM); Girls Engaged in Mathematics and Science (GEMS); LEGO WeDo Construction Kits, Problem Based Learning (PBL)***

## I. INTRODUCTION

Science, technology, engineering and mathematics (STEM) have permeated nearly all facets of modern life and hold the key to meeting many of our most critical and current challenges [1]. In fact, STEM innovations have become increasingly crucial as we advance in this new information-based and highly technological society [2]. Unfortunately, the U.S. is experiencing a shortage in the number of students pursuing STEM degrees [3-6]. Students are deciding early that STEM disciplines are too difficult or unwelcoming, which leaves them ill prepared to meet the needs of their generation, country, and world [7]. This deficiency impacts the personal well being of each citizen and the nation's ability to remain competitive in the global economy; thus, it has become a top priority for policymakers [1,8,9].

One factor that contributes to this shortage is the historical underrepresentation of women and minorities in STEM disciplines [3,7,10,19]. When compared to other groups, women, American Indians/Alaskan Natives, Blacks, and Hispanics are considered untapped resources [11,19] and are less likely to complete a STEM major [2,12]. According to the Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development [13], students, especially girls, begin to lose interest in STEM by middle school. Consequently, we see fewer women pursuing in these fields at the undergraduate level.

Engineering is an effective approach to illustrate how math and science concepts integrate to make technology possible. More specifically, robotics, an interdisciplinary engineering subject [14], allows students to experience designing and building [15,16]. More and more teachers are moving toward robotics as an educational tool because it affords students the opportunity to test the results of abstract design concepts through concrete, hands-on robotic manipulatives [17]. In order for students to be prepared for life in the 21st century, it is critical to cultivate their interest in STEM at a younger age [18,19].

Efforts to bring engineering to elementary schools have been reported through studies involving the First LEGO Leagues (FLL). Survey data validate that 94% of students participating in the FLL had increased interest in STEM subjects, programming skills, problem-solving skills, teamwork skills and leadership skills [19]. A study conducted by Geeter, Golder, and Nordin [20] discovered that the FLL students: 1) gained a better understanding of engineering; and 2) improved creative thinking, critical thinking and problem-solving skills; and increased self-confidence levels, interest, and involvement in science and math. More importantly, research has shown that the skills developed using LEGO programs were transferable to other situations. Waks and Merdler [21] determined that designing, building and programming helped to develop a student's spatial reasoning and creative problem solving abilities. LEGO WeDo Kits help students develop key skills needed to be successful in today's world.

The Girls Engaged in Mathematics and Science (GEMS) Summer Program was developed to increase upper elementary girls' awareness of STEM related careers and nurture a lifelong interest in STEM subjects. The two primary goals were to increase upper elementary girls' awareness of and interest in STEM related fields and inform girls from low socioeconomic circumstances, their families, and their teachers about robotics. The program objectives were: 1) 75% of the participating girls will increase their ***awareness*** of STEM careers in broad science areas as measured by the Career Interest Questionnaire; 2) 75% of the participants will increase their ***interest*** in STEM and careers as measured by the STEM Semantics Surveys; and 3**)** 100% of the participants will work in collaborative teams to design and construct robots using LEGO WeDo Construction Kits. The purpose of this article is to share an innovative approach to build awareness and interest in STEM to urban, underserved girls through robotics. This paper presents the details of the GEMS summer program along with evaluative data of the program's effectiveness.

## II. CONCEPTUAL UNDERPINNINGS

Traditionally, STEM topics have been taught using well defined problems; but in the real world, problems are not well defined [18]. Concrete STEM tasks, similar to those in engineering, allow students to work in real-world settings, focusing on real-world problems. In engineering, robotics provides STEM experiences that are concrete, authentic, accessible, and motivating [22-25]. Like robotics, problem based learning (PBL) teaches students to "interpret the question, gather additional information, create possible solutions, evaluate options to find the best solutions, and then present their conclusions" [26].

Problem solving or the preparation for problem solving exists in all educational settings. Problem based learning is a teaching technique that presents the student with a situation that leads to a problem to solve. It provides a structure for motivation and discovery that helps students identify and research concepts and principles needed to work through the problems [26]. Problem based instruction affords students with the ability to "think critically and be able to analyze and solve complex, real-world problems; find, evaluate, and use appropriate learning resources; work cooperatively in teams and small groups; demonstrate versatile and effective communication skills, both verbal and written; and use content knowledge and intellectual skills…to become continual learners" [27]. Students learn to internalize learning while directing their own activities, making learning an act of discovery [26,27].

An engineering curriculum naturally involves problem solving, which at the least should be real world problems. Instruction involving robotics offers support for authentic learning in problem based situations [28]. Research shows successful results in implementing engineering-robotics via a problem based approach [28-32]. However, robotics/PBL studies that focus specifically on increasing STEM awareness in young girls from underserved populations are insufficient in the literature.

## III. CONTEXT: GEMS SUMMER CAMP

The GEMS summer program, featuring a one-week robotics camp, was held at an urban, underserved elementary school in the Southeastern United States. Camp instructors included a university science faculty, a science and mathematics lab teacher and a preservice teacher who utilized a problem based and student-centered approach. On day one, students learned about the engineering design process and were divided into LEGO robotics teams to work on the construction of their robot using LEGO WeDo Construction Kits. Each day, students were presented with an engineering design challenge they had to solve, worked together to build and program their robot, and engaged in discussion with a woman in STEM. At the end of each day, students wrote reflections in their journals. The program concluded with the girls presenting their projects to other students, parents, and school and university faculty. (See Figure 1).

Fig. 1. *Students during the culminating ceremony*

Twenty-one girls between the ages of 8-10 completed 22.5 hours of instruction. The participants consisted of 14 African Americans, 3 Hispanics, 3 Whites, and 1 Indian, all receiving free/reduced lunch. Ten 4th graders and eleven 5th graders were strategically placed in pairs with at least one girl within the pair having had LEGO robot experience. Each partner was allowed to select their role in the pair and make adjustments in roles as deemed necessary.

The assessment design consisted of quantitative and qualitative measures. External evaluators collected data using the STEM Semantics Survey (Appendix A), the Career Interest Questionnaire (Appendix B), and focus group interviews. Participants were asked to complete pre and post assessments that serve as major indicators for perceptions of STEM disciplines and careers. The STEM Semantic Survey measures interest in science, technology, engineering and mathematics as well as interest in STEM careers while the Career Interest Questionnaire measures interest in careers in broad science areas. Both instruments are appropriate for students and are valid and reliable [33].

Focus group interviews took place to gather data on the program's overall effectiveness (Appendix C). A final Program Evaluation Survey was administered to determine which activities were ranked as favorite or least favorite (Appendix D). All assessments except the focus group interviews were completed digitally using Google Docs. Focus group interviews were conducted on site in two small groups. The results from all assessments are reported at the group level.

Fig. 2. *Participants during a field trip at a robotics facility*

## IV. RESULTS

Results show that objectives 1 [75% of the participating girls will increase their awareness of STEM careers in broad science areas] and 2 [75% of the participating students will increase their interest in STEM and careers] were met. Objective 1 was measured using the pre and post Career Interest Questionnaire completed at the beginning and end of the program. The participants were given an opportunity to choose between a series of adjectives to describe STEM domains. For each STEM domain, five adjectives were positive and five were negative. Table 1 shows the change in the percentage of students selecting the positive adjective for each domain. One student's response is equivalent to 5.3; therefore, a change of 5.3 shows one more student chose the positive adjective on the post-test than they did on the pre-test. Numbers in parenthesis represent a negative change. (See Table I)

TABLE I. CHANGE IN STUDENTS' SELECTIONS ON STEM SEMANTICS SURVEY

| | To me Science is: | To me Math is: | To me Engineering is: | To me Technology is: |
|---|---|---|---|---|
| **Fascinating** | +21.1 | (5.3) | +21.1 | +21.2 |
| **Appealing** | +26.3 | 10.5 | +15.8 | NC |
| **Exciting** | +15.8 | 36.8 | +15.8 | +5.3 |
| **Means a lot** | +31.6 | (5.3) | NC | +5.3 |
| **Interesting** | NC | NC | +10.5 | +5.3 |

The greatest change was in the domain of science with four adjectives representing double-digit support. Engineering also had four adjectives with double-digit growth although the average was slightly lower than for science. The domain with the least amount of positive change in student feedback was technology.

Fig. 3. *Students programming their robot*

Fig. 4. *Sample robot design*

Objective 2 was measured using a pre and post STEM Semantics Survey completed at the beginning and end of the workshops. Participants were given an opportunity to choose between a series of adjectives to describe STEM domains. For each STEM domain, five adjectives were positive and five were negative. Table 2 shows the change in the percentage of students selecting the positive adjective for each statement. Again, one student's response is equivalent to 5.3. A change of 5.3 shows one more student chose the positive adjective on the post-test than they did on the pre-test. Numbers in parenthesis represent a negative change. (See Table II)

TABLE II. CHANGE IN STUDENTS' SELECTIONS ON STEM SEMANTICS SURVEY AND CAREER INTEREST QUESTIONNAIRE

| Statement | Change |
|---|---|
| To me, a CAREER in science, technology, engineering, or mathematics means a lot. | +5.3 |
| To me, a CAREER in science, technology, engineering, or mathematics is interesting. | +10.5 |
| To me, a CAREER in science, technology, engineering, or mathematics is exciting. | NC |
| To me, a CAREER in science, technology, engineering, or mathematics is fascinating. | +15.8 |
| To me, a CAREER in science, technology, engineering, or mathematics is appealing. | +21.1 |
| I would like to have a career in science. | +15.8 |
| I would enjoy a career in science. | +5.3 |
| I will get a job in a science-related area. | +10.5 |

While there was no change in the number of students who thought a career in STEM would be *exciting*, positive change occurred in the number of students who viewed a career in STEM as *meaningful, interesting, fascinating*, and *appealing*. Student feedback showed a positive change in the number of girls who agreed they would like to have a career in science, enjoy a career in science, and get a job in a science related field. Students responded to the statement, "I would enjoy a career in science" using a Likert scale. Six students responded positively from the pre to post assessment, 11 students showed no change and two students showed a decrease in interest in a career in science.

Objective 3: 100% of the participating girls will work in collaborative teams to design and construct robots using the LEGO WeDo Construction Kit was measured via classroom observations. (See Figures 3 and 4)

Two participants were absent on the day these activities were completed resulting in 90% of the program participants working collaboratively to complete the activities.

Nineteen students participated in focus group discussions. Students described their workshop learning experience as appealing, fascinating, fun, exciting, and expanding. Of the 19 students participating in the focus groups, seven students liked math best; six students liked science best; five students liked technology best; and one student liked engineering best. When asked why they prefer one subject to another, students' responses included:

*I like science because you can do lots of stuff with science like some experiments or lots of things.*

*I like math more than the others because almost everything you do it involves math.*

*I like science better than any other subjects because when I grow up I want to be a vet and that has more to do with science than any other subject.*

*I like engineering the most because I can be creative and I can build robots and stuff and I can be creative with the engineering and design and stuff.*

*I like science best because I think that it's a lot fun and I can be creative and make new worlds and just investigate what you like.*

Seventeen students reported that the program enhanced their knowledge/awareness of STEM fields/careers. Eighteen of the 19 students who participated in the focus group said that they would enjoy attending another workshop like this one in the future. When asked to rate the programs' activities from one to six with one being their most favorite activity to six being their least favorite activity, 11 students rated the Robotics Field Trip as their 1st (See Figures 2 and 5), most, favorite activity; 6 students rated WeDo Kits as their 2nd favorite activity; 9 students rated STEM Challenge – Invitations as their 3rd favorite activity; 7 students rated WeDo Construction Kits as their 4th favorite activity; 9 students rated STEM Challenge – Silly Straws as their 5th favorite activity; and 14 rated Journal Reflections as their 6th least favorite activity. Table III shows students' ratings of program activities.

TABLE III. CHANGE STUDENTS RATING PROGRAM ACTIVITIES

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| STEM Challenge – Angry Bird Display | 4 | 5 | 3 | 2 | 3 | 2 |
| STEM Challenge – Invitations | 2 | 2 | 9 | 6 | 0 | 0 |
| STEM Challenge – Silly Straws | 1 | 3 | 4 | 1 | 9 | 1 |
| LEGO WeDo Construction Kits | 4 | 6 | 0 | 7 | 2 | 0 |
| Journal Reflections | 0 | 1 | 0 | 1 | 3 | 14 |
| Robotics Facility-Field Trip | 11 | 1 | 2 | 2 | 1 | 2 |

## V. DISCUSSION

The data show positive change in students' perceptions and feelings toward STEM domains and careers. One of most significant findings from the data is the overwhelming majority of girls that rated the robotics field trip as their 1st most favorite activity. This response rating is contributed to the hands on and problem based approach of the experience. Participants were allowed to test drive robots, work in collaborative teams to build a robot using scrap materials, and interact with high school females who are members of their school's robotics team. (See Figure 5). In addition, they were able to observe, on a larger scale, how larger and more sophisticated robots are designed and programmed. The robotics field trip was embedded in the program to expose students to robotics in every day, realistic situation and to "give students something to do…and the doing is of such a nature as to demand thinking or intentional connections" [34].


Fig. 5. *Student test driving a robot at robotics facility*

Overall, the participants and instructors were satisfied with the implementation of the program. However, areas of improvement include: 1) modifying the schedule to incorporate more team building activities on the first two days, 2) allowing the girls to select a partner to encourage a richer bonding experience, and 3) modifying the journal writing component. Fourteen of the 19 students who participated in the end of the program evaluation rated the journal writing as their least favorite activity. Because communication (written and oral) is a vital component of the program, instructors suggested keeping the written component but also embedding an oral component. This modification would still allow us to capture students' voices in addition to building communication skills.

The GEMS summer program has the potential to impact many students' awareness and interest in STEM careers. This is especially significant for students of different cultural and socioeconomic backgrounds. The next steps of this program are to expand to other elementary schools and embed a mentoring component that involves middle and high school girls. Teachers and curriculum specialists are encouraged to use these findings to structure similar summer programs or in-school collaborative robotics projects. Elementary level, STEM focused programs, like GEMS, are necessary to build and nurture the STEM pipeline. GEMS provides a model program that has only touched the surface toward helping underserved females increase their awareness of and interest in STEM careers at an early age through robotics.

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**Appendix A: STEM Semantics Survey**

*On-line Text:*

Last Name First Name

Birth date (month/day/year) Last grade completed

Instructions: Choose one circle between each adjective pair to indicate how you feel about the object.

To me, **SCIENCE** is

1. fascinating 1 2 3 4 5 6 7 mundane
2. appealing 1 2 3 4 5 6 7 unappealing
3. exciting 1 2 3 4 5 6 7 unexciting
4. means nothing 1 2 3 4 5 6 7 means a lot
5. boring 1 2 3 4 5 6 7 interesting

To me, **MATH** is

1. boring 1 2 3 4 5 6 7 interesting
2. appealing 1 2 3 4 5 6 7 unappealing
3. fascinating 1 2 3 4 5 6 7 mundane
4. exciting 1 2 3 4 5 6 7 unexciting
5. means nothing 1 2 3 4 5 6 7 means a lot

To me, **ENGINEERING** is

1. appealing 1 2 3 4 5 6 7 unappealing
2. fascinating 1 2 3 4 5 6 7 mundane
3. means nothing 1 2 3 4 5 6 7 means a lot
4. exciting 1 2 3 4 5 6 7 unexciting
5. boring 1 2 3 4 5 6 7 interesting

To me, **TECHNOLOGY** is

1. appealing 1 2 3 4 5 6 7 unappealing
2. means nothing 1 2 3 4 5 6 7 means a lot
3. boring 1 2 3 4 5 6 7 interesting
4. exciting 1 2 3 4 5 6 7 unexciting
5. fascinating 1 2 3 4 5 6 7 mundane

To me, **CAREER** in science, technology, engineering, or mathematics (is):

1. means nothing 1 2 3 4 5 6 7 means a lot
2. boring 1 2 3 4 5 6 7 interesting
3. exciting 1 2 3 4 5 6 7 unexciting
4. fascinating 1 2 3 4 5 6 7 mundane
5. appealing 1 2 3 4 5 6 7 unappealing

(Tyler-Wood, Knezek, & Christensen, 2010)

**Appendix B: Career Interest Questionnaire**

*On-line text:*

Instructions: Select one level of agreement for each statement to indicate how you feel.

SD = Strongly Disagree

D = Disagree

A = Agree

SA = Strongly Agree

**PART I**

1. I would like to have a career in science.

2. My family is interested in the science courses I take.

3. I would enjoy a career in science.

4. My family has encouraged me to study science.

**PART II**

5. I will make it into a good college and major in an area need for a career in science.

6. I will graduate with a college degree in a major area needed for a career in science.

7. I will have a successful professional career and make substantial scientific contributions.

8. I will get a job in a science-related area.

9. Some day when I tell others about my career, they will respect me for doing scientific work.

**PART III**

10. A career in science would enable me to work with others in meaningful ways.

11. Scientists make a meaningful difference in the world.

12. Having a career in science would be challenging.

(Tyler-Wood, Knezek, & Christensen, 2010)

**Appendix C: Focus Group Protocol**

**GEMS Focus Group Protocol**

Identification of focus group participants:

Every participant will participant in a focus group.

Group Facilitators: External Evaluators

Focus Group Directions:

Upon meeting the students, introduce self. State your appreciation of their willingness to talk with you. Ask them if it is okay with them to record the conversation. (Indicate your willingness to turn off the recorder at any time they signal you to do so.)

**Focus Group Questions:**

Opening script: Thank you for agreeing to talk with me. Your comments will be kept confidential and your name will not be used on any reports.

The purpose of the focus group is to help us gather information that can be used to improve STEM education, the program in which you are now participating. Your responses will help us to make improvements to other programs for students in the future.

1. What words you would use to describe your learning experience this past week. (Randomly select students to share.)

2. Think about how you feel about Science, Technology, Engineering and Math and which one you like BEST.

Raise your hand if you like Science best.

Raise your hand if you like Technology best.

Raise your hand if you like Engineering best.

Raise your hand if you like Math best.

3. Thinking about Science, Technology, Engineering and Math, why do you like one subject more than other subjects? (Randomly select students to share.)

4. Were you aware of STEM careers before attending the program this week? Which careers are of most interest to you? (Randomly select students to respond.)

5. Did this program enhance your knowledge/awareness of STEM fields/careers? If so, how?

6. Would you enjoy attending another workshop like this in the future? (Count show of hands YES and NO)

7. Please rate the program activities from this week with 1 being your favorite activity to 6 being your least favorite activity.

8. Does anyone have any additional comments that they want to share?

That's it! Thank you for your participation.

**Appendix D: Program Evaluation Survey**

**GEMS Follow Up/Program Evaluation Survey**

Please rate the items below on a scale of 1 – 5 with 5 being the best possible rating.

1 2 3 4 5

Strongly Disagree Disagree Undecided Agree Strongly Agree

1. We had enough room in the classroom to complete the activities. ____________

2. The snacks and lunches were good. ____________

3. The teacher(s) taught me a lot about science. ____________

4. The teacher(s) taught me a lot about math. ____________

5. The teacher(s) taught me a lot about engineering. ____________

6. The teacher(s) taught me a lot about technology. ____________

7. I enjoyed the STEM women speakers each day. ____________

8. The activities were challenging. ____________

9. The activities were interesting. ____________

10. I would like to do participate in these activities again next summer. ____________

For the next question, select one from the list. Which activities did you enjoy the most? (Circle One)

- Technology activities
- Science activities
- Math activities
- Engineering activities

Which woman of STEM did you enjoy the most? Why? (Open response)

What would you like to learn next summer? (Open response)