Introducing Middle School Girls to Engineering Design and Manufacturing Activities at STEM Girls' Summer Camp

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Introduction

During the past decade, STEM-oriented education and activities have proved to enhance middle school students' interest in subjects usually perceived as difficult, such as mathematics and science. Also, STEM fields tend to engage students in the learning process, giving them the skills and competencies needed for future careers. Despite the overall efforts to include STEM subjects, the engineering component is almost missing in most middle school curricula across the nation. Moreover, students from underrepresented communities are less likely to have the opportunity of benefitting from STEM-enhanced curricula. Engineering activities for middle school students are mostly reduced to simple "applied science" experiments, without introduction to realistic scenarios [1].

During the past two years, during summer terms, the authors developed two activities designated for STEM Girls' Summer Camp, held over a week period. However, each activity was only two hours long and accommodated about fifteen middle school girls age 11 to 14 years old (entering 6^{th} to 8^{th} grade). In this paper, we present activities related to engineering design (the 3-D Printed Electronic Mood Ring) and introduction to industrial robots using a robotic arm.

The most recent workshop was held at Drexel University on July 9 to 13, 2018. There were two groups of 14 to 15 girls engaged in several STEM activities from 9 am to 4:30 pm. The workshops presented below were held on July 9^{th} and 11^{th}, from 2:30 PM to 4:30PM. The program is organized by Girls Inc., and is designed for underrepresented minorities (mostly), therefore more than 80% of the girls were African-American. Since our university was the venue of the summer camp and provided curricular and learning content to the groups of girls, we could not assess students' social and economic background as enrollment and other organizational features belonged to Girls Inc. However, on an informal verbal survey, more than 85% of the girls had a genuine interest in STEM fields, hence they enrolled this program. While we may not formally survey them, through informal discussions carried during workshops between authors and the participating girls, 5 out of 15 girls said that they had programming/coding experience before and about half of them had 3-D printing and Google Sketch-up prior experience.

Another important aspect of the summer camp is that both workshops were presented to the same group of girls, therefore having a continuity of the learning process.

In this paper, we present the concepts and notions that were covered, such as: angles, rotation and translation, mirroring motion, lines, geometric figures, ratios and proportions and so on. Also, we evaluated the girls' level of understanding of these notions as they were applied to a real-life scenario. A summative assessment of each activity will be also presented.

Workshop Rationale

The projects developed aimed increasing participation of the underrepresented middle school students at STEM subjects (Girls' summer camp). The summer camp workshop modules provided students with learning opportunities that are unavailable during the regular curriculum. There is evidence that extracurricular engineering education can provide important benefits such as increasing scores in core subjects such as mathematics and science while enhancing their interest in STEM fields [1, 2]. The main principles followed in developing the workshop modules were:

1. The 80-20 rule: 80% active engagement and 20% lecture.
2. The activities are "smart"- focusing on problem solving and STEM related.
3. Doing activities that hands on, messy, relevant to the girls' world, and age appropriate (11yo to 14yo).

Engineering is based on design that includes identifying a problem and finding a solution while considering constraints and trade-offs. While students are introduced to STEM concepts and notions, there is a stringent need to present them with design principles blended with open-ended problem-solving approaches faced by engineers in real life applications.

The activities presented aimed to tap into the natural curiosities of the young women for inquiry, communication, construction and expression. Inquiry into the topics presented below for process understanding of design, communication through peer collaboration, construction through peer and participatory learning for individual and group knowledge growth, and creative expression to aid learners emotionally and culturally. Using culturally congruent instructional strategies, the designed experiences using 3D modeling and programming will aid understanding of the topics and engage the women in transformative experiences to integrate through design their personal experiences from their homeland into their projects. The connection of their personal experiences to the design of technological artifacts will stimulate situational interest and support epistemic curiosity for long term valuing and interest beyond the life of the program.

The key educational components for our STEM related engineering technology-based workshop modules are as follows:

Mathematics: Diameter, Circumference, Angles, Graphs, Linear relationships, Scaling and models, Boolean logic, Spatial reasoning, Patterns
Science: Hypothesis & evidence, Engineering design, Observations & predictions, Data analysis & acquisition, Measurement, Speed and distance
Technology: Purpose of technology, Technology relationships, Systems, Design tradeoffs, Troubleshooting, Sensors, Performance, Boundaries, Mechanical elements, Controls
Communication: Brainstorming solutions, reasoning with evidence, explanatory composition.

There will be two projects used to engage learners in understanding the process of design. Project 1 will be a hands-on practical implementation to create a functional prototype of artifact (the mood ring). Project 2 will be a computer-based design implementation using 3-D modeling to support **online game design and programming.**

Outcome of the workshop will also be reflected in participant behavior and hands-on application of gained knowledge and skills (we will have to include evaluation plan). Participants will gain experience in using freely available and popular software tools.

The Electronic Mood Ring

The original Mood Rings were popular in the 1960s and 1970s; they included a special type of material that changes color in response to heat. As body heat warmed up the ring, it would change from dark to brown to yellow to green to blue. The electronic ring that girls were asked to design is similar, but it uses a temperature sensor and a microcontroller to produce the same result. We provided the students with a circuit board assembled onto the base. Students were asked to design their ring according to their preference but also according to the specifications and restrictions presented. It is to be noted that none of them have any prior engineering design experience. The ring was 3D printed and assembled for them after the conclusion of the first workshop and then delivered to them before the summer camp ended.

Assembling the circuit board takes special skills and tools and would take longer than the length of this workshop (it took about a week to design and test.) We provided students with a circuit board and it was assembled it onto the base for them. The mood ring consists of three printed parts.

The base ring part has been designed to fit the circuit board. For this part, students must ask an adult to help measure their finger with the gauge, so they would know what size ring will fit correctly and comfortably. They can also choose their preferred color for this part.

The cap goes over the circuit board, and is probably best printed in clear plastic, to let the light from the LED though. If they choose to use an open top design, though, they can pick another color. This part has also been made to fit the base and circuit board.

The top part is where students do the designing! Girls had to "Go to www.pt0.us/ring and download the "RingDecorationTemplate.skp" file you see there. (Just click on it, and the browser should download it.) Open it in SketchUp to start designing!"

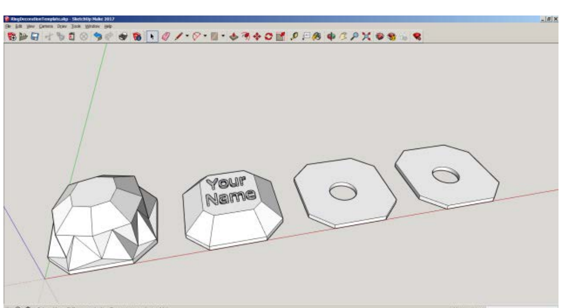

Figure 1 Mood Ring Designs

We walked the middle schoolers through the basics of using SketchUp, and we helped them define and determine their design. They had to finalize their ring decoration as follows:

Excerpts from the workshop activity manual: "Designing your ring decoration

You will be designing a decorative top to go on your ring. This can be as simple as a plate with your name or other text on it, or (within reason) as complicated as you like.
Some examples that you can modify are included in the SketchUp template.

Not all designs can be printed, however. Here are a few guidelines to make sure your designs can be printed with good quality. We will describe each of these in the demo.

- **No overhangs of more than 45 degrees.** 3D printers can't print in midair. It is sometimes possible to use "support material" to allow overhangs, but this usually ends up making the part look bad. Keep any overhangs under 45 degrees – less is better.
- **Keep it simple.** 3D printers aren't good at printing fine detail. Anything under 1mm in size might not print. Keep features relatively large and simple to make them work well.
- **Leave room for the LED.** The LED extends 10-12mm above the cap, so make sure to leave room for it when you make your design. (Basically, just don't design anything on top of the hole, and you'll be fine.)
- **Make sure you can see the LED.** If you request clear plastic for your parts, the light should be visible through the plastic. Keep this in mind as you design your cap; if you use all opaque parts, you might not be able to see the color!
- **Make sure your part is solid.** 3D printed parts have to be solid so that the printer software understands how to make them. You are basically creating a hollow shell that will be filled with plastic. The inside of this part should be one solid piece, and it should be "airtight," so that the inside is not visible.
  Think of it this way – if your part were filled with water on the inside of the plastic, it should not leak.

Please remember these rings are experimental! They are a brand-new design, created for this exercise. Other than the prototype ring, yours will be the first ones in the world. Like most prototypes of new technology, they're a bit larger and more fragile than commercial products – but since you helped design them, they're *yours*!"

We directed the girls design as an engineering design endeavor: following some of the basic steps (Imagine, Plan, Create, Improve) and explaining this process as they created their files.

Industrial Robotic Arm

The second activity had two parts: the first one involved an industry-grade ABB Robotic arm, each girl having the opportunity to manipulate the robot to perform a simple task. The second activity was to modify an Arduino C program to manipulate a small robotic arm to stack building blocks.

Robots are often used to automate tasks in industry. Any dangerous, repetitive, and/or boring motion is a candidate for automation. However, developing good motion-control routines for robots is generally much more difficult than completing the same tasks ourselves. Picking up, moving, and placing stacking blocks, for example, is a trivial task for most adults, but can be quite challenging to program.

Starting from the provided code, students' task was to accomplish as many of the following challenges as they can in the time available. Place the blocks on their respective squares and run the program to manipulate the blocks as needed. (Blocks must start out as diagrammed in the sheet provided.)

In order to manipulate the blocks, they need to control the arm via Arduino C code. Some basic functions have been provided, so they only needed to write the correct angles to the servo motors to move to each desired position. In addition, code to smoothly (more or less) move between positions is also provided in the form of the smoothMove() function.

From bottom to top, the servos are named as follows:

Rotation → Waist → Shoulder → Elbow → Wrist → Gripper

Here are the provided functions as provided in the lab manual:

```
openGripper() ;        //Opens the gripper fully (or enough to grip a 30mm block)

gripperGrip();         //Closes the gripper enough to hold a block, but not fully

closeGripper();        //Closes gripper fully (PLEASE DO NOT USE THIS TO GRIP!)
```

Please only use openGripper(), gripperGrip(), and closeGripper() to control the gripper.

```
smoothMove(rotate, waist, shoulder, elbow, wrist); //Move from one position to another

rotate.write(angle);        // Rotate the robot base to the selected angle (azimuth)
waist.write(angle);         // Rotate the waist to the selected angle (vertical)
shoulder.write(angle);      // Rotate the shoulder to the selected angle (vertical)
elbow.write(angle);         // Rotate the elbow to the selected angle (varies)
wrist.write(angle);         // Rotate the wrist to the selected angle (rotates gripper)
```

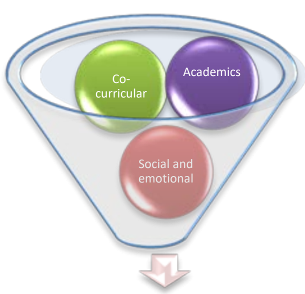

Figure 2 Robotics and their main ingredients

Robotics field is an intrinsically linked to STEM related education, stimulating and integrating critical and innovative thinking skills, and the most needed problem-solving skills that students starting today's economy. This robotics summer program will from early stages of education should develop to become successful adults in enable many middle and high school students to design and build robots, to "wrench" on robot designs of their own creation while they learn new concepts from abroad range of disciplines that come together in robotics—mechanical and electrical engineering, math, physics and more.

One of the main goals of these module is to teach students how engineers solve problems and manage projects. The modules will engage students to fit the design, analyze and build the concept that is being simulated. ***Another goal of these modular and project-based modules is to teach the design process in an engaging, hands-on manner to challenge, motivate, and inspire students.*** By applying STEM principles to actual engineering projects, the module helps students quickly understand the relevance of what they are learning and master the fundamentals of the engineering design process using 3D design software and the Arduino coding combined with Robotics Design System. The modules are created to ensure that students with varying learning styles and levels can accomplish the workshop goals. No prior robotics or 3D modeling experience was required.

Each module was structured to cover the full design process in four different phases: Think Create, Build, and Amaze.

Think Phase – Scientific and engineering concepts that support the project phase. It provides a foundation for understanding the topics and successfully completing the projects. Students will use the units to understand building concepts, learning about design process, ratios and proportions, geometrical design, angle magnitude and orientation. They learn about systems and how they use them in programming; **The ultimate objective of this phase is to introduce students to "logical thinking".**

Create Phase – 3D solid modeling, digital prototyping, and visualization using Sketch-Up design software. This phase supports the creative process of designing and developing an idea using 3D modeling.

Build Phase – Hands-on assembly of the mood ring and manipulation of the robotic arm . This phase validates the conceptual knowledge learned in the previous Think and Create phases.

Amaze Phase – Classroom challenges: Using the robotic arm students have fun testing the limits of their robot through various challenges. Both workshops provided students with engineering design and programming skills required in the real world. The challenges in the Amaze Phase have been designed for these workshops limited to the activities presented but, but it can be easily modified to become multi-robot challenges.

Results and Conclusions

Each workshop session was 2 hours long and students expresses their interest in each activity. They were actively engaged in each activity and asked many questions. Of particular interest was the industrial robotic arm, where girls acknowledged the mathematics concepts that they learned in school and how those notions related directly to this second module (industrial robots). Students were given the opportunity to operate an ABB industry grade robotic arm as well to have the realistic feeling of manipulating a real equipment. They were amazed by each activity presented.

The assessment of the activities is focused on the learning objectives and outcomes below:

Learning Objectives:

- To provide competence with a set of tools and methods for product design and development.
- To provide product development experience using Computer Aided Design (CAD)-Mechanical Design tools.
- To develop student's skills in perform kinematics analysis of robot systems and knowledge of the issues associated with the operation of robotic systems.
- To provide the student with analysis skills and some programming knowledge associated with robot programming.
- To provide the student with experiments associated with robot control for automation.

Learning Outcomes:

- Students will use mathematics to make appropriate choices of angles to move a robotic arm to perform required tasks and to generate the required design for the mood ring 3D modeling.
- Students will assess robot performance against predicted performance
- Apply creativity and persistence, and develop awareness of their own thinking, in defining problems and developing strategies to solve them.
- Demonstrate flexibility in thinking.
- Independently pursue learning.
- Students will build team work skills (brainstorming, integrate independent work in a team environment, respect and appreciate other opinions, share learning)

We did an ad-hoc assessment of the above-mentioned learning outcomes as we could not have our own surveys. Assessing informally their level of interest and engagement, all 15 girls were 100% engaged in every activity and enjoyed their time. Students were asked questions such as:

1. Do you find a connection between what you learn in school and the real engineering world? What specific connection did you find in doing this activity? (both activities)
2. What mathematics concepts did you apply here (for both activities)?
3. How did you come up with this design? (mood ring)
4. How did you make the robot arm to turn in this position? Why did you take this approach? Could you have done it differently?

All students were able to answer to our questions satisfactorily, proving their genuine interest in learning. There were couple WOW moments, when students realized that they actually use their formal mathematics instruction to manipulate the robot and how using line intersections and angles lead to a beautiful ring cap.

However, as these modules will be offered next summer, we do expect to have a more meaningful insight of the level of achievement of the outcomes. We are presenting below the only feedback that we received last July from the organizers:

> “Thanks so much for being part of the STEM University for girls. I’ve got feedback that your workshops were fun and that the girls very much enjoyed programming their mood rings and coding with Arduino. I also heard that the counselors liked the activities too! It’s fantastic to have hands on activities like the ones your team offered, and I do think that your participation makes the program that much better.”

References

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