Design and Evaluation of a Computer Science and Engineering Course for Middle School Girls

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ABSTRACT

A significant focus in the United States recently has been to increase engagement and interest in STEM curricula, particularly among girls and underrepresented minorities [3]. In this work, we take an approach to teaching and learning that supports flexibility, experimentation, and play with technology. With this approach, we aim to make STEM curricula more comfortable and engaging for all types of children and teens, with a particular emphasis on lower socio-economic status female students. We designed and tested a computing course for middle school girls, and this work resulted in three best practices: hands-on work incorporating creativity through crafts into engineering and computing, the frequent presence of an audience to motivate engagement, and engineering-focused individual roles structuring group work. Pre- and post-surveys and exit interviews revealed significant changes in attitudes and an enthusiasm for engineering projects and careers as a result of participation in the course.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education – *computer science education, information systems education, curriculum.*

General Terms

Measurement, Experimentation, Design

Keywords

Computer science and engineering education, gender issues, diversity in computing, hands-on curriculum.

1. INTRODUCTION

A major challenge to middle and high school computer science curricula stems from the differences in the way girls and boys engage with the material. Margolis and Fisher have described a "'magnetic attraction' that motivates many boys to engage in intense self-guided exploration of computing" while "girls … then are often sitting shoulder to shoulder in classes with boys who have spent endless hours learning everything they can about computers and who have friends to turn to when they want to learn even more" [7]. With a focus on hands-on activities that result in meaningful products related to real-world applications, girls can become more engaged. In addition, increased confidence with STEM and interest in its applications can help girls experiment and learn. In this work, we take an approach to teaching and learning that supports flexibility, experimentation, and play with technology. With this approach, we aim to make STEM curricula more comfortable and engaging for all types of children and teens, with a particular emphasis on lower socio-economic status female students. This approach includes an emphasis on sharing and presentation of projects, based on the idea that performance for an audience can motivate at-risk children and teens to engage with technology [5].

We developed and tested a four-week course on computing and engineering for middle school girls—primarily Latinas and other minorities from low-income families. We used several innovative pedagogical tools in the curriculum designed to improve the attitudes of participants towards engineering and computer science, improve confidence with these activities, and increase interest in these careers. In particular, we found three features of our course to be particularly successful: hands-on work incorporating creativity through crafts into engineering and computing, the frequent presence of an audience to motivate engagement, and engineering-focused individual roles structuring group work.

2. CURRICULUM

This engineering instruction was offered as part of Eureka!, a four-week summer camp held each year for middle school-aged girls affiliated with Girls Incorporated of Orange County, a non-profit organization inspiring girls to be strong, smart and bold. 53 girls participated in the Monday to Friday camp and all of them took our required course, along with a variety of courses with themes ranging from body image, to film, to college preparation. Instruction lasted an hour a day twice a week and one half-day, totaling approximately 12 hours of instructional time. The 53 girls were divided up into three consecutive class periods.

A female recent college graduate served as the primary instructor for the course, facilitating activities and enforcing timelines and rules. One male undergraduate student and eight female high school students provided additional instructional support. The high school girls, who had taken classes in computer science, served as mentors and role models to the girls in the course. At the same time, the high school volunteers were mentored by the undergraduate student and recent graduate who were in turn mentored by the three female and one male professors involved in this work. At least four high school volunteers were present at each class session, providing hands-on help for each of the four groups of students in a class. This one-on-one attention for the groups created a supportive environment for learning through exploration, including minimal troubleshooting support.

SIGCSE'10, March 10–13, 2010, Milwaukee, Wisconsin, USA.

2.1 Pedagogical Design

The curriculum was based on the principle that students learn best when they are actively involved in the process [1][10]. We designed the curriculum to be entirely hands-on, embracing both Piagetian and Vygotskian perspectives on learning. Specifically, we drew on Piaget's formulation of learning and cognitive development as constructed through hands-on experience of the world [9]. Further, we drew on Vygotsky's emphasis on how children imagine and play [11]. In his view, they begin their play with pivots (*e.g.,* sticks, dolls) and can then move on to imaginative play without any props. In our curriculum, we wanted a focus on tangible devices to provide pivots to allow students to begin through playful interaction, and move eventually into the deeper understanding and imagination required for abstract programming and engineering abilities.

Thus, we found Papert's development of Piaget's work to be particularly influential. Building from constructivism, Papert described the educational theory of constructionism in which learning is a *reconstruction* as opposed to a *transmission* of knowledge [8]. He further extended these ideas to include manipulation of materials and technologies with the idea that students learn best when the learning is associated with the creation of a real-life product. We thus wanted the curriculum to involve design projects and the creation of final, presentable products.

To accomplish these educational goals, we used PicoCricket Kits[1], which combine basic programming concepts, electrical devices, and creative designing, as the focus of our course. These kits include electrical devices such as a light, speaker, motor, light sensor, and sound sensor, which are connected to a computer through USB cables (see Figure 1, left) and controlled using composable drag-and-drop programming elements (see Figure 1, right). Legos ® and craft supplies are also included to involve artistic design and to foster creativity. All devices in the PicoCricket Kit have a Lego ® base, allowing them to be integrated into Lego ® construction.

We divided the girls into small groups and created a role for each group member that was conceptually linked to a component of the kit and a related field within engineering. The roles were: software engineer, electrical engineer, civil engineer, and design engineer. The girls rotated through the roles, taking on a different one each class until each group member had performed each role at least once. One of our goals was to help the girls gain an understanding of what it means to be an engineer through experiencing both the hands-on and conceptual work of several different kinds of engineers, thereby showing them a path to a career in computer science and engineering. Working on small group projects with designated roles also had the benefit of allowing each girl to master a particular task and conceptual domain of knowledge before moving on to the next role [2]. Moreover, students working in small groups tend learn more of what is taught and retain it longer than they do when the same information is presented in a more traditional one to many lecture format [6].

The roles were defined solely by designated tools from the PicoCricket Kits. In this way, we hoped to facilitate learning about the roles and tasks through objects, and thereby ground understanding of these abstract professional identities. No further explanation or description of the roles was given other than of the purpose of the tools. The software engineer used a laptop to write programs using the PicoCricket software, PicoBlocks. The electrical

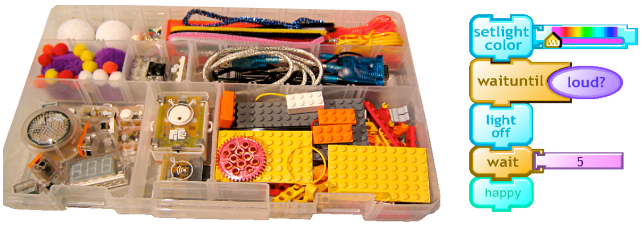

Figure 1. The contents of a PicoCricket Kit. Left, all physical parts: devices, cables, Legos, and craft supplies. Right, a sample program written using PicoBlocks software.

engineer was responsible for the devices (light, speaker, motor, light sensor, sound sensor) and cables. The civil engineer was tasked with building a structure for the devices using materials such as Legos ® and Play Doh ©. The design engineer was encouraged to bring an artistic perspective to the design of the project with a variety of craft materials including pipe cleaners, fuzzy balls, feathers, popsicle sticks, and glue. Each girl wore a small, color-coded pin to help her formally embody her role.

2.2 Schedule

The course met eight times and was divided into four parts: introduction to PicoCrickets, one-day assigned activities, a larger creative project, and preparation for final project presentations. The first one-hour day was intended as a non-structured introduction to PicoCrickets. Girls were divided into groups of four and each group was provided with a PicoCricket Kit. The girls were instructed to open the kits, see what was inside, and try experimenting with the parts to see how they worked. No roles were assigned at this first session, because the focus was on the girls learning about the PicoCrickets.

Over the next two class periods, the girls completed "out of the box" PicoCricket projects and began rotating through the roles. Assignments included making a musical instrument by conducting electricity through a pickle and creating a kinetic sculpture that moves based on sensor inputs (*e.g.,* noise or light). Groups were tasked with following the instructions included in the kit while being as creative as possible. One project was assigned per session resulting in varying degrees of "completeness" from groups that were completely polished to those that were only partly finished. Many groups added a lot of their own creative ideas to design a more complex product. A future audience was emphasized by holding project demonstrations at the end of each class session. These were lively, positive events, and the instructor took photographs and videos as each group presented.

The second half of the course was devoted to a longer-term group project of the girls' design. The girls brainstormed collectively about different things in the world they could build using PicoCrickets, which they then turned into a project idea in their small groups. Over the next three class periods they completed their projects and continued rotating roles each day. The projects included such diverse ideas as an amusement park, the internal organs of the human body, and a fairy tale house in the woods.

At the end of the third week, the girls spent a day at our university. A panel of professionals representing the four engineering roles spoke about career paths and daily activities. The girls watched demos of research projects. They then divided into groups based on their favorite roles to prepare posters about each career.

[1] http://www.picocricket.com/

During the final class day, we video recorded the girls demonstrating their projects. On the last day of camp, at an all day celebration, this video was shown for family and friends.

3. ASSESSMENT METHODS

We used a mixed-method approach to evaluating the course: pre and post-surveys, observation of in-class activities, and interviews with both the girls in the course and the high school student mentors. This approach enabled us to collect a large amount of empirical data even within the constraints of only a four-week course during which we could not interfere with class instruction time substantially. Girls in the course were between the ages of 11 and 14. More than half (30 of 53) self-identified as Hispanic. Girls enrolled in camp pay tuition for the entire four week course on a sliding scale, with most girls served by the organization coming from low income families. The high school girls came from relatively higher income families and were aged 15 to 17. One had limited knowledge of Spanish.

A pre-survey was administered at the beginning of the first class and a post-survey at the beginning of the final class. Both surveys took approximately 10 minutes to complete and included questions on a five-point Likert scale about attitudes towards engineering and computer science, confidence with engineering and computing, and interest in these careers. The post-survey also included assessment questions about the workshop itself. To test changes in participant perceptions, we used Mann Whitney's U Test for significance to analyze the pre and post-surveys. This choice is appropriate for independent, ordinal data, and also allowed us to compare our significance levels with those reported in previous work [4].

Extensive field notes were used to document a total of 30 hours of observation. All students and instructors were observed for the duration of the course, at each class session.

Optional interviews were conducted with fifteen girls during the final class session either individually (n=6) or in groups of 3 or 4. The interviews were semi-structured in nature to allow the girls to lead the discussion to those issues they found most important. Topics included what they liked about the course, what they learned, and how they envision an improved course in the future. A group interview was also conducted with the high school student instructors, focused on what they enjoyed about their experiences, their challenges, and what they learned.

4. RESULTS

Interview and survey results indicate the course was both fun and educational. All 15 girls interviewed reported that they had fun, learned new things, and would participate in the course again. Their favorite reported aspects of the course were using the PicoCrickets, using their creativity, and being able to choose their final projects.

Post-survey questions evaluating the course yielded positive responses. In response to "this workshop was fun", 41 of the 53 girls (78%) either agreed or strongly agreed. When asked if they learned something from the workshop, 45 (85%) either agreed or strongly agreed. The girls also reported an increased interest in STEM because of the workshop. When asked about an increased interest in computers, 31 (59%) either agreed or strongly agreed, and in response to engineering, 34 (65%) either agreed or strongly agreed. In addition, 34 (65%) of the girls agreed or strongly agreed that they would recommend the workshop to their friends. Furthermore, the girls reported more positive attitudes towards, perceptions of, and confidence and interest in engineering and computer science after the course (see Table 1). The most significant survey items focused on understanding what programmers and engineers do, suggesting that one of the greatest strengths of this course was making participants feel that they have a better understanding of these careers. The second highest significance was in the survey items regarding the difficulty of programming and engineering, and the girls' answers lowered by almost one full point on the five point Likert scale. These changes indicate that the course raised girls' confidence. The rest of the survey items that are significant focus on the girls' interest in, and confidence with, engineering and computing. These survey results suggest that we improved perceptions and attitudes, and this was further demonstrated in interviews with the girls.

Table 1. Survey Items with Mann-Whitney U Significance Levels, Ordered by Significance. The darkly shaded values are significant at the p < .01 level, and the lightly shaded values are significant at the p < .05 level.

Survey Item	Pre Mean (St. Dev)	Post Mean (St. Dev)	*p*
I understand what programmers do.	2.94 (.99)	3.85 (.92)	.0000
I understand what engineers do.	3.16 (.99)	4.12 (.73)	.0000
Engineering is hard.	3.21 (.83)	2.47 (.98)	.0001
Programming is hard.*	3.12 (.75)	2.56 (.71)	.0003
I know more than my friends about computers.*	3.10 (.92)	3.63 (.91)	.0032
I like engineering.	3.39 (1.0)	3.96 (.89)	.0037
Engineering jobs are boring.	2.53 (.83)	2.06 (.88)	.0076
Engineering is fun.	3.52 (.99)	4.00 (.96)	.0095
Computer jobs are boring.*	2.54 (.90)	2.06 (.81)	.0105
I am good with computers.**	3.82 (.91)	4.22 (.80)	.0300
I like the challenge of engineering.	3.39(.98)	3.78(1.0)	.0545

** Questions replicated from previous work [4] with similar levels of significance. ** Question replicated from previous work [4] in which we found significant results, but others did not.*

Towards the end of the camp, most girls expressed having a more positive understanding of engineering. For example, one girl was so excited about the prospects of programming that she wanted to use her new knowledge on an older piece of hardware:

> *P08: "My dad has this old calculator… and I kind of want to program it!"*

Even those girls who continued not to perceive computing or engineering as potential career paths still expressed more positive views than when they began camp four weeks earlier:

> *P06: "I like it. I mean, I don't think it would be the career for me, but I think it's definitely better than what I used to think it was. Just building stuff."*

4.1 Hands-On Work

Results suggest that the hands-on work with PicoCrickets changed the girls' understanding and perceptions of engineering and computer science. Interviews revealed that the girls were able to express important concepts about the nature of engineering work, particularly in relation to their roles.

P08: "[With programming], you want a certain thing, and you have a certain thing in your head. But… you have to make it, and you have to figure out how do you make it."

P02: "[Civil engineers] make sure it all works together and…the foundation is strong and it doesn't fall over."

These concepts and challenges inherent to engineering fields were learned through the manipulation of objects and hands on problem solving – never through lectures or explicit teaching. The girls exchanged the real world actions of developing software or building a new road for the playful actions of creating an Ice Cream Shop from PicoCrickets and crafts. These pivots allowed them to learn about engineering in a safe, fun environment in the short term that lays the scaffolding for later more complex concepts upon returning to school or even in subsequent workshops [11].

In addition, when the panel of engineers discussed their jobs and their enjoyment of daily activities, the girls were able to connect their own tasks to the real-world ones being described. They discussed the significance and impact of engineering, as well as the relevance of the engineering activities they themselves took part in.

P02: "[This course is] not like the big engineering that adults do, but it's a step towards it"

P10: "There's so much things (sic) you can do with [engineering]."

In interviews, the girls explicitly cited the hands-on work as the source of their learning about general engineering concepts. They expressed surprise and amazement at uncovering all the different things they could do with engineering through working with the PicoCrickets. These comments suggest that their hands-on work served as significant exposure to new concepts and was a perception altering learning experience.

P02: "Programming? I thought it was all just html and stuff. I didn't really think there was programming for making things move and light up and stuff… I think it's cool how you can do almost anything…. Make it do what you want."

P04: "I didn't know that we could do that. I could never imagine us doing that."

Some interview participants framed the changes in their perceptions and attitudes within the context school, pointing out the potential failure of school-based STEM curricula to provide positive exposure to computing and engineering.

Figure 2. A sample PicoCricket project. PicoCricket devices are connected with cables. Legos ®, Play Doh ©, and craft supplies complete the project.

P05: "I thought [engineering] was just computer stuff. And I don't like computers at my school. But after we went through this, it was really fun."

P04: "At school they should have this. I would love that class."

These views indicate that a shift in school-based STEM curricula towards hands-on exploration could impact girls' interest in computing and engineering more broadly. As Papert noted, "Learning in our schools today is not significantly participatory—and doing sums is not an imitation of an exciting, recognizable activity of adult life." [8, p.179]. In this course, however, we created a participatory learning environment in which young girls who were novices worked alongside young women and adults who were more expert to develop projects jointly. Multiple times during the course, the authors—all who have advanced degrees—learned something unexpected from working alongside the girls. Whether it be that a pulley controlled by a simple PicoCricket motor could be made to hold the weight of a large platform or that music could be looped to create multi-layered songs, the young girls contributed to the discovery and co-creation acts and taught the mentors as well.

4.2 Roles and Group Work

Interviews also revealed that having specified roles for each group member improved the group work experience, particularly by structuring collaboration, facilitating expertise sharing, and allowing the girls to mimic each other and their mentors when they were not sure about the right course of action [11]. The girls expressed an appreciation for the benefits of working on a project in a group rather than individually.

P01: "You just can't do it all on your own. You really have to rely on the people you're working with. And it could turn out better than just you working by yourself."

P11: "When you work in a group, other people have different ideas. So it adds more to what you already had."

Having gained a better understanding of engineering through the course, the girls were also able to apply their appreciation for group work to real-world engineering.

P06: "You have a bunch of different engineers, and you can't just have one building the whole entire building. You have to have different ones do it."

Results demonstrate that the knowledge and understanding the girls gained about engineering made the field much more appealing to them. Girls reported coming into the course with very little knowledge about engineering, being ignorant about what it even is, often thinking that engineering is equivalent to math. They also were unaware before the course that there are different types of engineering. The results of our surveys and discussions with the girls indicate that these initial perceptions led them to view engineering as uninteresting.

P01: "I thought [engineering] was like a lot of building and math. I didn't used to like it. Cause it was math….[now] it's fun…. Engineering is a lot of things…. Its not just math."

Many of the girls reflected on what they learned about working with others on a collaborative project, demonstrating the valuable life skills that were emphasized for them during the course.

P07: "I learned that some people might be a little bit harder to work with than others, but you just have to – everybody has to have respect for each other and it'll work out."

The girls also gained engineering skills through their group work. If one girl either already had a particular skill, or learned it through taking that role during the course, as roles were rotated she would share her expertise with the others.

P10: "Basically we just helped each other out with all of the jobs." P11: "She was really good at the computer, so if it was our turn or something, she would be the expert in it." P10: "I learned a lot."

P10: "I did not know how to make the things rotate or change color until… I think it was her… I think she was the one who taught me. I'm like, Oh! Okay! I get this!"

By working together and miming what they saw each other do, the girls were able to accomplish much more than any one individual's skills and development might make her independently capable of [11]. Furthermore, the girls learned about engineering even through group conflict. For example, through a persistent struggle with conflict in her group, one of the girls learned an important lesson about documenting design decisions and requirements: *"Put it on paper!"*

4.3 Audience

Throughout the course, we used performance for various audiences to motivate the girls to work hard on their projects and be as creative as possible. This emphasis on presenting to an audience helped the girls develop pride in their work. This pride was important in reinforcing what the girls learned and establishing confidence in the knowledge and skills they gained. One of the girls exuded this pride and confidence in her interview:

P02: "It feels good. I actually built something…it looks nice and it actually works. I'm proud of myself and my whole group."

The girls yelled and cheered during the presentation of posters describing their favorite roles and potential career paths (Figure 3). For example, the poster about software engineering reads that they "enjoy programming because… it is easy … it's like magic! … [you are] responsible for making it work! … it's fun!!!"

With occasional reminders of the requirement of presenting their project at the end of each class session, girls were motivated to be more creative, and finish on time. Reminders were met with exclamations and a sudden sense of urgency and hurriedness to their work. The girls would say their projects weren't ready yet and they wanted more time, demonstrating care and pride in their work.

Figure 3. Two girls enthusiastically presenting their poster about why software engineering was their favorite role.

5. CONCLUSION

In this work, we took an approach to teaching and learning that supports flexibility, experimentation, and play with technology. We developed a course featuring hands-on building of projects combining crafts with technology, engineering-focused roles structuring group work, and the frequent presence of an audience to motivate engagement. Results indicate that this approach helped students gain an understanding of what it means to be an engineer through experiencing both the hands-on and conceptual work of several different kinds of engineers. This knowledge and understanding led to significant improvements in the perceptions of girls enrolled in this course towards computer science and engineering, and significant increases in their confidence and interest in these fields. Despite entering the course with largely negative views towards computing as "boring" and "all about math," the girls finished the course with enthusiasm and appreciation for these subject areas and the careers they might obtain through them. Our results indicate that a shift in school-based STEM curricula towards hands-on exploration, group work, explicit consideration of future careers or roles, and a focus on an audience to consume their end products could impact girls' interest in computing and engineering more broadly.

6. ACKNOWLEDGEMENTS

We thank Microsoft, the NCWIT Seed Fund, and Google for their generous support of this project. Thanks to Khai Truong and David Kay for their thoughtful critique of earlier drafts.

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