Teaching Engineering in Single Gender Middle School Classrooms

Abstract
Students in middle school are often given pre-planned laboratory experiments which provide little or no opportunity to develop creativity or problem solving skills. This paper describes an investigation of middle school students’ reactions to an open-ended engineering design problem, specifically to create a machine to move a Cheerio™ or a plastic egg seventy centimeters. If the problem was solved quickly, a modified problem was provided that forced the students to redesign their solutions. Student attitudes to the design problem solution process were assessed although direct observations during the activity, and written reflective responses afterwards. The results indicate that most students were enthusiastic about developing their own in the science classroom. An interesting aspect of this study is that it was conducted in four single gender eighth-grade classrooms: two classes of males and two of females. Classroom dynamics to the activity were affected by the student demographics. Thus, this study contributes to our understanding of male and female students’ creativity and approach to design processes.

Background
Middle school students do not know what engineers do¹. They know the stereotype better than the reality and perceive engineers to be people lacking interpersonal skills with an interest in things. In reality, engineers are creative people who work in teams to create solutions for many of today’s problems, such as water purification and creating medicines to cure diseases. Studies have shown that students respond positively to engineering when they understand its historical contributions and social relevance. Engineering is the application of science, technology and creativity that has led to inventions such as iPods®, computers, telephones and airplanes².

The Graduate Teaching Fellows in K-12 Education (GK-12) program from the National Science Foundation (NSF) provides fellowships to graduate students (GK-12 Fellows) to enhance science, technology, engineering and mathematics education. The study reported in this paper was conducted by an engineering GK-12 Fellow who worked in single-gender, eighth-grade science classrooms in a metropolitan area in the Southeastern United States. The Fellow works in this classroom two days a week. The Fellow works alongside a classroom teacher in developing and teaching lessons and activities with a focus on engineering examples, design approaches and problem solving techniques to show the application of science, technology and math concepts³. This study is based upon an open-ended design challenge to assess and hopefully develop positive attitudes and reactions towards science and engineering in middle school students. The approach was to illustrate the importance of creativity in the engineering design process.

According to Torrance⁴, creativity is a process that begins when people sense a problem or gap in information. Upon realizing the problem, people begin to formulate hypothesis about the problem then test it, possibly revising and retesting of the hypothesis. The data gathered is then communicated to others by various means⁴. The creative process mirrors the scientific method of finding a problem, making a hypothesis, testing the hypothesis, then reporting the results⁵. In engineering, testing a hypothesis could involve designing and building new equipment through the tinkering process.
Females in general have a lower tinkering self-efficacy or competence and comfort with manual activities. In turn their self-assessment of problem solving skills is lower than their male counterparts. Females as young as five report less competency in physical science than their male counterparts which could explain why males students tend to take more science and engineering.

In a co-ed middle school classroom, females often are afraid to raise their hand when either they have a question or know the answer because of the fear that male students will make fun of them. On the other hand, middle school aged males that typically enjoy competition sometimes believe they cannot beat the top females in the class, and thus do not try. Both males and females need to learn to work in a group environment. It has been suggested that by using teaching strategies that accommodate gender-related differences, one will see increases in middle school females’ self-esteem in science and males’ willingness to try through competition. In single-gender classrooms, middle school students are able to focus more on learning and less on the opposite gender. There can be a sense of additional security for students, emotionally and intellectually. Females can ask more questions or answer a teachers question correctly without fear of being laughed at by the males. Males, on the other hand, enjoy the competition and games that can be played in the classroom.

Project Overview
The main objective of this study is to determine the attitudes and reactions of middle school students in single gender classrooms towards engineering design problems. Questions addressed in the study include:

1) How does the student's gender affect his or her attitude towards open-ended design projects?
2) What are the differences in the responses of honors students and regular students to open-ended design projects?

The Students
This study was conducted in a single-gender middle school magnet program in a public school district in the Southeastern US. The program is a school-within-a-school. The students are grouped by gender during science, math, language arts and social studies classes. Other classes, such as a foreign languages and art, are comprised of co-ed students who may or may not participate in the single gender program. Class sizes range from 11-16 students. The study was conducted with four groups of students: one class of each gender is categorized as honors, the other non-honors or regular. The project took place during the first five weeks during the school year. However, most students in this study had had GK-12 Fellows in their classrooms for the previous two years.

The Units of Study
The activity that provided the basis of this study occurred during the transition period from a unit of study on the scientific method unit to a unit of study on forces and motion. It gave the students an opportunity to work as a team, designing and testing equipment in a process intended to increase their self-efficacy and self-confidence. The scientific method unit included lessons on designing a controlled scientific experiment and writing lab reports. The forces and motion unit included topics on analyzing the effects of gravity and friction on the direction of an object,
the effects of varying the amount of force on the motion of an object, and determining the effect of unbalanced forces on an object. This activity was intended to support both units of study.

The Student Activity

The activity design was guided by the desire to give students an opportunity to apply knowledge of the scientific method and to examine their activities through the lens of Torrance’s creative process. Also desired was to allow students to explore new concepts that would be further explained in the upcoming forces and motion unit. Therefore, students were given the goal of moving an object 70 centimeters. For two of the classes (one male and one female) the object was a Honey Nut Cheerio™. Due to food allergies in the other two classes, the object was a plastic egg. Students were paired in groups of two or three. Groups were given the materials which included two balloons, two rubber bands, straws, a 30 cm ruler and a small block of wood. The procedure was intentionally left vague so students could create or invent something to complete the task. The procedure given was as follows:

1) Discuss the problem and come up with a solution with your partner.
2) Draw your ideas in your lab notebook.
3) Build your idea.
4) Test your idea. Does the Cheerio™ or plastic egg travel the required distance?

In Torrance’s creative process, the first task is to identify the problem and information gaps. For this project the missing information was the specific instructions on how to design a machine to move the object 70 cm. The next step in Torrance’s process is to formulate a hypothesis. Students were given an opportunity to brainstorm possible solutions to move the object 70 cm, and were required to draw a schematic in their journal (lab notebook) to formulate their hypothesis. In the third step of the creative process, students tested their hypothesis by building their machines and testing them. The fourth step involved students determining if their hypothesis needed modification and retesting. Students asked themselves “Did the Cheerio™ or plastic egg go the required distance?” If the answer was no, they revisited their hypothesis, asking themselves “What was preventing the object from moving?” Students would then create a new hypothesis and retest it until the object moved the required distance. The fifth step in the creative process is to communicate results. In this case, students were asked to prepare a written lab report.

By the end of the class period, each group of students was able to move their object the 70 centimeters. As some students finished the task early, additional challenges, such as moving the object across the classroom or to a specific location, were given. This allowed students to remain busy by modifying their machine, as the other groups completed their projects. These additional tasks had the added benefit of enabling students to practice the creative process repeatedly in order to make necessary modifications to their invention.

Data Collection and Analysis

Student responses and attitudes to the activity were assessed through direct observations during the activity and written reflective responses afterwards. Classroom observations were performed by the GK-12 Fellow, who designed the activity, and the classroom teacher, who provided support during implementation. The Fellow recorded field notes and notes from conversations...
with the classroom teacher at the end of each day. The Fellow also recorded her reflections of the activity in a weekly journal that was required by the GK-12 program. The data was then coded and analyzed. The participant-observer data collected by the GK-12 Fellows was supplemented by written reflections from the students. Student reflections were collected the day after the project was completed and the students’ reports were submitted. Thus, multiple methods of data collection were a means of triangulating the data. Member checking with the classroom teacher was used to support the validity and reliability of findings.

**Results: Observations of Student Behavior**

The creative process described by Torrance provides a theoretical framework for interpreting observations of student behavior. The author’s interpretation of the student behaviors are described below with respect to each of Torrance’s creativity processes.

*Step One: Sensing difficulties, problems, gaps in information or missing elements.*

Classroom observation of the initial response of the honors female class suggests that these students were very apprehensive about the activity. Comments and questions from these students indicated that they did not know where or how to start the project. Questions asked included, “So what do we do?”, “I don’t get it. How to we build the machine?” and “What’s the procedure?” These students asked for detailed step-by-step instructions, but the teacher’s and Fellow’s replies were to create their own machine to move the object, and to create their own step-by-step instructions. The honors females needed repeated reassurance that there was no “wrong” solution. This is in contrast to the other groups. The females in the non-honors class were excited to build something with their hands and appeared less timid. They began working on their designs immediately upon being given the problem statement. Both classes of males were excited and wanted to start building immediately. This was a challenge. The teacher and Fellow had to remind them to discuss the problem and formulate a hypothesis before building their machines.

*Step Two: Making guesses or formulations of hypothesis on the deficiencies.*

Both of the males’ classes and the non-honors females’ class requested additional material, such as more tape, string, rubber bands, paper and additional wooden blocks, during the project period to implement their design solutions. If the material was in the classroom, they were allowed to use it. On the other hand, the honors females did not request additional material during the project period. One could argue that this limited their creative efforts because they did not seek alternative solutions. One could also argue that it forced them to be more creative by finding a way to solve the problem with limited resources. In either case, it appears that the honors females were comfortable with more structure in the classroom activity.

*Step Three: Testing their guesses.*

Some of the males in both classes struggled with their assigned partners during the process of building and testing their machines. In particular, one group of three boys included a student who wanted to use his idea and build it by himself without including his partners, despite the fact that his partners eagerly wanted to participate. When the partners complained, it was reiterated to the group that the project was a group activity, and they had to work together as a team. It was observed that the female students generally worked well in pairs and groups, even though the groups were assigned by the teacher (not self-selected). For example, one of the more
popular females was paired with a female who is frequently ostracized by other students. The teacher and Fellow closely monitored the team due to concern that the more popular female would tease the ostracized student, but the two females listened and cooperated well together.

**Step Four: Possibly revising and retesting their solution.**

In the honors females’ class, one team discovered a major design flaw in their initial design. They had threaded the Cheerio™ through the cotton string and raised the string higher on one side than the other. The idea was original, but it did not work. The group spent a few minutes of working with another team and yet was still unable to create a new hypothesis and solution to their problem. They then asked the GK-12 Fellow for help. This gave the Fellow the opportunity to discuss the concept of friction with the group. The Fellow asked them if they thought that a smoother string, like fishing line, might work. The females asked “What is fishing line?” The Fellow explained that it was a thin, plastic string. Once they understood the suggestion; they wanted to try it. Fortunately, there was a spool of fishing line in the room, which the group used to modify their design and achieve successful in their second attempt.

The males sought little guidance when revisiting their design and retesting their new hypothesis. Most groups created their own original idea, but a few modified designs that were being implemented by other groups. When one group began to complain that their idea had been copied, the Fellow asked them if their idea had been identically copied. They said no. This enabled a short discussion on how engineers and scientist create and protect new inventions through patents, trademarks, copyrights and other forms of intellectual property.

**Step Five: Communicate results.**

As the females finished their original project, they completed their lab reported in order to communicate the results to the classroom teacher. The males waited until the very end of class and some of them did not finish this part in class, and had to do it for homework.

**Results: Students’ Reflections**

The next day, students were asked to write what their favorite and least favorite part of the design project was. The males and the females had fun (48% and 32%) and enjoyed being creative (30% and 25% respectively). As teenagers, they also appreciated not being told what to do. One of the males gave the lab a 5-star rating. Males and females requested similar labs for the future. Some students wished they had had more materials, especially the honors females (14%), though during the project time they never asked for additional material. Many students stated they liked working with balloons and that balloons were fun. Males and females stated that there was no worst part of this lab (26% and 18% respectively).

**Discussion**

Many great inventions, companies and opportunities of today come from risks. During this study, one has to wonder about the apprehensive nature in the class of honors females. They did not want to take risks. The females in the non-honors class along with both classes of males were not apprehensive about the open-ended nature of this project. They took risks. Why did the females in the honors class not want to take risks? Can they learn to take appropriate risks in science or is perhaps their fear of failure too strong? Future studies should be conducted in the
single gender program to further understand this phenomenon and help females overcome this fear.

Despite the initially subdued nature of the students in the honors female class, they, like the other classes, eventually began smiling and laughing during the activity. Students in all classes appeared to be enjoying themselves. Each classroom was very active with students talking about problems and possible solutions amongst themselves. It is critical at this point in their education that students realize that science and engineering are fun and an integral part of their everyday life. If students enjoy science in middle school, perhaps they will take rigorous science courses in high school, enter a STEM discipline in college and create a solution to one of the world’s problems.

Conclusion
The activity described in this paper provided an opportunity for creativity to occur in the science classroom during a transition between units of study on the scientific method and on forces and motion. The students, teacher and Fellow all reported that the students had the opportunity to be creative. Based on students’ reflections, they enjoyed being creative and wanted to have additional open-ended problems, where they can take ownership of their solution. Although limited, the results suggest areas where middle school students could benefit from instruction on creative processes. For example, the males in this study needed help with articulating hypotheses and communicating their findings. The honors female students needed help in overcoming an unwillingness to propose a solution that may not be correct. It is suggested that creativity and design skills can be learned when one identifies instructional approaches that target specific stumbling blocks faced by students. The experiences and findings described in this paper represent a case study to support this effort.

Acknowledgements
This material is based upon work supported by National Science Foundation Award 0440568.

Bibliography
