

Catapulting into STEM Education: Female Students' Interactions within a Middle School Engineering Project

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Abstract: *Despite efforts to motivate students to engage in Science, technology, engineering and mathematics (STEM) education, women are still underrepresented in these areas in the workforce and higher education. Targeting females at high school or earlier may be a key towards engaging them in STEM. In this paper we report on the research question: How do middle school females interact for learning about engineering education? This ethnographic study, part of a three-year longitudinal research project, investigated Year 8 female students' learning about engineering concepts associated with designing, constructing, testing, and evaluating a catapult. Through a series of lead-up lessons and the four lesson catapult challenge (total of 18 x 45-minute lessons over 9 weeks), data from two girls within a focus group showed that the students needed to: (1) receive clarification on engineering terms to facilitate more fluent discourse, (2) question and debate conceptual understandings without peers being judgemental, and (3) have multiple opportunities for engaging with materials towards designing, constructing and explaining key concepts learnt. Implications for teachers undertaking STEM education are evident, including outlining expectations for clarifying STEM terms, outlining to students about interacting non-judgementally, and providing multiple opportunities for interacting within engineering education.*

Keywords: middle schooling, girls' education, engineering education, science and mathematics

1. Introduction

Girls have been targeted in STEM education programs to advance their thinking about STEM subjects. In the US, there are summer programs that provide week long camps for girls to focus on instilling ideas about STEM subjects as university subject choices. Research on these programs indicates that girls are as much as ten times more likely to seek enrolment in a STEM degree than those without such opportunities (Bee, Puck, & Heimdahl, 2007). Other research (Hubelbank, Demetry, Nicholson, Blaisdell, Quinn, Rosenthal et al., 2007) has shown that girls involved in STEM education camps are more likely to enrol in STEM type subjects at high school. This infers that more experience in STEM areas may have an influence on students seeking STEM subject choices. In addition, websites have been launched to address the gender gap in engineering, such as <http://www.engineergirl.org/> which in particular aims at educating middle school girls (Watford et al., 2008). Studies are now uncovering how girls may be attracted into the STEM fields. For instance, an Australian study (Little & León de la Barra, 2009) outlines that middle-school girls prefer group work, practical activities, and using technology to understand topics about biology and the environment, Recognition of achievements in the STEM fields such as the young Australian of the Year winner for 2012, Marita Cheng, promotes girls into STEM areas.

Girls require open-ended career choices that are not limited by stereotyping but provide opportunities to discover employment prospects in STEM fields. Targeting girls in their senior years is an option, especially if they are more connected with STEM content towards career choices than in junior years (Cantrell & Ewing-Taylor, 2009). However, early adolescence is a period of developmental brain activity (Ramowski & Nystorm, 2007), especially as the brain shapes itself during this period of physiological development (Wormelli, 2003). Technological advances have determined that learning occurs when an electrical signal is transmitted "through the axon, across a small gap known as a synapse and with

the assistance of neuro-transmitters (chemical messengers)” (Nagel, 2005. p. 68). There is the concern that unused synapses are pruned for hardwiring the brain for the future (Nagel, 2011). Hence, physiologically, it appears that early adolescent girls need to be nurtured into STEM areas if they are to have options about constructing STEM career identities. Even with intervention programs that aim to advance girls’ opinions about STEM subjects, girls may consider STEM but fear the prospect at the same time (Steinke, Lapinski, Long, Van Der Maas, Ryan, & Applegate, 2009). Nevertheless, girls with more knowledge about STEM increase their university degree aspirations in this field, although still less than male aspirations. Keys to increasing STEM aspirations include explicit education and the provision of STEM career choices (Porche, McKamey, & Wong, 2009).

Middle year schooling may be an appropriate level to target in STEM education though some claim it needs to occur in earlier grades (English & Mousoulides, 2011). Other researchers (Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007) claim students start to make career choices in middle schooling, yet many students do not know about the STEM career options at this stage. Girls in particular, may not engage in STEM conversations or activities outside school with family and friends, which is another reason to focus on girls’ STEM education within the middle years of schooling. It is claimed (Gweon, Ngai, & Rangos, 2005) that engaging girls requires sound pedagogical planning with appropriate content that transition from concrete examples to abstract concepts. They also require immediate feedback on their work to ensure they are progressing. Indeed, immersion in engineering activities may lead to increased problem-solving skills and understanding career potential for themselves in engineering (Donna, 2009). Consequently, engineering engagement programs are being developed to cater for girls’ learning of engineering (e.g., Cheng, 2008); however little is known about how female middle school students work in engineering education subjects.

The research question for this ethnographic paper was: How do middle school females interact for learning about engineering education?

Context

Three private Queensland schools (two single-sex and one co-educational) were involved in this part of a three-year longitudinal study within the middle years of schooling (i.e., grade 7 in 2009; grade 8 in 2010, grade 9 in 2011). As background to the current study, the first year of engineering education (grade 7) for these schools involved a series of civil engineering activities focused on building bridges over five lessons. The lessons included: learning about civil engineers and their work; exploring the types and structures of bridges in the local area; investigating key engineering concepts aligned with bridge construction (e.g., compression, tension, reinforcement, strength, structural shapes); designing, constructing, testing, and evaluating a small-scale truss bridge made from straws and paddle pop sticks; and reflecting on the work of civil engineers within monetary and resource constraints. This presented foundational experiences in STEM for the current study based on middle-years students constructing a catapult.

This paper analyses engineering education conducted in the second year of the project with Year 8 students. It focuses on students learning about simple machines towards designing and constructing a catapult (trebuchet). The key engineering concepts included: levers as force multipliers, incline planes and screws, wheels and axles, and pulleys that could be considered in their catapult challenge. The simple machines unit extended over 18 x 45-minute lessons. Each activity provided background information and an experimental preliminary activity for understanding associated key concepts.

This study focused on the construction of a catapult over four 45-minute lessons using the aforementioned key engineering concepts. These Year 8 students were required to design, construct, test, and evaluate a trebuchet catapult within the last four lessons of the unit. Teachers were provided guidelines by the researchers on how to engage their middle school students in the proposed engineering education lessons. The last three lessons focused on constructing the catapult (2 lessons), and testing and evaluating the catapult with a written explanation of conceptual understandings (1 lesson). The catapult’s effectiveness was tested by flinging a marshmallow to hit a bull’s eye target at a two-metre distance. Questions that allowed students to investigate the catapult’s effectiveness included: How does your design

comply with the design brief? What is practical about your design? What makes you think it is sturdy and will work? What is creative about your design? What simple machines does your catapult use in the design? How efficient is your catapult in using resources? Why do you think so? What else could you improve with your design? Why?

2. Data collection methods and analysis

This qualitative study uses multiple sources of data collection to triangulate information (see Hittleman & Simon, 2006). As an ethnographic study (see Yin, 2009), it investigates the nature of girls' interactions for learning about engineering education. Two focus groups of students from six classes across three schools were video and audio recorded during the last four 45-minute lessons of the simple machine unit. Students used work booklets to record their thinking about the key engineering concepts used for designing, constructing, testing, and evaluating a catapult. These documents were scanned for analysis, and booklets were returned to the students.

Teacher and student resource booklets were analysed for conceptual information. All audio recorded data were transcribed with the analysis focused on girls' interactions for learning about key concepts associated with constructing and testing the catapult. Students were required to provide explanations that focused on their design, construction, testing and evaluation of the catapult, which included a labelled drawing, descriptive writing, and evaluating the tested design. To capitalise on space and consider the data in more depth, this paper reports on one focus group's work, determined to be generally representative of the participant pool.

3. Results and discussion

The Year 8 class was divided up with four or five students to a group. The teacher explained to the students the Catapult Challenge activity and reviewed the student workbook with them. One focus group of students (Nikky, Jim, Mike, & Bree, pseudonyms) was standing around a table where they initially discussed their catapult design and the resources needed to construct their trebuchet catapult. The resources were limited, which required the students to construct their catapult within material and budget constraints. It appeared that gaining a common understanding of the terms for entering into the discourse around constructing a catapult was essential, as illustrated in the following:

Mike: I think we will need dowel.

Nikky: What's a 'dowel'?

Mike: Dowel is like round pieces of wood.

Jim: Wood.

Bree: Has anyone got any ideas of what we're gonna do?

Nikky openly asks questions of the group to clarify the term "dowel", which appeared to be known by both boys. They were directed to look at the resources by the teacher before they commenced their design. This class had undertaken lessons involving simple machines so it was assumed they had an awareness of the three classes of levers, pulley systems, incline planes, screws and wheels and axles. At this stage of the lesson, all students were involved in the discussion about the types of simple machines they could use to make the catapult. In particular, this group had an opportunity to connect with the task brief and strengthen their conceptual understandings by discussing the forces (push and pull) that these simple machines used, and discussing ideas about what constitutes a simple machine. For instance:

Nikky: Um. One question: for the wheels, are we allowed to push it up?

Mike: And then we have a lever.

Nikky: We could have a pulley or something.

Bree: Yeah.

Jim: I think we have to push it up.

Bree: Cause didn't it say somewhere that we had to use a simple machine or whatever it's called.

Nikky: We could make a pulley as well, like tie it around the thing there and then reel it up or something. That'd be good.

Bree: [reading from student booklet] “Only simple machines may move the catapult.”

All students were collectively engaged in the initial task, and Nikky’s questioning provided a direction for the group. Although Mike suggested a lever, Nikky quickly responded about using a pulley as a simple machine and explained how it could be used to reel the catapult up the incline plane. Indeed, Nikky had drawn upon the student booklet guidelines and demonstrated her understanding of using a pulley. Bree supported Nikky’s suggestion and referred directly to the booklet with a quote. It appeared that clear instructions within the student workbook supported the girls’ engagement in the task. At this stage, no-one debated over whether a set of wheels or a pulley would be used to move the catapult up the incline plane.

Students were given a budget of \$100 and, as each resource was price tagged (e.g., 3 rubber bands for \$2.25, 30cm string cost \$2.50), they discussed the cost of these resources and how many they would need to construct their catapult. The boys were less likely to ask questions in this group, while the girls asked questions frequently for clarification and to elicit responses for advancing their design. The question from Bree provided a tentative answer as well, that is, possibly skewers could be used to hold the trebuchet up but may also be too thin. Mike provided a response and explanations to the girls’ questions. Although the boys worked on their individual designs with hands-on materials, the girls continued to talk about the design, which indicated a willingness for understanding how to accomplish the task. The boys continued working on their designs independently while the girls discussed the practicalities of constructing the catapult. Further in the lesson, Bree and Nikky question and support each other towards problem solving the catapult construction. Vygotsky (1978) highlighted social constructivism as a way for learners to construct concepts through social forums. In this case, the girls bounced ideas off each other during their discussion on the practicalities of constructing the catapult. There were no negative remarks about the ideas; instead they continued the flow of discussion by working with each other. It was nearly 32 minutes into the lesson and there was a continued focus by the group on materials for the design in an attempt to gain collective agreement. In drawing the catapult design, Bree considered a top view perspective (Figure 1) to make sense of the structure but also seeks clarity from the group about her idea, as noted in the following.

Bree: I thought, that’s like a bird’s eye view. We have like the lines, the little pole and then the two wheels and then like a base of paddle pop sticks and then have that on either side of the wheels and then in the middle have like stacked up paddle pop sticks or something and then have a spoon on one side and then we fling the spoon back and it like shoots the marshmallow out. Does that make sense?

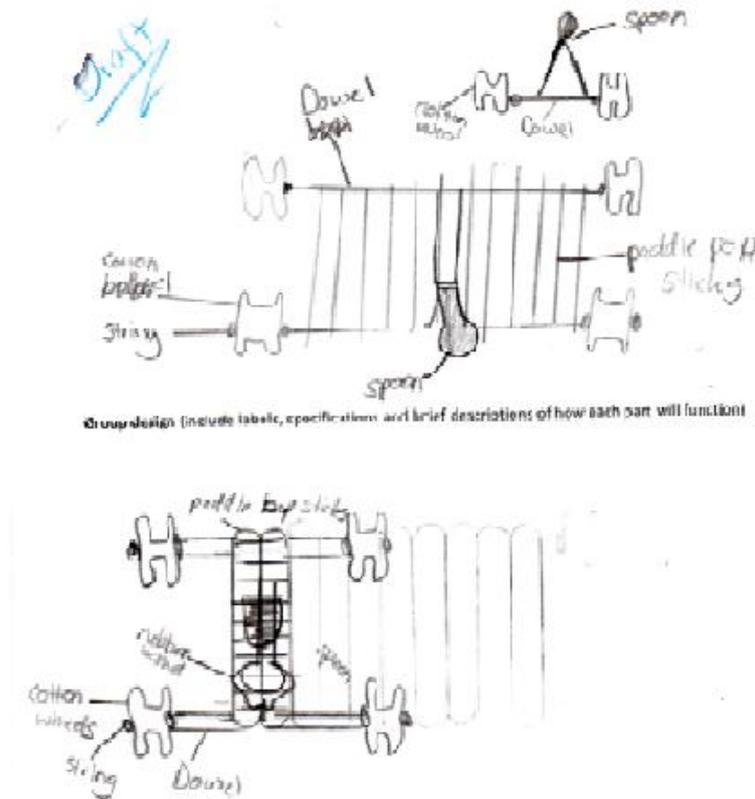


Figure 1. Designing a catapult

The group continued to brainstorm ideas with Mike suggesting an x-frame with string to stand the trebuchet up (i.e., spoon and rubber band) with consideration of a wheel as a gear to “tension the rubber band and then we’ll have a lever to hold it there, and then you pull the lever when you want it, to release it”. During their discussion, these students attempted to clear up conceptual differences between levers and wedges (i.e., determining if scissors were wedges or levers or both). Workable ideas were pooled and accepted by the group for commencing the construction in the second lesson, which proceeded with students speaking in shorter sentences as they were aware of the time constraints. They used questions to clear up their understandings and refined their ideas about the practicalities of their design. The two girls followed the group’s design brief; however the time limit created a slight tension within the group, particularly when there was no consensus for the design. Comments such as “we’re not doing that”, “that won’t work”, and “you can’t attach two axles to the frame, otherwise it won’t spin”, lead to non-verbal actions with the girls working on one section of the catapult (cotton reels and axle) while the boys were working on another. Lesson three continued in a similar way where the group worked sometimes individually, sometimes in gender pairs, and sometimes as a whole group, and lesson four tested the catapult in which all members of the group assisted in setting up, testing, recording the findings, and writing up the results. Each member was required to articulate clear understandings of simple machines and the catapult design. The following outlines Nikky’s account of simple machines and the constructing of a catapult:

Our catapult has a number of simple machines.... We decided that a lever was the best way to fling the load at the target because applying a lot of effort on the spoon creates potential energy. This potential energy will then become kinetic when the effort stops being applied and the load will fling and (hopefully) hit the target. A wheel and axle was also used to get the catapult up the ramp. The wheels were made of cotton wheels and dowel was used as the axle. A wheel and axle was used because not only does it make it easy to get up the ramp, it also gives the catapult’s fling more force by rolling forward. The only disadvantage was the cost.

Although Nikky reported that the tight budget meant not achieving a more complicated pulley system, she wrote that creating a more secure base would improve the design. She used the terminology to describe the design and outlines key concepts such as lever, wheel and axle. Nikky connected other key scientific concepts in her explanation such as the

trebuchet transferring potential energy to kinetic energy. The focus on one group allowed for a dissection of the group's work. Other groups followed similar patterns though the labelled diagrams and written descriptions varied according to individual differences. For instance, Patricia in the same class presented her catapult design in segments and wrote about "The spoon was used as a lever. It had a load, pivot and counterweight/effort," while other girls focused on the class of levers. Importantly, conceptual understandings appeared more fluent as a discourse when students were versed with the engineering terminology.

In summary this study showed that the girls needed to: (1) receive clarification on engineering terms to facilitate more fluent discourse, (2) question and debate conceptual understandings without peers being judgemental, and (3) have multiple opportunities for engaging with materials towards designing, constructing and explaining key concepts learnt.

5. Conclusion

This study did not set out to establish differences between boys and girls in learning about engineering designs and constructions but rather identified what girls may require to undertake engineering education in the middle school. In this ethnographic study, the girls sought opportunities to clarify the engineering terms in order to enter into the discourse around designing and constructing a catapult. Also, it appeared that regular discussion allowed them to connect the task brief, which was available to each student, with their conceptual understandings. The girls' frequent questioning provided directions for the group by seeking clarification towards advancing their design and construction of a catapult. Although clear instructions within the student guidebook provided scaffolding towards their engineering education, the girls discussed the practicalities of constructing their design and debated ideas without being judgemental, which tended to produce fluent and positive interactions. Teachers entering engineering education for girls need to provide opportunities for multiple interactions with engagement in materials for designing and constructing engineering structures. As a way forward for future lessons, a teacher can scaffold the engineering education learning by prefacing it with ways in which students can interact. For instance, as communication appears essential for clarification of terms and design in group work, the teacher can highlight the skills of bouncing ideas off each other without being judgemental and using purposeful questioning that can lead to consensus for a final design.

All students require equal opportunities for learning about STEM, though it is pertinent to facilitate ways to create further gender equity in these fields. Contextualising STEM education can increase STEM employment aspirations for females (e.g., Bee et al., 2007) for which this current study showed a high level of engagement in learning about engineering concepts by designing and constructing a catapult. Females are largely underrepresented in STEM fields around the world; consequently middle-school programs that provide first-hand experiences in what constitutes engineering education may assist girls to undertake a STEM field as a career option. If career choices are considered within the middle-schooling period (Cantrell & Ewing-Taylor, 2009) then it becomes imperative that STEM opportunities are presented more purposefully to females during their middle schooling. There can be a fear of the unknown; thus enlightening females through engineering education may assist to reduce such fears (Steinke et al., 2009). Furthermore, as the adolescent brain is physiologically shaped during adolescence (Wormelli, 2003) and it is suggested that the brain may be hardwiring itself by discarding unused synapses during this period (Nagel, 2005, 2011), not providing STEM engagement during middle schooling may be detrimental for future uptake in these fields.

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