International Journal of Engineering Education Vol. 29, No. 4, pp. 814–821, 2013
Printed in Great Britain
0949-149X/91 $3.00+0.00

Female Students' Interactions in a Middle School Engineering Project: A Case Study*

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Targeting females at high school or earlier may be a key towards engaging them in science, technology, engineering and mathematics (STEM) 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. There was a series of lead-up lessons and four lessons for the catapult challenge (total of 18 x 45-minute lessons) over a nine-week period. Data from two girls within a focus group showed that they needed to: (1) receive clarification on engineering terms to facilitate more fluent discourse, (2) question and debate conceptual understandings without peers being judgmental, and (3) have multiple opportunities for engaging with materials towards designing, constructing and explaining key concepts learnt. There are implications for teachers facilitating STEM education, such as: clarifying STEM terms, articulating how students can interact in non-judgmental ways, 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 these subject areas. In the US, there are summer programs [1, 2] that provide week long camps for girls to consider ideas about STEM subjects as university 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 [1]. Other research [2] has shown that girls involved in STEM education camps are more likely to enroll in STEM type subjects at high school. This research 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 [3] which in particular aims at educating middle school girls [4]. Studies are now uncovering more specific ways girls may be attracted into the STEM fields. For instance, an Australian study [5] outlines that middle-school girls prefer group work, practical activities, and use of technology to understand topics about biology and the environment.

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 [6]. However, early adolescence is a period of developmental brain activity [7], especially as the brain shapes itself during this period of physiological development [8]. 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)" [9]. There is the concern that unused synapses are pruned for hardwiring the brain for the future [10]. 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 these options but fear the prospect at the same time [11]. Nevertheless, girls with more knowledge about STEM increase their university degree aspirations in this field, although still less than male aspirations. Middle year schooling may be an appropriate level to target in STEM education though some claim it needs to occur in earlier grades [12]. Other researchers [13] 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

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* Accepted 15 January 2013.

friends, which is another reason to focus on girls' STEM education within the middle years of schooling. It is claimed [14] that engaging girls requires sound pedagogical planning with appropriate content that helps them to 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 [15, 16]. Consequently, engineering engagement programs are being developed to cater for girls' learning of engineering [17]; however little is known about how female middle school students work in engineering education subjects.

A gender investigation into engineering education by the researchers [18] with data from a survey and written responses showed that girls responded higher than boys on 13 of the 24 survey items that focused on STEM education opportunities. However, 48% of girls believed they achieve in STEM areas compared with 80% of boys. As a possible flow-on effect, only 17% of girls wanted to seek a career in STEM compared with 39% of boys. It was concluded that "Exposing students to STEM education facilitates an awareness of their learning and may assist girls to consider studying STEM subjects or STEM careers" [18, p.1]. Yet more ethnographic studies are needed to understand how females interact in engineering education. Hence, the research question of interest here is, "How do middle school females interact in learning about engineering education?

1.1 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 included 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 [19]); 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. Theoretically framing this study is Vygotsky's [20] social constructivism which posits that people construct knowledge socially. This study investigates the social construction of knowledge within a small group of middle-school students working on an engineering education project, that is, designing and 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 $\times$ 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? This paper focuses on the students' social interactions as they design and construct a small-scale catapult from accessible materials and low technology (e.g., paddlepop sticks, plastic spoon, string, thumb tacks).

2. Data collection methods and analysis

This qualitative case study uses multiple sources of data collection to triangulate information [21]. As an ethnographic study [22], 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 machines unit. The teacher was provided with a teacher's guide to direct the students' design and construction of the catapult (e.g., see Appendix for lesson 1 guidance). 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. One researcher (Hudson) observed the students working in groups and took notes on how they interacted. Data from digital recorders (audio and video) of the group of four students were transcribed with the analysis focusing on the girls' interactions for learning about concepts associated with the design and construction of 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 to consider the data in more depth, this paper reports on one focus group's collaborative work, determined to be generally representative of the Year 8 participant pool.

3. Results and discussion

One Year 8 class of 28 students in the co-educational school 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 (Appendix). 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 asked 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. As previously indicated, 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."

The four 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, however, later on they decided it was easier to use a pulley system 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, 30 cm string cost $2.50), they discussed the cost of these resources and how many they would need to construct their catapult. Overall 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 suggested 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 questioned and supported each other towards completing the catapult construction. Vygotsky [20] highlighted social constructivism as a way for learners to construct concepts through social forums. In this case, the girls debated ideas 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 (Fig. 1) to make sense of the structure but also sought 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?

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. For example, Nikky asks, "Is the rubber band actually even gonna pull it back. Yeah. Yes. That is gonna be seriously strong". Bree responds with a statement but has a rising inflection in her voice indicating a question, "And we can put the marshmallow like under the rubber band?" Nikky and Bree continued to ask questions on the different ways they could test the strength of the design "I know but it's not as strong. Do you want to try and do that? (Bree).

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

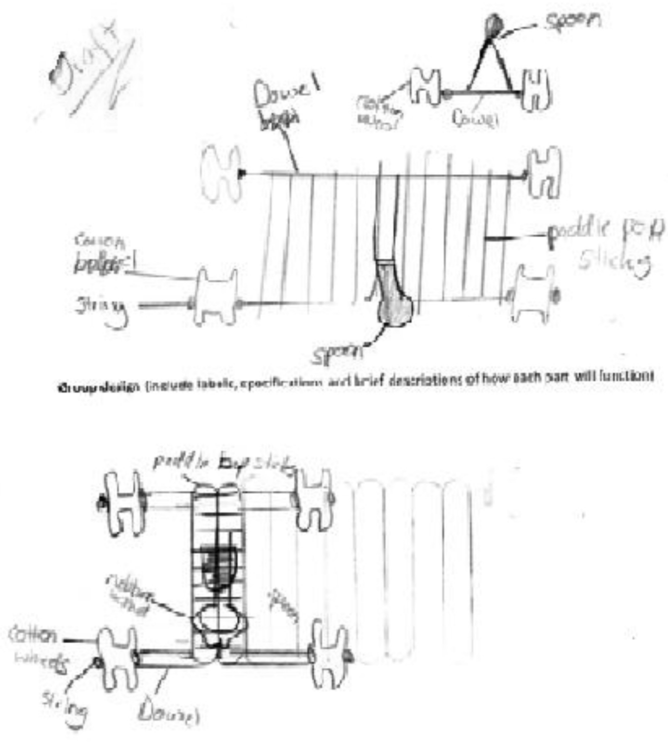

Fig. 1. Designing a catapult.

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. During lesson four, they tested their 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 written 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 outlined key concepts such as lever, wheel and axle. Nikky connected other key scientific concepts in her explanation such as the catapult transferring potential energy to kinetic energy.

The research focus on one group allowed for a dissection of the group's work. Nevertheless, 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.

Researcher observations indicated that the girls' reactions to this engineering education project seemed mostly positive with their collaborative efforts to design and construct the catapult. Even though they appeared to enjoy working together as a female-female pair, the mixed group work was not always successful with social interactions during the constructing of a catapult. There were tensions between the two boys and two girls, particularly when the girls were exploring ideas on how to move the catapult up the incline plane (using either a pulley or lever). Engineers also construct knowledge through social interaction, which can involve debating controversial ideas within the problem solving space. There was an instance where the two girls withdrew themselves from the boys to work on their own, indicating that the conversations may have been construed by the girls as judgmentally negative. Nevertheless, both girls and boys worked together productively for the majority of their work, which was evident through the final product, their verbal and written responses on how they engaged with the engineering education activity and researcher observation.

Similar to findings from [5], these middle-school females (and males) preferred practical activities with multiple opportunities for designing, constructing and explaining key concepts learnt. In addition, the immersion in the engineering activities presented them with problems to solve [15] in where they had to use prior knowledge about engineering concepts (e.g., incline planes, wheels and axles, pulleys) to complete the activity. Despite having 18 lessons that lead towards the catapult construction, we did not gather data around students' aspirations towards undertaking STEM-related subjects in high school or whether they would consider a STEM career as a result of these catapult lessons; even though some would argue that many career decisions are made in the middle years [13]. Yet, there was no indication that these girls feared the prospect of STEM education opportunities, as argued elsewhere [11]. Regardless, it was shown that these middle-school females were very capable of interacting within the engineering project and provided insights into the concepts associated with the activities. Year 8 is an appropriate level to target STEM education; however, targeting engineering education in earlier years would also need further investigation [12].

The females (and males) gained conceptual understandings through an engineering education activity and learnt about wheels, axles, pulleys, inclined planes, and so forth for understanding engineering concepts towards the catapult challenge activities. The lessons were sequential and built from concrete ideas to more abstract concepts, as suggested by researchers [14]. The brain shapes itself during adolescent development [7, 8], thus the engineering education activities may have helped students to make synaptic connections. Theoretically, the chemical messages [9] would be in the form of making conceptual understandings and creating neurotransmissions for closing synaptic gaps.

It seemed that the boys had an understanding of some terms and concepts prior to involvement in this engineering education series of lessons. For instance, they understood the term "dowel" and appeared to have more understandings about wedges and levers, which may be the result of conversations and activities held outside the school context. As another example, in a pre questionnaire that asked these Year 8 students about their conceptual understandings about a pulley (before commencing the series of engineering education activities leading to the catapult challenge), Mike had written, "a pulley is a wheel and axle with rope of some sort that helps to lift and move an object", Jim had written, "a pulley is used to lift heavy things easier", Nikky wrote, "a round object which rope/chain is put over and pulled. It is to make the job easier", and Bree wrote, "I don't remember this one, but I have been told". Three of these students demonstrated prior knowledge but Bree did not have an understanding of a pulley. Research is required around the engineering concepts that students bring to the school to determine the types of activities they have been engaged in beyond the school context, which would assist towards understanding gender inclusiveness. There was little doubt that engineering education programs for middle school would require the availability of engineering terms to facilitate student communication. Even though engineering programs are being developed to cater for girls' engineering education, such as [17], more programs are needed to cover the breadth and depth of engineering education fields [23].

In this ethnographic study, the girls sought opportunities to clarify 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 judgmental, this tended to produce fluent and positive interactions. 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 sharing ideas with each other without being judgmental and using purposeful questioning that can lead to consensus for a final design. Teachers can also outline that part of engineers' work involves debating issues as a problem-solving approach. Such scaffolding prior to commencing an engineering task may reduce potential conflicts with awareness that non-judgmental debating can lead towards solving problems.

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 consider the STEM fields as a career option. As career choices can be considered within the middle-schooling period [6], it becomes imperative that STEM opportunities are presented more purposefully to females during their middle schooling. Furthermore, as the adolescent brain is physiologically shaped during adolescence [8] and it is suggested that the brain may be hardwiring itself by discarding unused synapses during this period [9, 10], not providing STEM engagement during middle schooling may be detrimental for future uptake in these fields.

4. Conclusions

This study found that productive interactions with the girls involved in the catapult project relied on: (1) receiving clarification on engineering terms to facilitate more fluent discourse, (2) questioning and debating conceptual understandings without peers being judgmental, and (3) receiving multiple opportunities for engaging with materials towards designing, constructing and explaining key concepts learnt. This has implications for teachers involved in engineering education and how they might consider their own pedagogical practices. 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. However, there is a need for larger scale qualitative studies on how girls (and boys) interact for developing conceptual understandings in engineering education.

Acknowledgements—The project reported here is supported by a three-year Australian Research Council (ARC) Linkage Grant LP0989152 (2009-2011). Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the ARC. We wish to acknowledge preservice teachers participating in this research and the excellent support provided by our research assistants, Jo Macri and Lyn Nock.

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Appendix

Lesson 1: Catapult design

Time	Lesson direction
5 mins	• Focus Question: What have you learnt so far in this unit on simple machines? Students should pick up all the concepts about simple machines (incline planes, pulleys, levers, wheels, axles), if not ask probing questions towards these concepts.
5 mins	• Focus Question: Why were catapults engineered? Explain history of catapults. • What if the catapult could have been used for helping people? Ask students to make suggestions. • Bugs and catapults (Watch only from 3mins to 5 mins) http://www.youtube.com/watch?v=sWukBzB6RAs
10 mins	• Explain and distribute design brief for the Catapult Challenge • Remind students to use their knowledge of simple machines (inclined planes, pulleys, levers, wheels, axles). • Measures include: Distance the projectile travels and accuracy to complete the operation. • Advise students of budget constraints for purchasing resources (e.g., $2.50 for 30cm string).
25 mins	• Divide students into groups with four in each group (Cooperative Learning roles are designated for individuals within the group). • Request all students to individually design a catapult, labelling all parts on their "Catapult Challenge Sheet" • Have individuals bring their designs to the group of four and discuss their designs. They select the best features of each design to form a new group design. • Students have their completed designs (one per group), which are labelled showing specifications and how each part will function.

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