Imbalance of Power: A case study of a middle school mixed-gender engineering team

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Abstract - This paper presents a mixed methods case study of a middle school mixed-gender team participating in an after-school environmental engineering workshop. The curriculum was part of a STEM program in which youth were engaged in a studio approach to design-based engineering. Data includes video of a girl-boy team working together (both 6th graders) tasked with creating a working model of a solar car. Additional data was provided through interview transcripts of the girl and boy, along with pre- and post-test results of their learning of key scientific concepts. Discourse and observational analyses based on videotape documentation reveal power imbalances in the working relationship of the pair favoring the boy. These imbalances are most apparent in the amount of time that each spends handling the engineering equipment and in the nature of the dialogue, which is characterized in large part by directives rather than by constructive collaboration. These imbalances appear to reflect longstanding societal gender norms and may provide clues as to how females may feel excluded from engineering activities and why so few females enter the field of engineering. Recommendations for facilitation, instructional designs, and assessments are made with the goal of fostering equitable and harmonious mixed-gender collaborations in engineering activities.

Index Terms – Engineering education, girls, gender, discourse.

INTRODUCTION

Despite recent advances, participation by females in engineering careers and higher education engineering degree programs continues to be low in the United States [1]. Longstanding professional and academic traditions augmented by corporate campaigns that market engineering kits as “boy toys” partially explain the dearth of female participation in engineering. While the limited impressions formed by young children about engineers may contribute significantly to this trend [2], little is known about the experiences of females who choose to participate in engineering activities at a young age. This study contributes to this body of knowledge by providing an intensive case study analysis of a middle school girl-boy team from a rural Appalachian region who participated in an after-school STEM (science technology engineering and math) program focused on energy sustainability.

BACKGROUND

This after-school STEM club, Studio STEM, uses a curriculum with a Save the Animals theme given results from research studies [3] which indicate that many middle school students are interested in topics related to animals and environmental issues affecting animals and humans. The fundamental concepts related to alternative energy, energy transfer, and energy sustainability are woven into the Save the Animals theme in a manner that informally teaches scientific inquiry and engineering design skills. The curriculum used in this study was Save the Seabirds [4], [5] in which youth learn basic science concepts related to energy, force, and motion as well as the basics of engineering design. In Save the Seabirds the students were challenged with creating a model of solar-powered transportation. The design-based curriculum engaged students in guided inquiry. Students worked in small groups of 2-3. They were guided to explore basic concepts with clear and concise worksheets, and then encouraged to make design decisions based on their knowledge and understanding of the materials and key scientific concepts. The role of the instructor was to guide students through their decision-making, to model the new skills, and to help test and facilitate a critique of their designs. Using small magnetic motors, Lego pieces and gears, and solar cells, the students were tasked with creating a small solar vehicle that could pull a cart of plastic eggs filled with Plaster of Paris.

The Save the Seabirds curriculum was taught as an 8-week, after-school course in which middle school students (grades 6, 7, and 8) met for 1.50 hours per week as part of a National Science Foundation funded program named Studio STEM (http://studiestem.org). Students met in the school library and were led by a 5th grade science teacher with 33 years of experience in teaching. The “studio” in Studio STEM was a physical space in which youth had the opportunity to justify their designs, incorporate input from peers and facilitators, and work collaboratively toward developing a successful solution to the design challenge. Thirteen students (4 girls, 9 boys) from 6th and 7th grades participated in the Fall 2012 Save the Seabirds in a rural Appalachian community. In addition, one graduate student, a program manager, and two undergraduate facilitators were
also part of the instructional team. Undergraduate science and engineering students volunteered in the after-school program and their participation was viewed as an important feature of the curriculum delivery. The undergraduates acted as role models and asked the youth productive questions during the design and construction process. All adults received instruction in the curriculum and training on how to facilitate productive discussion in small groups. Youth were organized into five working “teams”: one all-girl group, three all-boy groups, and one mixed gender group that was the focus of this study.

**RESEARCH QUESTIONS AND THEORETICAL FRAMEWORK**

Ethnographic and discourse analysis by Schnittka and Schnittka [6] of video from Studio STEM at the same school in fall 2013 clearly showed gender stereotypes among the participants that are also prevalent in the scientific fields. Generally, the boys were loud, confident, and competitive, while the girls were more timid, unsure, and collaborative. Schnittka and Schnittka pointed to the importance of more research focusing on small group formation and gender norms. Similarly, Capobianco et al. [7] argue for other forms of qualitative inquiry that can examine the dynamics of identity work done in educational settings to understand how “young students develop a sense of personal and professional identification with engineering” (p. 702). Understanding that the gender gap in engineering is first noticed in the middle school years [8], our study examines closely the social interactions in one middle school mixed gender small group consisting of one boy and one girl in an after-school STEM curriculum.

Our research questions are: (1) How are power and control of the design and construction process during an after-school STEM program negotiated in a mixed gender small group? and (2) How do facilitators’ interactions with a mixed gender small group influence the group’s social dynamics, design, and construction?

Our theoretical framework draws from previous studies of middle school girls in science [9], [10]. These studies observed that girls are able to view possible future selves in STEM when their identity work is recognized, supported, and leveraged through meaningful participation in science activities. They argue that girls’ talents and skills need to be recognized and integrated into STEM activities. We define “power” as moments when one is able to retain possession of building materials, to make a bid for recognition, and to hold the floor during discussion uninterrupted.

**METHOD**

The primary data source for the study consists of videotapes of five workshop sessions, averaging 40 minutes each, of a girl-boy group: Lindsay (girl) and Curtis (boy) both in 6th grade. The videotapes range from 20:58 minutes to 1:06:50, totaling 3:21:24. Videotapes were transcribed and open coded [11] to make sense of how the team collaborated and negotiated power in the relationship, and to ascertain the facilitators’ roles in these negotiations. The videotapes provided additional valuable information: e.g., they revealed which student was assembling or operating equipment and for how long. After reading a few transcripts and viewing the corresponding videos, the first author constructed the coding categories found in Table 1 (and a few others omitted from the table due to a low number of occurrences). She then coded the complete set by reading each transcription and watching the corresponding video. Next, using the codes developed by the first author, the second author read and coded the transcripts independently, with an interrater reliability score of 82%. This percentage is calculated from the number of agreements divided by the total number of sections of text coded to calculate the degree of agreement between coders [12].

Several additional data sources were used: interview transcripts for Lindsay and Curtis (each about a half hour long); as well as pre-test and post-test scores from the *Save the Seabirds* after-school program. The interviews were administered by the program evaluation team, with questions that focused on the youth’s background interests and career aspirations. The pre- and post-survey were administered to measure participants’ interest and effort in the Studio STEM project, using a modified version of two scales from the Intrinsic Motivation Inventory [5] along with an energy, force, and motion learning inventory. The pre- and post-surveys had reliability and validity established as part of the Studio STEM pilot study [5].

**FINDINGS**

I. **Interviews**

The interview transcripts reveal several pertinent facts about Lindsay and Curtis. They consider themselves to be friends, and they worked together before as a team in a similar after-school engineering program. Both have science and technology oriented hobbies. Lindsay enjoys playing with Mega Bloks (by Mega Brands, Inc.) which are similar to but less expensive than Lego blocks (by The Lego Group). She enjoys creating digital animations with software based on Mega Blox and recently entered an animation contest. Lindsay persuaded Curtis to enter the competition as well. Lindsay aspires to be a digital animator.

Curtis very much enjoys playing with Legos. Prior to this workshop, he had experience with motors from working with Lego Mindstorms [13], and prior experience with gears and solar panels from working with remote-control (RC) cars. Curtis owns a Lego Mindstorms robotics kit and recently purchased what he referred to as an “expensive” RC car. When asked if any of the concepts in the *Save the Seabirds* curriculum sounded familiar, Curtis responded “Amps and voltage because my dad is an electrician so I’ve been with him and he’s yelling stuff out to his partner to write down to make sure everything works.” While describing his work with Lindsay on a prior engineering project, he positions himself as the team leader: My partner, she’s a really good artist, and I’ve been telling her the information then she’s been drawing. Curtis aspires to be a mechanical engineer for small cars. He shared that he hadn’t
done the math very well during the workshop because he had forgotten how to do it. Both Lindsay and Curtis express enthusiasm for the workshop activities. They both convey interest in the technical content and motivation for finding ways to save wildlife from oil pollution.

II. Videotapes and Transcripts

The videotapes indicate that Curtis consistently takes the lead while Lindsay participates primarily as his assistant. Each of the five videotapes begin with Curtis setting up the equipment for the day (by taking parts out of their equipment box labeled “lego geeks”). Subsequently he is the primary equipment handler. For the most part, he is the one who assembles and disassembles various aspects of the solar car such as the Legos, gears, motor, and solar panels. He is also the one who primarily hooks up the solar cells in parallel or series; powers on the motor; and uses a hand-held scale to measure how much load the car can carry. Lindsay exhibits considerable conceptual understanding of the process, but the contributions she makes with her hands are primarily assistive. For example, she take and records readings with the multimeter; she uses a pencil to do the math; and she spends a considerable amount of time holding their assembly steady while Curtis works with the motor and gears. An exception to this trend occurs when Curtis leaves temporarily for an interview on the fourth day. While he is gone, Lindsay spends time experimenting with gears and works on a gear assembly. After Curtis returns and their tests reveal that the assembly requires adjustment, Curtis takes charge of handling the equipment again.

One measure of the imbalance of power in the team can be observed on the videotapes by comparing the number of times that the boy and girl each connect alligator clips to turn their motor on. This activity begins in Session 3 when motors are introduced. In Sessions 3 and 4 the boy powers the motor on, by connecting alligator clips together, on 66 occasions; the girl never does so. In the fifth session, the girl powers the motor on 12 times. Overall in Sessions 3-5, the boy powers the motor on 83 times; the girl does so only 12 times.

An analysis of the dialogue between the boy and the girl also reveals a power imbalance. As shown in Table 1, the boy directs the girl (e.g. to hold, record, or fetch something) an average of 22 times per hour. In comparison, the girl directs the boy 5 times per hour. A pattern that occurs when the girl directs the boy is that the boy frequently either dismisses her direction or counters it immediately by giving her a directive. This reflexive pattern is not evident when the boy initiates a direction. In general the girl seems to accept her role as an assistant, though she occasionally resists lightheartedly (e.g. “Get me a taco!”). Relative to giving directives to her partner, the girl is roughly equally as likely to make a suggestions or to ask a question of her partner, for example to point out a mistake. In contrast, the boy gives direction to his partner over five times as frequently as he makes a suggestions or poses a questions to his partner. While the girl apologizes more frequently than the boy (12 times to 2), the boy is dismissive on more occasions than the girl, and he engages in more ridicule. There is also evidence of self importance from the boy (e.g. “I’m awesome like that”, “I’m just waiting for one of my awesome brainstorms”, [I’m] “older in the mind than them”).

The videotapes and transcripts also convey information about how the facilitators interact with the team. For example, in a dialogue during Session 1, Curtis lets the facilitator know that he has prior knowledge and experience with the technologies that will be used in the workshop:

Facilitator: So have you ever used one of these before?
Curtis: The multimeters?
Facilitator: Yeah.
Curtis: Yeah, because dad’s an electrician.
Facilitator: Okay, so do you know what all these different things mean? (pointing at multimeter)
Curtis: Not all of them.
Facilitator: So basically, what it means is, when you’re setting it- Say you set it to 20 milliamps that means that it can read, with accuracy, up to 20 milliamps.
Curtis: Ah.
Facilitator: When you put it to 200 milliamps that means that it can read, with accuracy, up to 200 milliamps.
Curtis: So if you put it to 200 amps?
Facilitator: That’s 200 mi- oh, micro-amps.
Curtis: So that’s a lot smaller.
Facilitator: That’s a lot smaller, exactly. So basically...

The dialogue continues for several more iterations as the facilitator confirms Curtis’s understanding. Missing from the transcribed dialogue and videotape is any verbal or visual evidence that Lindsay has prior knowledge of the equipment, or that she understands the information that the facilitator conveys to Curtis. The conversation above is one example in eleven, over the five sessions, in which a facilitator has a dialogue of three or more content-related, back-and-forth interchanges just with Curtis. In contrast, Lindsay has only three such dialogues with a facilitator. As Table 1 shows, in shorter exchanges where the facilitator asks a question of the team or asks them to confirm understanding about a concept, Curtis is the first to respond 38 out of 49 times and the only one to respond over half of the time.

### Table 1: Summary of Quantitative Discourse Analysis (Duration: 3:21:24)

<table>
<thead>
<tr>
<th></th>
<th>Girl</th>
<th>Boy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directs the other to do something</td>
<td>16</td>
<td>73</td>
</tr>
<tr>
<td>Asks, suggests, or questions the other</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Dismisses or ignores the other’s suggestion or opinion</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Ridicules the other</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Displays self importance</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Apologizes to the other</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Identifies as an engineer or as having prior knowledge, experience, or privilege related to engineering</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Is the primary conversant with a facilitator in three or more content-related back-and-forth interchanges</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Is the first to answer a facilitator’s question</td>
<td>11</td>
<td>38</td>
</tr>
<tr>
<td>Is the only one to answer a facilitator’s question</td>
<td>9</td>
<td>25</td>
</tr>
</tbody>
</table>
It is evident from the transcription that the facilitators are aware that Curtis is domineering. The following dialogue occurs during Session 2:

Curtis: Ah, don’t pull it.
Facilitator: Don’t be so bossy.
Curtis: Well, but-
Facilitator: Yeah I know you.
Curtis: But, it takes so-
Facilitator: Yeah, I know you.
Lindsay: It’s about the fifth time you’ve said that.
Instructor: Bossy, bossy.

It also evident from the videotape that the facilitators see on an ongoing basis that Curtis acts as the boss, takes charge of the equipment, and tells Lindsay what to do, because the facilitators are in close proximity to the team on numerous occasions when these kinds of interactions occur.

III. Pre-tests, Post-tests, and Math work

The pre-test and post-test consist of the same twelve open-ended questions. Questions include: What is a force?, What is an electric current?, Describe the difference between two solar cells arranged in a parallel circuit and the same two cells arranged in series circuit. The pre-test scores for eleven students range from 3 to 7 out of 12 possible points. Lindsay and Curtis both score 5 on the pre-test; the average score is 4.72. The post-test scores for eleven students range from 5 to 9. Lindsay scores 8 on the post-test; Curtis scores 9; the average score is 7.36.

The ways in which the team members approach the math work related to the project is of interest. During Sessions 1 and 2, the students are required to take measurements and perform calculations related to electrical force with respect to parallel and serial circuits. Initially, Curtis and Lindsay don’t have access to a calculator which necessitates that they do the calculations by hand. Curtis struggles with the math more (and/or has less patience) than Lindsay. In Session 2 he “lets” her do the math. Lindsay finds the work difficult but persists. She takes pride in the fact that once they are given a calculator, her work is verified as correct. The math work is perhaps the only aspect of the workshop in which Lindsay has more confidence than Curtis, yet he still subtly exerts dominance through bossing and sarcasm. For example he criticizes her for an extra trailing zero, and makes comments such as “You could have saved 5 minutes”, “fourth grade math”, and “You didn’t know that?”

DISCUSSION AND RECOMMENDATIONS

Choosing partners for working teams in order to optimize collaboration is a perennial concern for educators. If the educator chooses the team members, several factors are typically considered such as the students’ personalities and prior experience, the topic of study, resources and other logistics, and the teacher’s philosophy and preferences. Some argue that teams should be equally balanced in terms of prior knowledge and experience; others argue the opposite. Some argue that middle schools girls would benefit most from all-girl engineering workshops or teams, however this is not always possible and may not be desirable in all cases. This study takes an in-depth look at a mixed-gender middle school engineering team and makes recommendations for facilitation, instructional designs, and assessments with the goal of fostering equitable and harmonious collaborations in such groups.

In several respects, the pairing of Curtis and Lindsay as a working team has several desirable qualities. The two are friends who worked together in the past during a similar workshop. They have the same above-average pre-test scores which arguably puts them on equal footing in terms of prior knowledge. With their “lego geeks” equipment box and technology-based hobbies, they seem to have a shared “geek pride”. In other respects, the pairing of Curtis and Lindsay has the potential for significant imbalance with respect to expertise and gender norms. Curtis comes to the workshop with significant prior experience. As he relays to a facilitator on the first day, he already knows about electricity and multimeters because his father is an electrician, and Curtis has observed his father being the boss in the workplace. Curtis also has prior experience with gears and motors; he owns a robotics kit and a remote controlled car. While Lindsay has prior experience with Mega Blox which are similar to Legos, none of the data suggest that she has prior experience with motors, gears, or solar panels, or with assembling cars. Nor does any of the data suggest that she has a family member or mentor with an engineering or technology-related career. Role models aside, this boy-girl pair has a “tinkering gap”. Damour argues that girls need more time to tinker with electrical, mechanical, and computational toys in order to develop an affinity for them and confidence in working with them [14].

Differences in prior experiences and role models partially explain the roles that Lindsay and Curtis assume, that of director and assistant. In addition, societal gender norms with respect to STEM activities and occupations play a role. In their formative years, most elementary school children view engineers as being male; they often associate the word “engine” with “car” and think of an engineer as being a male car mechanic [2]. In order for a middle school girl to pursue engineering, she may need to perform a balancing act not required of boys, and adopt a “precarious identity” in an attempt to balance her STEM interests with social negotiations that maintain her female identity [15]. For Lindsay, her acceptance of the role of assistant may have been such a social negotiation. Research on adults reveals that the accumulation of subtle micro-inequities can have a chilling effect on females in male-dominated workplaces, similar to the diffuse but distinct boundaries around Saturn formed by its icy, sandy rings [16], [17]. It is reasonable to expect that young females will also experience such micro-inequities in engineering education settings unless more equitable norms are deliberately established. It appears that Lindsay experienced micro-inequities throughout the workshop, from her partner’s domineering words and near-
monopoly of the equipment, and from the facilitators who tended to converse primarily with her male partner.

It would be possible to frame this mixed-gender team’s inability to achieve collaborative balance as a series of missed opportunities on the part of the facilitators to intervene and disrupt the heuristically patterns as they formed. It is important for facilitators to be aware of gendered socio-historical patterns as they pertain to STEM education and careers. Archer et al. argue “we suggest that STEM participation interventions need to integrate ways for young people (and staff) to engage with and challenge dominant gender discourses. If not, they risk limited success in terms of encouraging more girls/women into STEM careers” [15]. The facilitators could have directed some questions directly to Lindsay instead of allowing Curtis to jump in and answer first so frequently. When Curtis did answer first, the facilitator could have asked Lindsay for her opinion as well. The facilitators could also have engaged Lindsay in longer conversations, and set an expectation for Curtis to wait, listen, and acknowledge her opinion. If the facilitators had been advised to moderate tinkering gaps in a team, they could have ensured that Lindsay and Curtis took turns with setting up, assembling, and disassembling the equipment. This probably would have required asking Curtis to do other tasks such as reading the instructions, calculating the math, or making other valuable contributions.

Facilitators have a profound influence on setting classroom norms of discourse and collaboration, but they are often very busy during workshops attending to multiple logistics and teams. Instructional designs can provide another pillar of support in establishing equitable norms of collaboration. Instructional designs that enlist the students in taking turns or in alternating roles are effective in this regard. Two examples are pair programming [18] and Process Oriented Guided Inquiry Learning (POGIL) [19]. With pair programming, students work together using one computer to write software. They take turns being the “driver” (the one who types in the code) and the “navigator” (the one who advises the other). When pair programming is enacted successfully, the facilitator ensures that the pair take turns even if they are resistant to doing so. Evidence-based research at the undergraduate level has shown pair programming to be effective in increasing confidence, scores, and retention of females in computer science [18], [20]. Werner and Denner conducted a discourse analysis of middle school girls engaged in pair programming [21]. They characterize features of this discourse as “productive” or “unproductive” with respect to successful collaboration. Productive features include exploratory talk, questions about what the other is thinking in order to develop a common understanding, elaboration on the other’s ideas, critical but supportive comments, and self-disclosure of ignorance. An example of an unproductive discourse is one that has many assertions and few questions to find out what the partner is thinking. Curtis and Lindsay’s pattern of discourse, characterized by commands from one to the other, is clearly on the unproductive end of the spectrum according to this rubric, and may have been disrupted if the workshop’s instructional design, or the facilitators, had required that the two take turns and change roles periodically.

POGIL is another example of an instructional design that supports effective collaboration and promotes learning [19], [22]. POGIL takes a structured small-group learning approach. It was originally developed for chemistry education but it has been adapted for other STEM fields such as computer science and mathematics. Members of a POGIL team (typically numbering 2-5), assume specific roles for a session, and alternate roles across sessions. Sample roles are manager, reader, presenter, strategy analyst, and technician. POGIL could be adapted for engineering workshops with roles such as electrical engineer, product manager, tester, and mechanical engineer. This would be a means of disrupting society’s normative notion of who is an engineer [2] by actively inviting a diversity of participants to “try on the identity” of being an engineer at a formative time of life in the company of friends.

A third recommendation to support equitable mixed-gender collaborations is to assess participants to find out if, during the enactment of a curriculum, the participant had enough turns, if their failures were expected and accepted as part of the engineering process, and if they felt valued as a team member. Encouraging the participant to reflect about being on a team and to share their reflections can inform the participant and the facilitators as well.

Regarding limitations, our observations of Lindsay and Curtis are not generalizable to all girls and boys in Studio STEM and these findings cannot be generalized to all mixed gender groups in this project. Thorne [23] reminds us that not all boys and girls fit into stereotypical roles, that non-aggressive boys exist as well. However, these results allow us insight into ways that gendered practices become “fixed” and “normalized” in STEM activities. Our point is that facilitators and instructors should be aware of how to disrupt imbalances of power in small group dynamics and strive to make the engineering studio an equitable learning experience where all youth have the opportunity to be creative and recognized for their contributions.

**Conclusion**

This paper presents a case study of a middle school mixed-gender team participating in an after-school environmental engineering workshop. Discourse and observational analyses based on videotape documentation reveal power imbalances in the working relationship of the pair. These imbalances are most apparent in the amount of time that each spends handling the engineering equipment and in the nature of the dialogue, which is characterized in large part by directives rather than by constructive collaboration. These imbalances appear to reflect longstanding societal gender norms and may provide clues as to how females may feel excluded from engineering activities and why so few females enter the field of engineering. Recommendations for facilitation, instructional designs, and assessments are made with the
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