

Student Participation in Small Group, Integrated STEM Activities:  
An Investigation of Gender Differences

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## **Dedication**

This dissertation is dedicated to my husband, Thomas Wieselmann. Thank you for supporting me in this dream and so many others.

## Abstract

With ongoing efforts to increase the representation of women in science, technology, engineering, and mathematics (STEM) fields, integrated approaches to teaching STEM are increasingly being implemented in elementary and middle school classrooms. Despite a variety of conceptions of integrated STEM, researchers agree that small group activities and teamwork play a central role in STEM learning. However, little is known about how young girls participate in the small group portions of integrated STEM curricular units. In three distinct but related studies, this dissertation addresses the gap in the literature to better understand the small group interactions that take place in integrated STEM activities.

First, a single embedded case study was used to explore the participation of four fifth-grade students in the small group activities of an integrated STEM unit focused on electromagnetism. This study revealed patterns of student participation within the mixed-gender group that varied based on the student gender and whether the activity was science-focused or engineering-focused. These findings informed the research questions explored in the next two studies.

Second, a multiple embedded case study design was used to examine group gender composition related to student participation in small group, integrated STEM activities related to the properties of light. Three groups of sixth-grade students (all-girl, all-boy, and mixed-gender) were included in the analysis. Findings highlight differences in the activity systems of the small groups, with students focusing on different objectives for completing STEM activities, utilizing different tools as they sought to reach their objectives, and dividing labor differently across the three groups. Like the first study, this

study also suggested that students, and girls in particular, are less prepared to navigate open-ended engineering activities.

Third, a multiple embedded case study was conducted to explore sixth-graders' participation in an engineering design challenge in further detail. In particular, the study considered differences in the engineering practices middle school girls and boys display during an engineering design challenge and whether group gender composition was related to student participation.

Together, these studies provide insight into small group interactions during integrated STEM activities and have implications for instructional strategies, professional development, and curriculum development. These implications include the need to facilitate equitable student participation in small group STEM activities, support students in open-ended STEM activities, and design STEM curricula with students' needs in mind.

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# **Chapter 1 - Introduction**

## **Organization of the Dissertation**

This dissertation comprises three papers in six chapters. Chapter 1 describes the organization and provides a rationale for the sequence of three studies conducted. Chapter 2 contains a review of the existing literature that served as the basis for all three studies. Chapters 3 through 5 each feature a distinct study, including the rationale, a brief literature review, theoretical framework, methods, findings, and implications specific to each study. Chapter 6 highlights key findings from all three studies, overall implications for research and teaching, and future research directions

Chapter 3 features the first study, which is a single embedded case study that explores the participation of four students in the small group activities of an integrated science, technology, engineering, and mathematics (STEM) unit. This study revealed patterns of student participation within the mixed-gender group that varied based on the student gender and whether the activity was science-focused or engineering-focused. These findings informed the research questions explored in the next two studies.

The second study builds on the first study's findings and is presented in Chapter 4. This study utilizes a multiple embedded case study design to examine group gender composition related to student participation in small group, integrated STEM activities. Three groups of students (all-girl, all-boy, and mixed-gender) are included in the analysis. Findings highlight differences in the activity systems of the small groups, with students focusing on different objectives for completing STEM activities, utilizing different tools as they seek to reach their objectives, and dividing labor differently across the three groups. Like the study featured in Chapter 3 (Wieselmann, Dare, Ring-Whalen,

& Roehrig, accepted), this study also suggested that students, and girls in particular, are less prepared to navigate open-ended engineering activities.

The third study is highlighted in Chapter 5. Because both of the first two studies indicate that open-ended engineering activities create additional challenges for equitable and purposeful participation among girls and boys, this work utilizes a multiple embedded case study to explore student participation in an engineering design challenge in further detail. In particular, the study considers differences in the engineering practices middle school girls and boys display during an engineering design challenge and whether group gender composition is related to student participation.

## **Rationale**

With increasing demands for expertise in STEM in the 21st century, STEM education is of growing concern in the United States and around the world. STEM knowledge and skills are central to manufacturing, healthcare, environmental protection, and national defense (National Science and Technology Council [NSTC], 2013). The President's Council of Advisors on Science and Technology (PCAST) points to STEM education as the determining factor in responding to the challenges of the 21st century (PCAST, 2010). The number of STEM jobs has a record of growing three times faster than non-STEM jobs (U.S. Department of Commerce, 2012), and this pattern is expected to continue in the future (Vilorio, 2014). This may result in a shortage of up to 1 million STEM workers in the United States (PCAST, 2010). In addition to the needs of workers within STEM fields, scientific and technological literacy are increasingly recognized as paramount to informed decision-making for all individuals living in the 21st century (National Research Council [NRC], 2011). With the need for a STEM-literate population

to fill the increasing number of STEM jobs and make informed personal and societal decisions, preparing students for success in STEM is of unprecedented importance.

Within the United States, educational standards have shifted toward integrated STEM education across all grade levels within the public school system. Engineering practices were included in the Next Generation Science Standards (NGSS Lead States, 2013), which indicates that the teachers responsible for addressing science standards are also likely to be responsible for teaching engineering. Teachers are challenged to provide authentic STEM experiences to students in grades K-12 in order to foster students' engagement and interest in STEM (NSTC, 2013). As teachers take on the additional task of teaching their students STEM skills and practices, it is necessary to learn more about effective means of doing so.

Teamwork and communication are key components to integrated STEM instruction (e.g., Brown, Brown, Reardon, & Merrill, 2011; Kennedy & Odell, 2014; Moore, Stohlmann, et al., 2014; Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016), yet little is known about how students at the elementary and middle school levels participate in small group STEM activities (Baillie & Douglas, 2014; Capobianco, French, & Diefes-Dux, 2012). In particular, with women underrepresented in a number of STEM fields (e.g., Corbett & Hill, 2015; Economics and Statistics Administration [ESA], 2017; National Science Foundation [NSF], 2017), it is important to consider whether the small group STEM activities that are commonplace in integrated STEM instruction are supportive of young girls' participation in STEM both within and beyond K-12 schooling.

Investigations of small group interactions in STEM fields tend to focus on engineering at the undergraduate level (e.g., Tonso, 2006; Wolfe & Powell, 2009), and studies of small group work in integrated STEM are lacking at the elementary and middle school levels (Baillie & Douglas, 2014; Capobianco et al., 2012). One study, conducted by Schnittka and Schnittka (2016), explored small group gender dynamics in a design-based afterschool program for middle school students; however, their work was in a rural, primarily White setting, included cooperative group roles within self-selected groups, and has not been extended to formal elementary and middle school classroom instruction of engineering-based integrated STEM. Compulsory coursework driven by a teacher's need to address specific academic standards in science and associated with grades for students is likely to create a different environment for student interactions than elective, non-graded, informal experiences. In addition, existing studies often use quantitative analyses to investigate associations between motivation, context, and engagement (Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018).

The three studies featured in this dissertation address the gap in the literature to explore how elementary and middle school girls participate in small group, integrated STEM activities in their formal school classrooms within a diverse, urban setting. The use of qualitative methods of analysis provide a rich description of student participation patterns, revealing key differences in how girls and boys participate in these small group activities that are ubiquitous to integrated STEM. Findings from this research can be used to inform future research, as well as gender equitable teaching practices and curriculum development.

## **Chapter 2 - Literature Review**

To understand how to promote girls' interest and participation in STEM, it is important to consider prior research findings. Throughout this literature review, students in K-12 settings will be referred to as girls and boys; those in undergraduate settings or beyond will be referred to as women and men. In the following sections, gender differences in STEM outcomes will be described to provide background about issues related to gender in STEM. Integrated STEM education and its potential impact for girls will then be explored. Finally, small group learning and gender differences in small group participation will be considered. Given the sparse literature in integrated STEM education, this literature review draws on research from science, mathematics, engineering, and technology education as available. Findings from these studies ground the current research and inform the research designs.

### **Gender Differences in STEM Outcomes**

#### **Representation in STEM Careers**

Although women and men receive undergraduate degrees at about the same rate, women account for only 30% of all STEM degree holders and have particularly low representation in engineering (Economics and Statistics Administration [ESA], 2017), holding just 12% of engineering jobs (Corbett & Hill, 2015). Women are also vastly underrepresented in physics, accounting for only about 20% of physics degrees (National Science Foundation [NSF], 2017). In examining the underrepresentation of women in STEM fields, a number of studies have investigated whether boys outperform girls in science and mathematics courses, largely determining that girls do not lack the ability to perform in these courses (e.g., Hazari, Tai, & Sadler, 2007; Hyde, Lindberg, Linn, Ellis,



& Williams, 2008; Hyde & Linn, 2006; Lindberg, Hyde, Petersen, & Linn, 2010). In fact, girls receive better grades than their male counterparts in high school mathematics and science courses (Shettle et al., 2007). Eighth-grade girls perform as well as, and sometimes better than, their male peers on science achievement tests, grades, and course enrollment (Catsambis, 1995). However, having high levels of achievement in science does not necessarily mean that girls will pursue further education or coursework focused on science (Calabrese Barton & Brickhouse, 2006); girls who are successful in mathematics and science courses are less likely than boys to choose a STEM career (Clewell & Campbell, 2002; Wang, Eccles, & Kenny, 2013). Thus, factors beyond grades and achievement contribute to girls' career paths.

Despite apparent gender equity in science and mathematics course performance as measured by course grades and standardized tests in K-12 education, women hold only 30% of STEM degrees and 24% of STEM jobs (ESA, 2017). In addition to worker shortages driving a need for more diverse individuals to be interested in STEM (President's Council of Advisors on Science and Technology [PCAST], 2010), STEM careers also tend to be higher paying; college-educated women in STEM careers earn 23% more than college-educated women in non-STEM careers (ESA, 2017). With ongoing wage gaps between men and women, it is important to note that the 23% salary premium for women in STEM jobs is greater than the 13% salary premium of men in STEM jobs versus others in non-STEM jobs, though a gap still exists between the earnings of women and men in STEM careers (ESA, 2017). Although a variety of factors, including stereotypes and biases, curriculum, and workplace environments contribute to the underrepresentation of women in STEM (Corbett & Hill, 2015), many researchers

(e.g., Archer et al., 2010; Eccles & Harold, 1992; Martin, Way, Bobis, & Anderson, 2015; Riegle-Crumb, Moore, & Ramos-Wada, 2011; Sadler, Sonnert, Hazari, & Tai, 2012; Wigfield et al., 2015; Xie & Shauman, 2003) point out low levels of STEM interest among girls as a particularly salient factor in influencing the career trajectories of young girls.

### **STEM Interest**

The importance of children's interests in shaping their career trajectories originated with Dewey's (1913/1979) assertion that play during early childhood is the beginning of interest development that eventually becomes intellectual interests of adults. Interest includes both a predisposition to engage with certain topics, as well as a psychological state marked by heightened attention and positive affect (Renninger & Hidi, 2016). This psychological component of interest serves as a positive feedback loop; children who show an initial interest in something and experience positive emotions as they engage with that topic are likely to develop positive associations and seek to further engage with it.

Children can develop an interest in science as early as the elementary grades, and STEM interest is most often sparked in the early childhood and elementary school years (Dabney, Chakraverty, & Tai, 2013; Maltese, Melki, & Wiebke, 2014; Maltese & Tai, 2010). In a survey of 7,970 individuals, Maltese and Cooper (2017) found that STEM interest was most often initiated prior to grade 6, and throughout the school years, STEM interest was fostered more through school experiences and coursework than out-of-school experiences. However, the influence of school experiences was greater for girls than for boys. Girls cited their teachers as having a strong influence on their STEM interest,

whereas boys attributed their STEM interest to their independent interests rather than school experiences. Positive school STEM experiences in the elementary grades are therefore critical for developing students' STEM interest (Mosatche, Matloff-Nieves, Kekelis, & Lawner, 2013; Shapiro & Sax, 2011), particularly for girls (Maltese & Cooper, 2017).

Although maintaining students' STEM interest is an important goal in itself, early interests are also closely linked to future career choices. A number of studies have found that personal interests have a large impact on career choice (e.g., Bandura, 1986; Fouad, Smith, & Zao, 2002; Lent, Brown, & Hackett, 1994), surpassing both future earning potential and parental influence (Hall, Dickerson, Batts, Kauffmann, & Bosse, 2011; Holmegaard, Ulriksen, & Madsen, 2014). These findings are true both generally and in relation to science or STEM; personal interest is a stronger predictor of enrollment in STEM courses and undergraduate science study than either prior enrollment or achievement (Maltese et al., 2014; Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006). Considering that career interests as early as eighth grade are predictive of future career choice (Lindahl, 2007; Tai et al., 2006), the importance of early efforts to foster STEM interest is clear.

Throughout elementary school, both girls and boys tend to have high levels of interest in science (Murphy & Beggs, 2005). However, as students transition from elementary to middle school, their interest in STEM tends to decrease (Capobianco, Yu, & French, 2015; Pell & Jarvis, 2001), especially among girls (e.g., Archer et al., 2010; Eccles & Harold, 1992; Riegle-Crumb et al., 2011; Sadler et al., 2012; Xie & Shauman, 2003). Girls' interest in science rapidly decreases between the ages of 10 and 14 (Archer

et al., 2010), and they tend to lose interest in science, particularly physical science, before they reach high school (Baker & Leary, 1995; Dawson, 2000; Jones, Howe, & Rua, 2000; Sullins, Hernandez, Fuller, & Tashiro, 1995; Weinburgh, 1995). Girls' interest in science and mathematics continues to decline in the middle and high school years (Martin et al., 2015; Wigfield et al., 2015), and by the end of high school, 39.7% of boys are interested in STEM careers, whereas only 12.7% of girls are interested in pursuing a STEM career (Sadler et al., 2012). Among high school graduates, fewer girls than boys report that they like mathematics or science or that mathematics or science was one of their favorite subjects (Cunningham, Hoyer, & Sparks, 2015). At the undergraduate level, girls are more likely than boys to drop engineering courses (Heyman, Martyna, & Bhatia, 2002), further exacerbating the gender gap in STEM courses.

### **Integrated STEM Education**

STEM disciplines are often taught as distinct subject areas in formal schooling, but modern careers in STEM fields frequently require a blending of content knowledge from different disciplines (Honey, Pearson, & Schweingruber, 2014). STEM integration seeks to merge the disciplines and is promoted as a means of increasing the number of students who are interested in and prepared to pursue STEM careers (Honey et al., 2014; Stohlmann, Moore, & Roehrig, 2012). For example, Guzey, Moore, Harwell, and Moreno (2016) found that students who were taught using an engineering design-based science curriculum showed more positive attitudes toward STEM careers following the unit of instruction. Teacher reports of student interest also show potential positive effects of STEM integration in terms of student confidence and interest in science and mathematics (Wang, Moore, Roehrig, & Park, 2011). As STEM integration becomes more common at

the elementary and middle school levels, it is important to consider key components of integrated STEM that are particularly supportive of young girls' interest in and continued study of STEM.

### **Conceptualizing STEM Integration**

Despite its increasing popularity in education, integrated STEM does not have a clear theoretical or practical definition. Educators use terms like integrated, interdisciplinary, and thematic interchangeably, when they in fact may actually be referring to different levels of integration (Czerniak, Weber, Sandmann, & Ahern, 1999; Honey et al., 2014). A variety of approaches to STEM education have been suggested, and researchers such as Bybee (2013) and Fogarty (1991) have outlined different models of integrated STEM, which range from STEM disciplines as completely separate and unconnected to full integration of all four STEM disciplines.

The most common classroom approaches to STEM integration generally take one of three forms: content integration, supporting content integration, or context integration (Bryan, Moore, Johnson, & Roehrig, 2016). In content integration, a single unit or lesson includes learning objectives from multiple STEM disciplines; this form of integration is the most fully integrated. In supporting content integration, the primary learning objectives from one discipline are supported by meaningful work in another discipline. Context integration involves contextualizing learning objectives from one discipline in a context from another discipline, often through a story.

Despite the lack of consensus around conceptualizing or defining integrated STEM (e.g., Breiner, Harkness, Johnson, & Koehler, 2012; Brown, Brown, Reardon, & Merrill, 2011; Bybee, 2013; English, 2016; Herschbach, 2011; Johnson, 2012; Koehler,

Binns, & Bloom, 2016; Ring, Dare, Crotty, & Roehrig, 2017), there is an emerging sense of agreement around several features that are indicative of quality integrated STEM instruction (see Table 2.1).

*Table 2.1. Key Features of Integrated STEM and Supporting Research*

Feature	Supporting Research
Learning situated within a real-world context	Breiner et al., 2012 Brown et al., 2011 Kelley & Knowles, 2016 Kennedy & Odell, 2014 Labov, Reid, & Yamamoto, 2010 Moore, Glancy, et al., 2014 Moore, Stohlmann, et al., 2014 Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016 Sanders, 2009
Student-centered pedagogies, including inquiry and hands-on learning	Breiner et al., 2012 Kelley & Knowles, 2016 Kennedy & Odell, 2014 Labov et al., 2010 Moore, Stohlmann, et al., 2014 Rinke et al., 2016 Sanders, 2009
Teamwork, communication, critical thinking, and other 21st century competencies	Brown et al., 2011 Honey et al., 2014 Kennedy & Odell, 2014 Moore, Glancy, et al., 2014 Moore, Stohlmann, et al., 2014 Rinke et al., 2016
Connections between STEM disciplines	Brown et al., 2011 English, 2016 Herschbach, 2011 Honey et al., 2014 Kelley & Knowles, 2016 Kennedy & Odell, 2014 Labov et al., 2010 Moore, Glancy, et al., 2014 Rinke et al., 2016 Sanders, 2009

First, integrated STEM instruction should be situated within a real-world context to engage students in meaningful learning (Breiner et al., 2012; Brown et al., 2011; Kelley & Knowles, 2016; Kennedy & Odell, 2014; Labov et al., 2010; Moore, Glancy, et al., 2014; Moore, Stohlmann, et al., 2014; Rinke et al., 2016; Sanders, 2009). Second, quality STEM instruction should utilize student-centered pedagogies, including hands-on and inquiry-based learning (Breiner et al., 2012; Kelley & Knowles, 2016; Kennedy & Odell, 2014; Labov et al., 2010; Moore, Stohlmann, et al., 2014; Rinke et al., 2016; Sanders, 2009). Third, teamwork, communication, critical thinking, and other 21st century competencies should be emphasized throughout integrated STEM instruction (Brown et al., 2011; Honey et al., 2014; Kennedy & Odell, 2014; Moore, Glancy, et al., 2014; Moore, Stohlmann, et al., 2014; Rinke et al., 2016). Finally, connections between STEM disciplines should be made explicit to students (Brown et al., 2011; English, 2016; Herschbach, 2011; Honey et al., 2014; Kelley & Knowles, 2016; Kennedy & Odell, 2014; Labov et al., 2010; Moore, Glancy, et al., 2014; Rinke et al., 2016; Sanders, 2009).

### **Integrated STEM and Girls**

Although beneficial for all students, integrated STEM may be particularly effective at fostering girls' STEM interest and engagement. For example, although girls are less drawn to physics than their male peers, the integration of physical sciences and engineering promotes interest among a greater range of individuals, including girls (Hazari, Sadler, & Sonnert, 2013). Instruction that contextualizes learning with real-world connections is important to all students, but girls report experiencing these connections less frequently than boys. For example, in a study of 3,829 students across the United States, Hazari, Sonnert, Sadler, and Shanahan (2010) found that girls were

significantly less likely than boys to indicate that their high school physics class focused on current real-world topics. Within undergraduate science courses, science professors often tend to focus on highly detailed scientific facts, without addressing how the details fit together or why that knowledge is useful (Johnson, 2007). This decontextualized nature of traditional science lectures negatively impacts girls' interest in science and identities as scientists, and young girls often do not see the connections between their science activities at school and the real-world work of scientists (Archer et al., 2010). Integrated STEM provides a means for this contextualization of learning and can thus support girls in STEM.

Researchers have identified instructional practices that are associated with positive outcomes for girls, including contextualizing learning in personally-relevant contexts (e.g. Thompson & Windschitl, 2005), involving students in hands-on learning (e.g. Chatman, Nielsen, Strauss, & Tanner, 2008), and providing opportunities for collaboration (e.g. Scantlebury & Baker, 2007). In a review of the gender literature, Brotman and Moore (2008) identified key features of gender-inclusive curricula and pedagogy across studies, including: drawing upon students' interests and experiences; using real-life contexts; emphasizing the societal relevance of science; facilitating active participation; and encouraging collaboration and communication. Notably, these practices align directly with the key features of quality integrated STEM instruction that are shown in Table 2.1. This alignment suggests that STEM integration may provide a meaningful context and effective learning opportunities to support girls' interest in STEM.



## **Small Group Learning**

Small group learning is common in integrated STEM and described as especially important for girls, yet little research has been done in this area. Small group learning activities became common in the late 1990s, promoted as a learner-centered teaching strategy (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010). As much as 46% of science teaching takes place within the context of small group work (Baines, Blatchford, & Kutnick, 2003), making it the second most common type of participant structure in science classrooms after direct instruction (Smith, Banilower, McMahon, & Weiss, 2002). Activities completed in small groups allow students to collaborate on tasks that require multiple people, while also addressing materials or equipment shortages by requiring students to share materials (Scanlon, 2000). With both practical and pedagogical reasons, small group work predominates within science and STEM classrooms.

Small group learning also aligns with integrated STEM instruction and current educational reform efforts, which emphasize the importance of teamwork and communication. Educational reforms, including the Common Core State Standards and Next Generation Science Standards (NGSS), have emphasized teamwork, argumentation, and complex problem solving (e.g., National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010; National Research Council [NRC], 2012; NGSS Lead States, 2013). The National Academy of Engineering (NAE; 2004) included teamwork as part of their vision statement, and teamwork is a key component of quality integrated STEM instruction (Brown et al., 2011; Kennedy & Odell, 2014; Moore, Stohlmann, et al., 2014; Rinke et al., 2016). Small group learning is

particularly effective when the learning task is ill-structured and does not have a clear procedure to reaching the “correct answer” (Cohen, 1994), which is the case in engineering design tasks. With small group work ubiquitous with STEM, the affordances and limitations of small group activities must be considered.

### **Benefits of Small Group Learning**

A variety of studies, including two meta-analyses (Lou, Abrami, Spence, Poulsen, Chambers, & d’Apollonia, 1996; Springer, Stanne, & Donovan, 1999) have found that small group learning contributes to positive outcomes in science and mathematics achievement, motivation, persistence, attitudes, engagement, and problem-solving (Acar & Tarhan, 2008; Baines, Blatchford, & Chowne, 2007; Baines, Rubie-Davies, & Blatchford, 2009; Cohen, 1994; Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018; Fung, Hung, & Lui, 2018; Lou et al., 1996; Meece & Jones, 1996; Qin, Johnson, & Johnson, 1995; Springer et al., 1999). These benefits likely arise from the combination of hands-on activities and discussions that take place in small groups. In order to develop procedural skills, students need to engage in the physical activity of the small group (Howe, 2014), but the conversations that occur within the small group setting are also important. Small group structures allow students to “talk science” (Lemke, 1990) and practice evidence-based argumentation (Osborne & Collins, 2001). Small group discussion appears to be particularly effective in promoting conceptual understanding when students propose and justify ideas to each other, explaining their reasoning in the face of potential disagreement (Howe et al., 2007). With an increasing focus on developing students’ ability to engage in science and engineering practices, as well as

their conceptual understanding (NRC, 2012), small group activities may provide an effective means for accomplishing both goals.

Small group instruction is proposed as an effective strategy for engaging girls in STEM because research indicates that girls are more cooperative and less competitive than boys (Belenky, Clinchy, Goldberger, & Tarule, 1997; Brotman & Moore, 2008; Ferguson & Fraser, 1998; Jones, Brader-Araje, et al., 2000; Zohar & Sela, 2003). A variety of researchers have found that small group learning environments have a number of benefits for girls (Brotman & Moore, 2008; Burkam, Lee, & Smerdon, 1997; Cavallo & Laubach, 2001; Fredricks et al., 2018; Heard, Divall, & Johnson, 2000; Lee & Burkam, 1996; Wang, 2012; Zohar, 2006). For example, Rivard and Straw (2000) examined girls' retention of simple scientific knowledge and found that opportunities to discuss scientific problems with peers resulted in greater retention than just writing responses to problems. Hands-on activities that emphasize applications of knowledge in real-world contexts can meet girls' desire to know how their learning can be applied (Baker, 2013; Baker & Leary, 1995; Geist & King, 2008; Kim, 2016; Lee & Burkam, 1996). With a variety of benefits backed by numerous studies, small group learning in STEM education may help girls become more interested in future STEM coursework and careers.

### **Problems with Small Group Learning**

Despite a number of beneficial outcomes associated with small group learning strategies, well-documented problems with small group learning also exist. The social dynamics and organization of small groups can interfere with learning in certain cases (Hammar Chiriack, 2014). In addition, there are issues related to knowledge construction

and equitable participation due to power dynamics. These issues will be further explored in the following sections.

**Cooperative learning versus collaborative learning.** Cooperative learning strategies utilize predetermined roles and responsibilities for individual students within a small group, and although these encourage participation of all students, they do not necessarily require co-construction of knowledge. In contrast, collaborative strategies require students to work together to solve complex problems and therefore encourage participation as well as co-construction of knowledge (Lumpe & Staber, 1995). Whereas cooperative learning strategies focus on group organization, collaborative learning strategies emphasize the cognitive aspects of working together (Crook, 1994).

It is often assumed that placing students in small groups will result in their learning of collaborative skills and teamwork (Singer, Hilton, & Schweingruber, 2006), but there is little research that supports this assumption (Sampson & Clark, 2009). Hogan (1999) examined students' sociocognitive roles in small group science activities and discovered that students may adopt roles that contribute positively to the group functioning (e.g., promoter of reflection, contributor of content knowledge, creative model builder, and mediator of group interactions and ideas) or contribute little or negatively to the group (e.g., promoter of acrimony, promoter of distraction, promoter of simple task completion or unreflective acceptance of ideas, and reticent participants in collaborative knowledge building). Having a greater proportion of group members in counterproductive roles was more likely to result in a group that only engages in surface reasoning rather than deep, collaborative reasoning. In contrast, having a greater number of group members who contributed positively to the group resulted in a group that was

more likely to engage in deep reasoning. Regardless of whether students formally assign group roles to the individuals in the small group, such roles often emerge. Group leaders, in particular, play an important role in shaping the participation of other group members. Leaders can be inclusive, persuasive, or alienating, and the leadership style can significantly impact group functioning (Richmond & Striley, 1996).

In a study of middle school students, Woods-McConney, Wosnitza, and Sturrock (2016) found that explicit instruction in how to engage in cooperative lessons is necessary to help students experience the benefits of cooperative, inquiry-based science. Without this instruction, the activities that occur within small groups may not support the goals of engaging students in meaningful science and engineering practices as they discuss disciplinary concepts. Simply placing students in small groups does not ensure that the activity happening within those groups promotes either knowledge construction or equitable participation.

**Knowledge construction.** Knowing that meaningful conceptual understanding can be developed through small group discussion (e.g., Howe et al., 2007), it is important to consider how often this type of knowledge-building discussion actually occurs. Elementary students working in small groups spend more time negotiating action and carrying out lesson requirements than negotiating meaning (Bianchini, 1997; Jiménez-Aleixandre, Rodriguez, & Duschl, 2000; Shepardson, 1996). They often focus on the tangible products they are supposed to produce, such as worksheets, rather than emphasizing conceptual development (Oliveira & Sadler, 2008). Among students in sixth and seventh grade, co-construction of meaning accounts for less than 5% of lesson time (Woods-McConney et al., 2016). Ultimately, very few small groups of students reach

observational and theoretical descriptions that adequately capture a scientific phenomenon, and the teacher must carefully attend to students' language use in order to move them toward explanations that are accepted by the scientific community (Roth, Lucas, & McRobbie, 2001). Thus, although small group learning offers a setting where conceptual understanding *can* be developed, this is often not the reality of what occurs within small groups.

**Equitable participation.** Despite a lack of time spent co-constructing meaning, students do negotiate actions and the use of materials in their small groups; these negotiations mediate their science learning but are often displays of power and authority between students (Shepardson, 1996). Perceived academic ability and social status in school are major factors in determining which students adopt the various group roles (Bianchini, 1997; Richmond & Striley, 1996). Social loafing, or a tendency to reduce individual effort when working in collaboration with others, can reduce engagement in group tasks (Karau & Williams, 1995), particularly among students who are perceived to have lower ability. For example, within mixed-ability, mixed-gender groups, those students who have high status or are already skilled in constructing scientific arguments participate more, thus getting more practice and feedback than their less skilled peers (Oliveira & Sadler, 2008; Webb, 1982). Students have differential access to academic language, which often results in authoritarian interactions among students (Wertsch, 1991), with those students who have greater access to academic language dominating the group. Students who talk more in small groups tend to learn more as well (Bianchini, 1997; Cohen, 1984). While it is unclear whether talking actually contributes to increased learning or those who have learned more are more likely to talk, having equitable

opportunities to talk within the small group is necessary in order to facilitate learning for all students, particularly girls.

### **Gender Differences in Small Group Interactions.**

Because both the procedural and verbal components of small group interactions support students in preparing for future STEM coursework and careers, it is critical to examine participation patterns of girls and boys within small groups. Girls and boys working in mixed gender small groups often display different interaction patterns (Tolmie & Howe, 1993), with girls often participating to a lesser degree in the small group activities (Hansen, Walker, & Flom, 1995). Participation of girls often focuses on passive assistance and note-taking (Jovanovic & King, 1998; Mewborn, 1999) or building positive relationships and following directions (Jones, Brader-Araje, et al., 2000). In contrast, boys are more likely to actively lead the group and manipulate the materials (Jovanovic & King, 1998; Mewborn, 1999), often dominating the small group activities and handling of lab equipment (Kahle, Parker, Rennie, & Riley, 1993; Patrick & Yoon, 2004). In mixed-gender groups of fourth- and fifth-graders, students of both genders view boys as team leaders with better ideas than girls (Lockheed, Harris, & Hemceff, 1983), and in practice, boys are also more likely than girls to express competitiveness with other group members (Jones, Brader-Araje, et al., 2000).

In addition to boys' tendency to control the physical materials in their small groups, Schnittka and Schnittka (2016) found that boys also dominated speech in terms of both frequency and volume. This pattern continues into college, when men are more likely to interrupt the women in their small group than they are to interrupt other men (Smith-Lovin & Brody, 1989). In a study of undergraduate engineering design teams,

Tonso (2006) found that the men's identities shaped the roles of the women within the group, leaving little autonomy to the women in determining their own level and modes of participation. Wolfe and Powell (2009) also investigated undergraduates engaged in engineering design and found that the engineering culture promoted aggressive self-promotion over female-typical interactional styles such as self-criticism, regardless of the gender of the person using these interactional styles. These interactional styles can further perpetuate gender stereotypes related to engineering.

These patterns of interaction clearly position boys as group leaders and girls as assistants. Ridley and Novak (1983) suggested that girls are socialized into rote learning modes in science because of their desire to please the teacher; boys, in contrast, are more willing to take risks. Support for this assertion is seen in both science classrooms (e.g., Novak & Musonda, 1991) and mathematics classrooms (e.g., Fennema & Peterson, 1985). These patterns of participation are problematic because when girls' involvement centers on things they already know how to do, like take notes and follow procedures, they are unlikely to be inspired to participate in science more in the future (Calabrese Barton & Brickhouse, 2006).

Despite issues related to equitable participation for girls and boys in small groups, it is unclear whether girls prefer this type of learning. While some studies suggest that girls prefer working in small groups (e.g., Boaler, 1997; Dare & Roehrig, 2016; Kahle & Meece, 1994), others indicate that girls prefer more structured activities (e.g., Dweck, 1986). Girls tend to prefer activities that allow for social interaction and collaboration (Dare & Roehrig, 2016; Labudde, Herzog, Newenschwander, Violi, & Gerber, 2000), but women in engineering disciplines frequently report negative experiences within small



groups (Tonso, 2006), likely due in part to the male-majority gender composition common in engineering courses and fields. In a series of focus groups with girls in sixth grade, Dare (2015) found that girls expressed frustrations with collaborative group work in their science classroom. They discussed other students copying their work, refusing to participate, being distracted, and controlling the entire activity without asking for others' opinions. In particular, girls had negative views of working with their male peers on science activities, citing examples of off-task behavior as a primary barrier to effective mixed-gender group work (Dare, 2015). In interviews with girls in fourth and fifth grade, Wieselmann, Roehrig, & Kim (accepted pending revisions) found that girls described their male peers as off-task and easily distracted and contrasted male participation to the focused participation they saw as more typical of girls. It is thus likely that the quality of small group interactions depends upon the gender composition of the small group.

### **Overview of the Studies**

A wealth of research suggests that small group learning has the potential to support girls' interest and engagement in STEM. However, with most research on small group interactions in engineering or integrated STEM at the undergraduate level (e.g., Tonso, 2006; Wolfe & Powell, 2009) or in after-school contexts (e.g., Schnittka & Schnittka, 2016), it is unclear whether small group activities in integrated STEM within formal classroom settings support the STEM interest and participation of upper elementary and middle school girls. Chapters 3-5 will explore girls' participation in small group, integrated STEM activities. Each chapter is a distinct study with a rationale and brief literature review unique to that study. Chapter 3 presents a single embedded case study that investigates the participation patterns of four students in small group,

integrated STEM activities. Chapter 4 describes a multiple embedded case study that examines small group gender composition in relation to student participation in small group STEM activities. Chapter 5 focuses specifically on the engineering practices displayed by girls and boys through a multiple embedded case study. The three studies featured in this dissertation seek to address the gap in the literature to explore how elementary and middle school girls participate in small group, integrated STEM activities in their formal school classrooms.

### **Chapter 3 - "I just do what the boys tell me": Exploring Small Group Student Interactions in an Integrated STEM Unit**

Recent educational reforms in the U.S. promote integrated science, technology, engineering, and mathematics (STEM) as a means of remaining globally competitive and advancing the knowledge and thinking skills of all students (National Research Council [NRC], 2012). Despite efforts to improve access and quality of STEM education, women continue to be underrepresented in STEM fields (National Science Foundation [NSF], 2017). STEM interest is often sparked in the early childhood or elementary school years (Dabney, Chakraverty, & Tai, 2013; Maltese, Melki, & Wiebke, 2014), and previous research indicates that integrated STEM instruction may support increased STEM interest among all students (e.g., Guzey, Moore, Harwell, & Moreno, 2016; Honey, Pearson, & Schweingruber, 2014), but particularly among girls (e.g., Hazari, Sadler, & Sonnert, 2013). As integrated STEM instruction becomes more common in the elementary and middle school grades, it is important to understand whether this integrated approach to teaching supports the STEM participation of young girls.

Small group activities play a key role in integrated STEM education and account for almost half of science teaching (Baines, Blatchford, & Kutnick, 2003), but boys and girls engage differently in these science group activities (Jovanovic & King, 1998). Investigations of small group interactions in STEM fields tend to focus on engineering at the undergraduate level (e.g., Tonso, 2006; Wolfe & Powell, 2009), and studies of small group work in integrated STEM are lacking at the elementary and middle school levels (Baillie & Douglas, 2014; Capobianco, French, & Diefes-Dux, 2012). With the goal of increasing representation of women in STEM fields, it is imperative that young girls have positive and gender equitable STEM experiences. However, because much of the

research on gender differences in elementary students' participation in small group activities occurred in the 1990s and early 2000s, little is known about whether gender differences in student participation are present across the variety of small group activities that are a part of integrated STEM lessons found in today's classrooms. The present study aims to build on the existing body of literature to better understand how gender relates to student participation in small group STEM activities. The nature of gender differences in small group participation is explored to identify strategies for supporting girls' participation as well as areas for future research. This study addresses the research questions:

- 1) *What differences, if any, are seen in the ways fifth-grade girls and boys participate in small group activities during an integrated STEM unit?*
- 2) *What differences, if any, are seen in fifth-graders' participation in science-focused and engineering-focused small group activities during an integrated STEM unit?*
- 3) *How, if at all, do students apply their understanding of science as they work to complete an engineering design challenge in small groups?*

## **Literature Review**

Careers often require combining content from multiple content areas in order to solve new problems (Honey et al., 2014), and integrated STEM instruction moves beyond teaching facts and theories to include the practical application of knowledge in real-world contexts. These practical applications blend content and engage students in personally-relevant topics. This study is grounded in the framework for integrated STEM instruction (Moore, Stohlmann, et al., 2014), which includes six key tenets: 1) a motivating and

engaging context; 2) an engineering design challenge; 3) opportunity to learn from failure through redesign; 4) inclusion of mathematics and/or science content; 5) student-centered pedagogies; and 6) an emphasis on teamwork and communication. These six tenets were used to define integrated STEM instruction for the purpose of this study. In addition to these primary tenets of integrated STEM, the Framework for Quality K-12 Engineering Education (Moore, Glancy, et al., 2014) was used to define the key indicators of a quality engineering design challenge (see Table 3.1).

*Table 3.1. Framework for Quality K-12 Engineering Education*

Key Indicator	Description
Process of Design (POD)	Engineering design process
Problem and background (POD-PB)	Identifying an engineering problem in need of a solution – includes researching the problem, participating in learning activities to gain background knowledge, and identifying constraints
Plan and implementation (POD-PI)	Developing and implementing a plan for a design solution to an engineering problem – includes brainstorming, developing multiple solutions, and evaluating pros and cons of multiple solutions
Test and evaluate (POD-TE)	Generating a testable hypothesis/question and designing experiments to evaluate them – includes data collection and analysis for use in redesign
Apply science, engineering, and mathematics (SEM)	Applying mathematics or science in the context of solving engineering problems
Engineering thinking (EThink)	Applying independent, reflective, and metacognitive thinking to improve solutions and learn from failure – includes systems thinking, creativity, optimism, perseverance, and innovation
Conceptions of engineers and engineering (CEE)	Developing an understanding of what engineers do – includes work driven by client needs, design under constraints, and learning about various engineering disciplines
Engineering tools (Etool)	Developing proficiency using techniques, skills, processes, and tools used in engineering – <i>excludes</i> the engineering design process (POD)
Issues, solutions, and impacts (ISI)	Understanding the impact of solutions in a global, economic, environmental, and societal context

Ethics	Understanding ethical considerations inherent in engineering – includes responsibility to natural and client resources; effects of a design on public health and safety; governmental regulations and professional standards; and integrity
Teamwork	Developing teamwork and interpersonal skills – includes participating in collaborative groups in a variety of roles
Communication related to engineering (Comm-Engr)	Developing technical writing skills and ability to communicate technical ideas in common language – includes symbolic and pictorial representations

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*A Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) emphasize the importance of scientific and engineering practices to help students engage authentically in the activities of scientists and engineers. However, these documents are silent on the epistemological differences between science and engineering that need to be navigated by teachers and students within an integrated STEM learning environment. Science and engineering are distinct disciplines with different goals, processes, and products (Sneider & Rosen, 2009). While acknowledging that science and engineering are both iterative and systematic, *A Framework for K-12 Science Education* oversimplifies the distinctions between science and engineering in terms of discipline-specific goals (NRC, 2012). The goal of science is to develop a single theory to explain natural phenomena, which may not have a clear practical application. In contrast, the goal of engineering is to best address a human want or need by considering multiple viable solutions and how they fit with design criteria and constraints; this means there is not a single “correct” engineering design.

Despite these differences, the *NGSS Science and Engineering Practices* (SEPs) distinguish between science and engineering in only two of the eight practices: asking questions for science and defining problems for engineering (practice 1); and constructing explanations for science and designing solutions for engineering (practice 6;

NGSS Lead States, 2013). Cunningham and Carlsen (2014) assert that the language of the *NGSS* SEPs are science-oriented, with critical engineering language absent. Students also may struggle to distinguish between science and engineering. For example, sixth-graders often confuse science and engineering, and they typically believe that engineers are individuals, often male, who make or build products (Karatas, Micklos, & Bodner, 2011). As integrated STEM instruction becomes more common, further work is needed to support student engagement in both science and engineering practices.

### **Small Group Instruction**

Recent educational reforms have placed an emphasis on group work, argumentation, and complex problem solving (e.g., NRC, 2012), but even before this renewed focus on group activities, as much as 46% of science teaching took place within small group contexts (Baines et al., 2003), suggesting that a significant portion of students' science learning occurs in small groups. Teamwork and small group activities are key components of integrated STEM instruction (e.g., Brown, Brown, Reardon, & Merrill, 2011; Kennedy & Odell, 2014; Moore, Glancy et al., 2014; Moore, Stohlmann, et al., 2014; Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016), so knowledge of student experiences in small group settings is critical to understanding how integrated STEM activities support student participation in STEM education. Further, as science instruction continues to shift to integrated STEM approaches, there is a particular need to understand how to support girls in small group STEM activities.

Previous research, including two meta-analyses, suggests that small group learning is associated with positive outcomes related to STEM achievement, motivation, persistence, attitudes, engagement, and problem-solving (Baines, Blatchford, & Chowne,

2007; Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018; Fung, Hung, & Liu, 2018; Lou, Abrami, Spence, Poulsen, Chambers, & D'Apollonia, 1996; Qin, Johnson, & Johnson, 1995; Springer, Stanne, & Donovan, 1999). Some researchers have suggested that learning through collaboration is especially beneficial for girls (e.g., Brotman & Moore, 2008; Fredricks et al., 2018; Rivard & Straw, 2000; Wang, 2012; Zohar, 2006). For example, Rivard and Straw (2000) found that girls had better retention of basic scientific knowledge when they had opportunities to discuss scientific problems with peers. Combined with potential benefits of integrated STEM instruction for girls (e.g., Hazari et al., 2013), small group settings may be valuable in promoting greater STEM involvement among girls.

Despite promise, small group contexts for learning poses several challenges. First, simply working in groups does not ensure that students will learn collaborative skills and teamwork (Sampson & Clark, 2009; Singer, Hilton, & Schweingruber, 2006). Without explicit instruction in how to engage in teamwork, the activities that occur within small groups may not support the goals of engaging students in meaningful learning of science and engineering cultures (Woods-McConney, Wosnitza, & Sturrock, 2016). Second, with science talk recognized as a critical feature of science learning (Lemke, 1990), it is important to note that small group science activities do not necessarily result in increased science talk or understanding (e.g., Shepardson, 1996; Woods-McConney et al., 2016). Much small group student talk focuses on carrying out the lesson requirements, rather than discussing the science concepts of interest (Jiménez-Aleixandre, Rodríguez, & Duschl, 2000). Although small group settings can offer a context for meaningful learning of science concepts, this is not always the case. Finally, student participation within small



groups may be inequitable, with students taking on different roles and responsibilities. Academic ability and social status in school are major factors in determining which students adopt various group roles (Bianchini, 1997), and group leaders play a particularly important role in shaping the participation of other group members (Richmond & Striley, 1996). Given the goal of increased engagement of all students in STEM activities, the process of group role negotiation may be problematic in that it often perpetuates differential rates of participation in small group activities.

These concerns about equitable participation in small group activities extend to the experiences of girls and boys working within mixed-gender small groups. Girls and boys may display different interaction patterns in small groups (Tolmie & Howe, 1993). For example, in a study of student behaviors in science classrooms, Jovanovic and King (1998) found that boys were significantly more likely to engage in active leadership, like directing and explaining to others, and manipulate materials; in contrast; girls' participation often focuses on passive assistance and note-taking (Jovanovic & King, 1998; Mewborn, 1999) or building relationships and following directions (Jones, Brader-Araje, et al., 2000). These patterns result in girls participating to a lesser degree in small group activities (e.g., Hansen, Walker, & Flom, 1995), while boys actively lead the group (Jovanovic & King, 1998; Mewborn, 1999), control the activities and materials (Kahle, Parker, Rennie, & Riley, 1993; Patrick & Yoon, 2004), and dominate conversation (Schnittka & Schnittka, 2016; Smith-Lovin & Brody, 1989). Similar findings of male domination of conversation and activity are also seen in undergraduate engineering group activities. For example, Tonso (2006) found that men's identities shaped the role of women within their group, which dictated how the women would participate. Wolfe and

Powell (2009) found that male-typical patterns of aggressive self-promotion were promoted within the engineering culture.

Despite issues related to equitable participation for girls and boys in small groups, it is unclear whether girls prefer this type of learning. While some studies suggest that girls prefer working in small groups (e.g., Boaler, 1997; Dare & Roehrig, 2016; Kahle & Meece, 1994), others indicate that girls prefer more structured activities (e.g., Dweck, 1986). Girls tend to prefer activities that allow for social interaction and collaboration (Dare & Roehrig, 2016; Labudde, Herzog, Newenschwander, Violi, & Gerber, 2000), but women in engineering disciplines frequently report negative experiences within small groups (Tonso, 2006). In a series of focus groups with girls in sixth grade, Dare (2015) found that girls expressed frustrations with collaborative group work in their science classroom. They discussed other students copying their work, refusing to participate, being distracted, and controlling the entire activity without asking for others' opinions. In particular, girls had negative views of working with their male peers on science activities, citing examples of off-task behavior as a primary barrier to effective mixed-gender group work (Dare, 2015). In interviews with girls in fourth and fifth grade, Wieselmann, Roehrig, and Kim (accepted) found that girls described their male peers as off-task and easily distracted and contrasted male behaviors to the focused behavior they saw as more typical of girls. With the goal of increasing representation of women in STEM, it is important to investigate girls' participation in small group STEM activities to determine whether they support equitable participation patterns.

## **Theoretical Framework**

Given the key role of small group activities in integrated STEM instruction, this

study is grounded in sociocultural theories, with the social process of collaboration in the classroom cultural context playing a central role in student learning. Knowledge-building practices are influenced by social interactions (Lave & Wenger, 1991; Rogoff, 1990; Vygotsky, 1978) and have social consequences (Lemke, 2001). Social interactions can guide, support, direct, and challenge students' learning (Rogoff, 1990). As students learn, new information is incorporated into their existing ideas and ways of thinking (Leach & Scott, 2003). This is not a simple transfer of information, but rather an internalization that requires reorganization and reconstruction of knowledge.

Learning is a product of the interaction between the person, the activity, and the setting in which it occurs (Lave, 1988), so each individual within a small group may construct different meanings. Although students must learn within the school and STEM-specific cultures, they also bring their own cultural perspectives as they construct understanding (O'Loughlin, 1992). Students' perspectives include their home cultures, language, and backgrounds as well as their experiences of being female or male, which may contribute to different patterns of participation within small group learning. For example, girls tend to be socialized into rote learning models because of their desire to please the teacher, whereas boys are more willing to take risks (Fennema & Peterson, 1985; Novak & Musonda, 1991; Özer, Demir, & Ferrari, 2009; Ridley & Novak, 1983). Participation occurs on at least three levels: personal, interpersonal, and cultural/institutional (Rogoff, 2003). Thus, applying sociocultural theories to studies of small group interactions can help explain how students' individual perspectives and experiences, interactions among students, and socialization within the cultural institution of formal schooling may contribute to differences between boys' and girls' participation

in small groups.

Over the course of their schooling, students learn how to participate in formal school structures. Specific practices emphasized in the cultural institution of schooling can be connected to specific cognitive skills students develop (Rogoff, 1990). For example, students in Western schools often develop the skill of memorizing disconnected pieces of information. A number of rules and norms govern student behavior within the formal school culture (Mercer & Howe, 2012; Watson & Winbourne, 2008), and individuals must understand the rules for participation in a given setting in order to engage in practices that are relevant to that context (Calabrese Barton, Tan, & Rivet, 2008). Within the school culture, these norms include responding to teachers' questions, completing tasks and activities, and providing correct responses. A distinct set of norms guides student participation within small groups. One of these norms is sharing only those views or ideas that are known to be correct (Mercer & Howe, 2012).

Success in school depends on students learning the types of discourse and representations that are useful in the school culture (Lemke, 2001). Science and engineering, like other disciplines, have distinct social languages, or modes of discourse specific to those parts of society (Bakhtin, 1981). Thus, learning science is a process of enculturation (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Watson, Swain, & McRobbie, 2004) that depends on the acquisition of acceptable methods of classroom discourse (O'Loughlin, 1992). Science teachers should help their students use the cultural tools and conventions common to the scientific community (Driver et al., 1994), but integrated STEM activities require multiple sets of disciplinary cultural tools and conventions. For example, the emphasis on failure and iteration in engineering is distinct

from students' typical classroom experience. Teamwork is a key component of engineering (National Academy of Engineering, 2004), and hands-on experiences acculturate students into the engineering professional community (Brown & Campione, 1994). In efforts to help students participate in the engineering culture, small group, hands-on activities must be present in integrated STEM learning.

Sociocultural theories posit that the practices, values, and beliefs of science education depend on the time and location in which they occur (Lemke, 2001). With a dearth of research on small group learning in elementary science since the early 2000s, more current research must reflect current practices, including integrated STEM approaches within science classrooms. With their individual background experiences and perspectives, girls and boys can be expected to interact differently within small group STEM settings; however, little is known about how these interactions occur and whether they differ between science and engineering in the same classroom. In this study, sociocultural theories are used to understand students' small group interactions within the cultural context of formal schooling, specifically within a science classroom.

## **Methods**

### **Research Design**

A single embedded case study was utilized in this work to explore the phenomenon of students' experiences in small group activities during an integrated STEM unit. This method was selected because of the desire for in-depth exploration of a social phenomenon and how it works (Yin, 2014). In this study, a group of students working together represents the case, and the unit of analysis was each individual student. With the goal of understanding how participation patterns shifted between science and

engineering lessons, it was necessary to follow the group of students for the duration of the curricular unit.

Individual, student-level analyses were conducted first to understand each student's participation in an integrated STEM unit. Following the student-level analysis, a case-level analysis was used to compare the participation patterns of girls and boys as well as participation patterns in science versus engineering lessons in the integrated STEM unit. The research design is descriptive in nature and is appropriate to answering the research questions in an environment in which a contemporary phenomenon is studied with limited control over the relevant performance enactments (Yin, 2014).

### **Context**

This study was situated in the third year of a five-year, NSF-funded research project that provided ongoing professional development and coaching for in-service K-12 science teachers in the Midwestern United States. The project focused on helping science teachers move toward integrated STEM instruction based on Moore, Stohlmann, and colleagues' (2014) framework. Participating teachers attended a three-week professional development (PD) summer institute focused on exploring approaches to teaching engineering and data analysis, integrating engineering in science, and understanding how to create integrated STEM curricula. The PD also included discussions of girl-friendly teaching strategies and how to keep girls engaged in learning STEM. Teams of teachers wrote integrated STEM units during the summer institute, piloted their units with summer camp students, revised the units based on the pilot, and then implemented the units with their students during the school year.

Although the teachers did not specifically focus on creating a gender-inclusive

unit, the framework for integrated STEM instruction (Moore, Stohlmann, et al., 2014) that guided curriculum development is highly compatible with girl-friendly instruction (Dare & Roehrig, 2016). For example, integrated approaches to STEM utilize real-world, motivating contexts, student-centered activities, and collaborative learning, all of which are known to positively impact girls' participation in and attitudes toward science. In a review of the gender literature, Brotman and Moore (2008) identified key features of gender-inclusive curricula and pedagogy across studies, including: drawing upon students' interests and experiences; using real-life contexts; emphasizing the societal relevance of science; facilitating active participation; and encouraging collaboration and communication. Notably, these practices align directly with the key features of quality integrated STEM instruction. This alignment suggests that STEM integration may provide a meaningful context and effective learning opportunities to support girls' interest in STEM. In addition, the teachers kept their particular students' needs in mind as they developed the unit, discussing how the unit would appeal to and support students from diverse backgrounds.

The present work focused on students experiencing a curricular unit, which was selected for this study via purposive, criterion-based sampling (Miles, Huberman, & Saldaña, 2013) due to its inclusion of all six tenets of integrated STEM instruction (Moore, Stohlmann, et al., 2014; Ring-Whalen, Dare, Roehrig, Titu, & Crotty, 2018). The unit was written during the third year of the project by a team of three teachers, including the students' science teacher. Their teacher had four years of teaching experience and had been involved in the NSF project for three years at the time of data collection. Because of her involvement in the project, the students' science teacher had already piloted the unit

prior to implementing it with her students. In addition to their teacher, fifth-grade student participants also interacted with graduate students who collected data during curriculum implementation. These graduate students were licensed teachers and recognized by the students as teacher-figures, so they are referred to as teachers throughout the following sections.

### **Participants**

Participants in this study were four fifth-graders, aged 10-11 years, at a diverse urban school serving students in grades 5-8 in the Midwestern U.S. Their science class had 29 students (16 girls and 13 boys) who were assigned to teacher-selected small groups for the duration of the integrated STEM unit. There were three all-girl groups, two all-boy groups, and three mixed-gender groups. The participants in this study were assigned to a mixed gender small group with two girls, Ying and Maiv, and two boys, Koob and Cai (all pseudonyms). All four students identified as Asian. These students were selected for participation in this study via purposeful sampling based on several factors: consent to participate, comfort with the video camera and audio recorder, and identification with the same ethnicity to reduce issues of ethnic and gender intersectionality. It is important to note that, although issues related to gender in STEM are more complex when non-binary gender identities are considered, this study is limited in focus on the binary categories of female and male, which aligns with the literature cited throughout.

Ying was a Karen girl and spoke Karen as her home language. She received English as a Second Language (ESL) services in the past but no longer qualified for ESL support. Maiv was a Hmong girl and spoke Hmong as her home language. She received



ESL services to support her English language development and was approaching the highest level of language proficiency on the district's assessments. Koob and Cai were both Hmong boys who spoke Hmong as their home language. They had both received ESL services earlier in their education but no longer qualified for such services at the time of this study. Although the students all spoke Hmong or Karen at home, their level of English proficiency was high and did not seem to hinder their interactions.

In the state in which this study occurred, fifth-grade students complete standardized tests in both science and mathematics. Their achievement on these tests is classified into four levels: does not meet the standards, partially meets the standards, meets the standards, and exceeds the standards. On the state science assessment taken in the spring of their fifth-grade year, Maiv, Koob, and Cai met grade-level expectations. Ying partially met grade-level expectations in science. On the mathematics assessment, Maiv and Koob exceeded expectations, while Ying and Cai met expectations. These scores indicate that the students were performing as expected of students in their grade level, with the exception of Ying in science.

### **Curricular Context**

The curricular unit, *Electromagnetic Claw Game: Diggin' For Fools' Gold*, focused on science content related to magnets and electromagnetism. Students were introduced to a client who was seeking to redesign a mechanical claw game commonly found at arcades or shopping malls. After learning that mechanical claws were often rigged to make players unlikely to win, the client sought an electromagnetic arm instead of a mechanical claw to make the games more fair. Within the unit, students learned about magnets, magnetic materials, and electromagnets as they prepared to design an

electromagnetic arm for the game. They designed a prototype electromagnet and tested its use by picking up a small toy affixed with a metallic tag and reflecting on whether it met the design criteria and constraints. For example, one key design criterion required that electromagnet designs successfully pick up the toy on some, but not all, trials. Students redesigned their prototype and presented their final designs to the client, making a case for why their design was a good solution to the problem. The unit was composed of seven distinct lessons (see Table 3.2), each of which was intended to take at least one 50-minute class period. In this study, the unit was implemented during 14 class periods.

*Table 3.2. Electromagnetic Claw Game Lessons*

Lesson	Days of Implementation	Lesson Focus	Lesson Summary
Lesson 1	1	Engineering	Problem-Scoping: Students are introduced to the client and the engineering design challenge via a client memo. They review the engineering design process and engage in problem-scoping as they identify the design challenge criteria and constraints from the client memo.
Lesson 2	2	Science	Electromagnet Exploration and Variable Sort: Students investigate different aspects of electromagnets that affect the strength of the electromagnet. They identify variables that could be tested and select a variable to test in the following lesson.
Lesson 3	3-6	Science	Testing the Number of Coils: Within their small groups, students carry out an experiment to test the effect of the number of coils on the strength of the electromagnet based on how many washers it can pick up. Groups graph their data and write claims supported by evidence about the effect of coils on electromagnets.
Lesson 4	7-9	Science	Electromagnet Team Experiments: Teams select another electromagnet variable and conduct an experiment to test how their selected variable affects the strength of an electromagnet. They identify patterns in their data and create a poster to share their experiment and results with the class.
Lesson 5	9-10	Engineering	Plan and Design Electromagnetic Arm: Using the information they have learned about electromagnets, students design and build a prototype electromagnet for the client. They test their design to see how many washers it can pick up, learn about other groups' designs, and

			reflect on how to improve their design.
Lesson 6	11	Science	Magnets and Magnetic Materials: Students are introduced to a new client need for a “tag” material to be placed on the toys in the game. They investigate which materials are magnetic and make a recommendation to the client about the “tag” material.
Lesson 7	12-14	Engineering	Redesign Electromagnetic Arm and Communicate with Client: Students plan and redesign their electromagnet to best work with the toy tag material they selected in the previous lesson. They make a presentation to share their best design with the client, describing the results of their tests and the reasoning behind their design choices.

Although the teachers did not intentionally consider the *NGSS* in their development of the unit, significant overlap exists between the unit goals and activities and the Framework for Quality K-12 Engineering Education (Moore, Glancy, et al., 2014), and the *NGSS* SEPs (NGSS Lead States, 2013; see Table 3.3). The unit’s science content of magnets and electromagnetism also developed students’ understanding of the *NGSS* disciplinary core idea in physical science of forces and interactions (NGSS Lead States, 2013).

*Table 3.3. Unit Connections to NGSS SEPs and Framework for Engineering Education*

Lesson	<i>NGSS</i> Science and Engineering Practices (NRC, 2012)	Framework for Quality K-12 Engineering Education (Moore et al., 2014)
Lesson 1	Asking questions (science) and defining problems (engineering)	Problem and background (POD-PB) Conceptions of engineers and engineering (CEE) Issues, solutions, and impacts (ISI) Ethics Teamwork
Lesson 2	Planning and carrying out investigations Analyzing and interpreting data	Problem and background (POD-PB) Teamwork
Lesson 3	Planning and carrying out investigations Analyzing and interpreting data Engaging in argument from evidence Using mathematics and computational thinking	Problem and background (POD-PB) Teamwork

Lesson 4	Planning and carrying out investigations Analyzing and interpreting data Obtaining, evaluating, and communicating information	Problem and background (POD-PB) Teamwork Communication related to engineering (Comm-Engr)
Lesson 5	Constructing explanations (science) and designing solutions (engineering) Planning and carrying out investigations Analyzing and interpreting data	Plan and implementation (POD-PI) Test and evaluate (POD-TE) Apply science, engineering, and mathematics (SEM) Teamwork
Lesson 6	Planning and carrying out investigations Analyzing and interpreting data Engaging in argument from evidence	Problem and background (POD-PB) Teamwork
Lesson 7	Constructing explanations (science) and designing solutions (engineering) Planning and carrying out investigations Analyzing and interpreting data Engaging in argument from evidence Obtaining, evaluating, and communicating information	Plan and implementation (POD-PI) Test and evaluate (POD-TE) Apply science, engineering, and mathematics (SEM) Engineering thinking (EThink) Teamwork Communication related to engineering (Comm-Engr)

### Data Collection

Data were collected throughout the 14 days of unit implementation. Data sources included video, audio, and transcripts of small group interactions, the duration of which resulted in 3 hours, 27 minutes, and 19 seconds of small group video available for analysis. This dataset was inclusive of all small group work throughout the unit and included roughly equal science-focused and engineering-focused activity (100 minutes of science and 107 minutes of engineering). Student work artifacts, such as worksheets, notes, and posters created throughout the unit, were photographed so researchers could see students' written products that were illegible in the videos. Additional data sources included daily field notes taken by the graduate student coach during the unit implementation and memos written by researchers while watching implementation videos.

## **Data Analysis**

Because sociocultural theories were used for interpretation, data sources were analyzed in multiple phases to consider both the individual student and the social interactions among students in the group. During the first phase of analysis, each researcher focused on one student for the duration of the unit to better understand that individual's patterns of participation. Researchers took detailed notes while watching small group videos and wrote memos about their focus student's participation in each day of the unit, noting patterns of participation and salient quotes. Particular attention was paid to the sociocultural context of the learning, with memos describing how students interacted with each other, the activity, and the classroom setting (Lave, 1988). Researchers referred to the student work artifacts throughout analysis to determine which student or students suggested the ideas that were recorded on group artifacts.

A coding protocol was used to describe students' verbal and non-verbal performance enactments in the small group activities. Jovanovic and King's (1998) protocol, which focuses on science activities, was modified to effectively capture the types of participation that may be seen in integrated STEM activities. The researchers used the original protocol of 13 performance enactments and coded a video on integrated STEM small group activities together, identifying additional codes to be added to the codebook to reflect the sociocultural context of the study. Based on sociocultural theories, the codes included interactions between people (e.g., directing, following, expressing frustration with peers), the activity (e.g., reading directions, manipulating materials, initiating activity), and the classroom setting (e.g., referring to earlier material, record keeping, requesting help from the teacher).

After developing this initial set of codes, the authors conducted two further cycles of coding of the same videos, adding codes as necessary. Where differences in coding emerged between researchers, the performance enactment definitions were modified to reach consensus. Discussion amongst the team of authors helped refine the codes and ensure the authors were calibrated in their use of the codes (Wasser & Bresler, 1996). The final coding protocol used for this study (see Appendix A) included 26 different performance enactments. Performance enactments added to the coding protocol were both verbal and non-verbal and included, among others, expressing uncertainty, encouraging, disagreeing, judging (both task and person), expressing frustration (toward both task and person), avoiding, initiating activity through non-verbal means, and forcefully controlling the activity.

Following the codebook development and refinement, researchers coded 10% of the dataset, selected at random, to establish interrater reliability. Fleiss' kappa, which is a rigorous approach to reliability that accounts for chance agreement and allows for three or more raters (Landis & Koch, 1977), was calculated. The team reached an overall agreement of 0.68, which is considered "substantial agreement" (Cohen, 1960; Landis & Koch, 1977).

Once interrater reliability was established, researchers divided the video dataset into three-minute segments. A total of 75 segments were coded, and these segments included all of the small group activity throughout the unit. Segments of the small group activity were used in order to generate frequency counts of student performance enactments. For example, if a student recorded notes during 10 segments of a single class period, that student would have a higher frequency count for record-keeping than a

student who only took notes during one of the 10 segments. Researchers coded these three-minute segments of all small group activity throughout the entire unit, identifying all performance enactments a student engaged in during that period of time. Some of the segments were less than three minutes if the class period ended or the activity shifted from small group to whole group activity, as only small group portions were coded.

Each student received a score of 0 (performance enactment not present) or 1 (performance enactment present) for every enactment in every time segment, regardless of the duration of the enactment during the three-minute segment. The coding protocol scores were summed within each lesson, across science lessons, across engineering lessons, and across the unit as a whole. Binary performance enactment data were used to triangulate information in researchers' memos and examine the level of consistency in what students said and did. These data were used to write individual narratives about each student, which were shared with the teacher who taught the *Electromagnetic Claw Game* unit to ensure that they were valid descriptions of the students. The students' classroom teacher had taught them for several years and found the narratives to align with her perceptions of the students' participation.

During the second phase of data analysis, researchers focused on case-level analysis (Yin, 2014) to explore interactions within the social context of the small group and to identify similarities and differences between the individual students. During this analysis, girls and boys were also examined as sub-cases to explore patterns in interactions based on gender. Findings were based on researcher memos, comparisons of individual units of analysis (students), and data from the coding protocol. Transcripts were used to provide illustrative examples of patterns of student interaction within the

group. This allowed for a broader understanding of differences between boys' and girls' small group STEM participation in this case, as well as differences in student participation in science and engineering lessons.

## **Findings**

The findings of this study are presented first as brief summaries of the individual students' involvement in the *Electromagnetic Claw Game* unit. Following the summaries of individual units of analysis, case-level findings are shared, with brief vignettes used to highlight interactions that illustrate the findings. Based on the themes that emerged from the analysis of coding protocol data and researcher memos, particular attention is given to students' science engagement, engineering engagement, frustrations, group roles, interactions in which students explicitly discussed gender, and application of science in engineering.

### **Student-Level Findings**

**Ying: The deferential but engaged project manager.** Ying was focused, worked to keep the group on task by assisting them even when she was not asked, and accepted whatever roles were delegated to her. She engaged in the hands-on activities, was responsible for record-keeping for her group, and suggested ideas for design improvements. Although she was very involved in the activities, she did not push to make sure her ideas were taken up by her teammates, often deferring to the opinions of the boys and following their directions. Ying expressed self-doubt about her intelligence and ability on multiple occasions, but she also defended herself and her female teammate when boys made disparaging comments about them.



**Maiv: The invisible but interested onlooker.** Maiv was the quietest student in the group; she rarely engaged in any form of spoken discourse and only voluntarily spoke to Ying when both boys were away from the table. She took her turn testing the group's electromagnet and occasionally helped to wire the electromagnet, but she also declined to participate when directly asked. Maiv was rarely off-task, and although she was almost always silently observing, she was quick to assist with small tasks such as counting washers or completing group worksheets.

**Koob: The scholarly, designated leader.** Koob was a dedicated student and took on a leadership role within the group from the beginning of the unit. He frequently displayed his intelligence and was quick to suggest new ideas, but he was also quick to give up when challenged with content or tasks. Koob focused on being successful in the engineering design challenge no matter what it took, even if that meant controlling the task and directing other students, as he frequently did. His directions and suggested ideas were rarely questioned or challenged by his peers.

**Cai: The distracted class clown.** Cai was a social student who spent a significant amount of time telling stories and talking to his teammates. His interactions with the group focused on socializing, rather than science or engineering to move the group forward. Cai did not regularly contribute original ideas to the group. He preferred to be responsible for completing tasks rather than discussing ideas, particularly during the design portion of the unit. On the rare occasion when Cai did contribute ideas, he often did not push them forward, instead waiting until Koob supported an idea before following through with it. Cai did not actively seek out interaction with either of the girls on his team.

## Case-Level Findings

The following sections discuss case-level findings from the implementation of the *Electromagnetic Claw Game* lessons. Table 3.4 provides code frequency counts for girls and boys in science and engineering lessons; the most salient codes are included in the table and discussed in the following sections in more detail (see Appendix B for full code frequency table).

*Table 3.4. Small Group Performance Enactment Frequency Counts by Gender and Lesson Type*

Performance Enactment	Girls		Boys	
	Science	Engineering	Science	Engineering
Reasoning	0	2	6	21
Directing	17	17	3	26
Suggesting Idea	7	24	6	36
Encouraging	4	7	7	10
Disagreeing	8	13	2	7
Judging: Task	0	0	0	7
Judging: Person	9	13	8	12
Expressing Frustration: Task	4	14	8	13
Expressing Frustration: Person	3	13	3	3
Distracting Other Students	2	1	8	24
Off Task	8	25	13	34
Avoiding	4	6	0	3
Manipulating	35	36	28	42
Record Keeping	29	45	18	23
Assisting	18	15	19	20
Following	11	20	0	4

Observing	34	59	20	35
Initiating: Non-Verbal	1	5	6	17
Forcefully Controlling: Non-Verbal	2	6	3	13

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**Science engagement.** The first portion of the unit focused primarily on developing students' science content knowledge, which would be applied in the engineering design challenge in later lessons. The girls were slow to get involved in group discussions, which was apparent to the boys, as illustrated in Vignette 1.

*Vignette 1.*

Cai: We need to build a game, with skill and fun, so a lot of people can play.

Koob: They [the client] need us to create an electromagnet, so it will stick onto a magnet, and it's like a magnet. And it goes down and then it's stuck on like the magnet thing.

Cai: Let me ask you a question. Why do they want us to do that?

Koob: Why did it want us to do that? Because customers are not buying their machine.

Cai: How come you didn't talk? [To Maiv]

Maiv: [*Shrugs.*]

Cai: This a group, talk. Say, "yes".

Even after being directly prompted to speak, Ying and Maiv remained silent throughout the rest of this class period. As the boys continued to have a two-person discussion and recorded their ideas about the engineering design requirements on their papers, Ying and Maiv looked at the boys' papers as they recorded their own responses. While Maiv remained largely silent throughout the science lessons and the remainder of the unit,

speaking rarely and quietly, Ying became more vocal with her teammates as the unit progressed, expressing opinions about how tasks should be carried out. Koob and Cai continued to be verbally active throughout the science lessons.

Although Ying and Maiv were initially hesitant to engage with their team verbally, they participated in the hands-on science activities from the outset of the unit. As the group began their exploration of an electromagnet on Day 2, Koob and Cai were the first to use the hands-on materials. Vignette 2 shows that after their own manipulation of the materials, the boys offered Maiv and Ying the opportunity to use the materials.

*Vignette 2.*

Cai: Got it? [To Koob]

Koob: It is sticking but it's not like, see...

Cai: Let me try. [*Takes electromagnet from Koob, uses it for 18 seconds.*]

Cai: Alright, you can mess around. [To Maiv]

Maiv: [*Picks up electromagnet, tests for 12 seconds, sets electromagnet down.*]

Ying: [*Picks up electromagnet, tests it.*]

Ying: It's not working anymore.

In this instance, Cai gave the girls permission to use the materials, saying, "Alright, you can mess around" after he and Koob had already used the materials. In future lessons, Koob was often the one in charge of the materials and directed his teammates in what to do. Throughout the science-focused lessons, he remained cognizant of his female peers, and although he was leading the group, Koob included the girls. For example, as they tested how the number of coils on the hex bolt affected the number of washers they could

pick up on Day 4, the students negotiated whose turn it was. This exchange is captured in Vignette 3.

*Vignette 3.*

Ying: Can I try again? I want to try again.

Koob: You can try again. Should we do a trial of two and four?

Ying: Yeah. It's her turn.

Koob: No, let me see if you can grab four like this. If you do this, it's good.

Ying: Oh, that's good.

Koob: When you do that, it's better. Grab another one. Grab another one. [To

Ying]

Koob: Okay, Maiv's turn. How much was yours?

Ying: I got four.

Koob: Maiv's turn. [*Maiv takes electromagnet and tests how many washers she picks up.*]

Ying: Three? Get more.

Koob: Oh my! Okay, unclip it.

Ying: Oh my God, she [Maiv] got the most. She got six.

Koob: Dang!

Later the same day, Koob also asked, "Who wants to go first? Will I go first again?" It is interesting to note that in this particular lesson, during which Koob was most attentive to including his female peers, Cai was absent.

All four students continued to regularly manipulate the materials throughout the science activities, although Maiv deferred to another student with a shake of her head if it

was not clearly her turn to test the electromagnet. Even when they were not directly handling the materials, Ying, Maiv, and Koob remained highly engaged, observing their teammates and recording data in their individual notebooks. Of the four group members, Cai spent the most time disengaged in the science activities. He often fidgeted, tapping the table with his pencil or hand, swiveling in his chair, and knocking manipulatives together noisily. In addition, he wandered around the room to visit other groups, sometimes to get ideas or ask questions, but often just to visit.

Collaborative use of materials among students was relatively natural during the science-focused lessons, with students attending to turn-taking and equal involvement in the activities. The highly structured nature of the science investigations, with clear expectations communicated by the teacher for procedures and number of trials, seemed to be conducive to equitable participation. During the science-focused lessons, the girls manipulated the materials on 35 occasions, while the boys manipulated the materials on 28 occasions. The girls and boys also assisted their peers on almost the same number of occasions in science activities (18 occasions for girls, 19 for boys).

Although the girls manipulated the materials in more time segments than the boys, they often mimicked the methods of manipulation the boys had already demonstrated. For example, after seeing their male peers carefully form a pile of washers for electromagnet testing, both Ying and Maiv did the same. While researchers observed this tendency, Ying also verbally confirmed her mimicking of the boys, saying, “I want to go last because I watch how you guys do it, and I just copy what you guys do.”

**Engineering engagement.** When the unit focus shifted to engineering on Day 9, the students’ performance enactments also shifted. The record-keeping roles became

more distinctly female in the engineering-focused lessons. In these lessons, the team had a single worksheet, and Ying was almost solely responsible for filling it out at the direction of Koob. During the engineering lessons, the girls engaged in record-keeping on 45 occasions compared to 29 occasions of record-keeping in science-focused lessons. The pattern of record-keeping for boys was more consistent across science and engineering lessons, with 18 instances in science and 23 in engineering.

Students suggested more ideas during the engineering lessons (60 occasions versus 13 in science lessons), but they also forcefully controlled the materials more often (19 displays of control in engineering versus five in science). This pattern of increased control was especially apparent for boys, with 13 displays of control in engineering lessons versus three in science. The boys also became more involved in directing their peers during engineering lessons. Whereas the girls directed peers 17 times in science lessons and 17 times in engineering lessons; the boys directed only three times in science lessons but 26 times in engineering lessons.

Koob remained highly focused on completing tasks successfully, but he became more forceful with his teammates, often directing them in what to do and dominating the materials. He quickly and fervently made design suggestions, which resulted in his ideas being taken up by his group without question. Prior to constructing their electromagnet, the group had to specify the materials they would use and how they would be used. They had to select the type of battery, number of batteries, wire gauge, magnetic core material, number of wire coils, and number of alligator clips. Koob's domination of group decisions during the engineering activities was exemplified in the following exchange,

when students considered the components of their initial electromagnet design in Vignette 4.

*Vignette 4.*

Cai: One battery.

Koob: No. Three and three.

Cai: Three, three, three, three on everything?

Koob: No.

Cai: Three on everything?

Koob: Three batteries. Put three batteries. [*Points at worksheet for Ying to write.*]

Ying: [*Writes.*]

Koob: And then three. [*Points at worksheet.*] Three.

Ying: [*Writes.*]

Ying: Why?

Cai: Because, he's the captain.

Koob: We might need more. Because the more numbers ...

Cai: Can I read this thing? [*Takes worksheet from Ying.*]

Ying: I don't think we need 100 wire coils. I think we just need one and we need to wrap it 100 times. I don't think we need 100.

Koob: Yeah, 100 to wrap around.

Ying: Yeah, but it says number of wire coils.

Cai: 100 wire coils, why? Because it picks up more? Because it picks up more.

Koob: 100 wire coils.



With Koob's increased domination of the group, Ying quickly recognized her new role as a passive assistant in the engineering lessons. Shortly after this interaction, when the boys left the table to gather supplies for their prototype, Ying turned to Maiv and said, "I just do what they [the boys] tell me," referring to her male peers' role directing her involvement in the activity.

As the engineering challenge progressed, Ying continued to defer to Koob and follow the directions he gave her in what to write and how to participate. Although Ying and Maiv continued to suggest ideas, they quickly adopted Koob's ideas over their own. For example, on Day 12, the group continued to consider the components they would use for their electromagnet prototype, illustrated in Vignette 5.

*Vignette 5.*

Koob: Okay. Right here [*points at worksheet*] we're going to do ... Because, we don't want it to be too strong or too weak.

Ying: Just write it. [*Pushes paper to Koob.*]

Koob: We don't want it to be too strong or too weak. Come on, write it. [*Pushes paper back to Ying.*]

Ying: I wrote it already. See? I did the arrow. I don't want to write again.

Koob: Okay. Number of coils... 50.

Maiv: 75.

Ying: 75?

Koob: 50. And then right here, arrow. We need two alligator clips to connect everything. We need two, because we need to connect everything together.

Ying: Done.

Koob: We're going shopping. [*Walks away from table.*]

Cai: Let's go. Let's go shopping. [*Walks away from table.*]

Ying: We'll just sit here.

Maiv: The boys get to do something all the time. [To Ying]

Ying: I know they're just telling us what to do and we're doing it. So rude. [To  
Maiv]

In this exchange, Koob continued to exert dominance over the group's design decisions, overpowering Maiv's suggestion of using 75 coils, directing Ying in what to write, and deciding who would go "shopping" to retrieve the necessary materials. When the boys were away from the table, Maiv and Ying explicitly discussed their discontent in being told what to do. The girls followed directions on 20 occasions in engineering lessons, versus boys following directions on only four. These instances of following were more frequent in engineering than in science, when girls followed on 11 occasions and boys followed on zero. In addition to shifts in directing, controlling, and following, disagreements among the students were more frequent in engineering lessons for both genders (20 disagreements in engineering lessons versus 10 disagreements in science lessons).

As the boys became more directive, Maiv became less involved in the engineering activities, at times visibly moving back in her chair. Although she observed her teammates, fixed some wire connections, and recorded design plans and the results of prototype testing in her notebook, she did not suggest any ideas. Cai's generally low level of engagement increased on days when the tasks related to engineering rather than science content. In particular, he spent the most time on-task when engineering activities

were first undertaken (e.g., wrapping the copper wire) or when pivotal moments were happening (e.g., testing the electromagnet). However, Cai continued to talk about topics that were irrelevant to the group's tasks. For example, the following exchange took place on Day 10, with Cai randomly bringing up the topic of color blindness in Vignette 6.

*Vignette 6.*

Cai: Color blind. If I was color blind, Koob would be the color white right now.

Koob: Oh yeah.

Cai: You know dogs are color blind? The only color they can see is yellow.

Koob: 37. 38 [counting the number of coils]. Oh my God, seriously?

Cai: How come they're called washers? Dude, why did we choose 100?

This meandering type of vocalization was typical of Cai throughout the unit, though his teammates rarely engaged in the tangential and off-task topics of conversation he raised.

While the students designed their electromagnet prototype for the engineering design challenge, they expressed more competition than they had previously. They began to engage more with other groups, both to share ideas and to compete with the groups, and they also became more aware of time limits. The increased urgency related to completing the engineering design challenge resulted in students expressing judgment of the task and each other more frequently, with 32 displays of judgment in engineering-focused lessons compared to 17 in science-focused lessons. With this increased movement and interaction with other groups, the students also spent more time off-task during engineering focused activities (59 occasions in engineering versus 21 occasions in science).

**Frustration.** All of the students expressed frustration at some point during the unit, but markedly more frustration was present in engineering-focused lessons compared to science-focused lessons (43 occasions in engineering versus 18 in science). The pattern of increased frustration during engineering-focused lessons was true of both girls and boys; the causes of their frustration, however, were quite different. Ying and Maiv, the female students, were much more likely to become frustrated with a person, expressing such frustration on 16 occasions throughout the unit. The boys only showed frustration toward a peer on six occasions.

Day 10, an engineering-focused lesson, seemed to be a source of frustration for Ying. Although she assisted with the hands-on activities to help drive her group forward, she was primarily responsible for record-keeping. Throughout the lesson, Ying made exasperated noises, rested her head on the table, and expressed frustration about the task and her teammates. As the lesson concluded, Ying and Maiv focused on creating a sketch of their prototype design, but Cai's frequent interjections frustrated Ying, as illustrated in Vignette 7.

*Vignette 7.*

Cai: What about the washers?

Ying: You're not supposed to draw the washers; you're just supposed to draw your thing [electromagnet].

Cai: Who cares?

Cai: Hey, what about the alligator? You forgot about the alligator clips.

Ying: [*Draws.*]

Cai: Wait, what's that? [*Takes paper from Ying.*]

Ying: You guys are more awful than us. What are you doing?

Cai: It's called alligator clips, why didn't you write it?

Ying: She [Maiv] was about to write it. You're so rude.

Cai: Dude, Koob, help me draw.

Ying: Oh my God.

Both boys and girls demonstrated frustration directed at a task, with 21 occasions for boys and 18 occasions for girls. Although the frequency of this type of frustration was not vastly different between genders, the students' means of handling frustration differed. When the boys were frustrated, they often walked away from the table or placed blame on the girls. In the following example from Day 7, after struggling to coil copper wire around a hex bolt, Koob delegated the task to Cai and walked away. In Vignette 8, Cai repeatedly said that Ying had taken responsibility for completing the task, which was not true.

*Vignette 8.*

Ying: Can you ...

Koob: Can I what?

Ying: Can you do this [wrap wire around the hex bolt]?

Cai: Dang you, I thought you said you were doing it. [To Ying]

Koob: I don't want to do that. Come on, why don't you do it? [To Cai]

Cai: What?

Koob: Do 75 coils.

Cai: She said she was doing it. She said, "I want to do it, all mine."

Koob: What number you left off? [To Ying]

Ying: Huh?

Koob: What number you left off?

Ying: Eight.

Koob: Eight? Okay, next is nine.

Cai: This is not even working. This is how you do it, that's it?

Koob: Dude, you gotta do all the way.

Cai: Dude look when I do it, this is moving too. This is so annoying.

Koob: Just do it. [*Walks away from table.*]

Cai: Oh my God, you guys messed it up.

As Cai continued to wrap copper wire around a hex bolt to create the team's electromagnet, he grew more visibly frustrated. He threw the hex bolt down and walked away from his group's work table. This behavior was a typical display of frustration for Cai; he spent time distracted and off-task before he was willing to re-engage with the team.

Koob's frustrations reflected his desire to finish tasks successfully and efficiently. This pattern of task frustration continued as Koob faced new challenges, and his need to be successful was often observed in his comments to his teammates, such as when he said, "Would you speed up [in coiling the wire]?" on Day 10. Ying also became frustrated with her group's lack of efficiency, but her frustrations extended to her ideas not being taken up by the group. For example, on Day 4, the students added 10 coils to their electromagnet at a time, then conducted multiple trials with each number of coils to see how many washers the electromagnet could pick up. As Koob coiled the wire, Ying became frustrated with his slow pace and played with the materials as she waited. In the

same exchange, highlighted in Vignette 9, she also demonstrated her frustration with her ideas not being heard, as she manipulated the washers without her teammates' input.

*Vignette 9.*

Ying: Let's see if our hand is magnetic. [*Presses hand to washers to pick them up.*] It's better using a hand.

Koob: [*Continues adding coils of wire to electromagnet.*]

Ying: Hurry up! [To Koob]

Ying: Look how much I got. Two, four, six, eight, ten, twelve, fourteen, fifteen.  
Let's put some back now.

Koob: Okay, I'll go first.

Ying: [Sighs.]

Ying: I have an idea. I'm going to do something for myself. [*Carefully creates pile of washers.*]

Ying's frustration continued to build throughout Day 4, and she eventually cheated during the activity, picking up additional washers by hand when her teammates were away from the table. Whereas Koob and Cai often left the table when they were frustrated, Ying remained with her team but attempted to alleviate the perceived wrongdoing.

**Group roles.** The girls and boys took on distinct roles within their small group. Koob was the clear leader, and he and Cai were more vocal participants in the activities. They were also "doers," initiating activity 23 times (compared to six initiations by Ying and Maiv) and twice as likely as their female peers to take physical control of the materials (16 occasions of control for boys; eight for girls). In addition to taking charge

of the activities, the boys took control of the conversations in their group. All students suggested ideas throughout the unit (31 suggestions from girls and 42 suggestions from boys), but differences were apparent in how the group responded to the suggested ideas. Koob's ideas were taken up by the group without question, whereas Ying's ideas often remained unacknowledged. For example, on Day 7, the group struggled to get their electromagnet to pick up any washers and attempted to troubleshoot their prototype. Ying erroneously believed the problem was the use of both red and black alligator clips to complete the circuit. Although the color of the insulation had no impact on the electromagnet, Ying's comment went entirely unacknowledged by her teammates, who also did not raise alternative options for troubleshooting. This exchange is shown in Vignette 10.

*Vignette 10.*

Cai: Why is this so weird? Why is this so weird? How do we do this again?

Okay, this is the edge, we connect this to here, right? Something like that?

Ying: We don't know where to put it.

Koob: Oh my God.

Cai: Oh, we have one more. Oh, never mind.

Ying: We need alligator clips. Oh, it's because it has the red thing. Take it off.

*[Removes red alligator clips].* We can't use the red thing.

Cai: Ha, ha, ha.

Ying: What is that? Why do you have red wire?

Although no one acknowledged her idea, Ying proceeded to remove the red clips and replace them with black clips. Notably, this instance of Ying taking initiative to test her



idea occurred when Koob was away from the group's table, and she later faced ridicule from the boys for having this idea.

Throughout the unit, both boys and girls engaged in directing their peers. They directed in nearly equal proportions (34 for girls and 29 for boys), but their reasons for directing and the outcomes of their directions differed. The girls tended to direct peers in order to stay on task and encourage participation from those who were less involved, particularly during the science lessons. These directions tended to be more social in nature, yet they were less frequently followed. In contrast, directions from the boys tended to be specifically focused on making decisions related to the tasks at hand, particularly during the engineering-focused lessons, as described in the engineering engagement section.

In contrast to the boys, Ying and Maiv were less active in determining the direction the group would take. Instead, they frequently observed their peers (93 observations for girls; 55 observations for boys) and took notes. Differences in record-keeping were apparent between genders, with girls record-keeping 74 times compared to 41 times for boys. This difference was especially apparent in engineering-focused lessons.

**Interactions related to gender.** The students had unique ways of addressing gender within the group. The contrast between Koob and Cai, the two boys, was especially stark. Koob interacted with Ying quite frequently, demonstrating his willingness to engage with peers of the opposite gender in order to accomplish the tasks they were given. In Vignette 11, as the group considered the client (Orion Nova) seeking

a redesigned electromagnetic claw game, Koob referred to the client as female in wondering about how to pronounce her name.

*Vignette 11.*

Cai: Oh, who's hiring us? The president of Galactic Games.

Koob: Who's hiring us? The president of the Galactic Games, Orion Nova. Is that how you say her name?

Cai: It's a him.

This gendered comment from Cai was not unusual. He frequently expressed gendered views about who should engage in certain tasks. For example, Vignette 12 occurred on Day 7 as Cai coiled copper wire around a hex bolt.

*Vignette 12.*

Cai: I feel like a girl doing this. I feel like a girl doing this.

Koob: Maybe you are.

Cai: Girls do this stuff, not men.

Koob: You're not a man. Oh my God.

Both Ying and Maiv were present for this interaction, but they did not remark on the gendered comments. Cai also said, "Girls go shopping" when considering who should gather the materials for their group, and "I see... these girls draw big old heads, but little bodies" as Ying and Maiv sketched their team's electromagnet design. Cai explicitly discussed gender on a number of occasions, and he also directed his language toward Koob, referring to his female peers as "they" and "them," even when the girls were sitting at the table.

Ying and Maiv explicitly discussed gender less frequently, but their remarks illustrated their discontent with the responsibilities that were delegated to them by the boys. On Day 12, there was a distinct shift from Ying in charge of record-keeping to Koob taking the lead on building. As shown in Vignette 13, Ying also noticed this shift and was unhappy about it.

*Vignette 13.*

Ying: Where's the nail?

Cai: This is not a nail. This is a metal bolt.

Ying: How are we going to stick the Minion [toy]? Oh, the Minion is the thing that we have to get.

Koob: I'll try to help you on something. [*Manipulates materials.*]

Ying: You done? [*Rests head on arm.*]

Koob: Remember, 50, dude. [To Cai]

Cai: I'm at 10.

Koob: These are all messed up, though. [*Manipulates materials.*]

Ying: It seems like the boring stuff we [girls] have to do, and the fun stuff they [boys] have to do. [To Maiv]

Although Ying continued to do the “boring” task of record-keeping, she was not satisfied watching her male teammates doing the “fun” design tasks throughout the engineering lessons. Maiv’s comment in Vignette 5 that “The boys get to do something all the time,” combined with her quiet agreement with Ying indicate that she, too, noticed gender disparities in their participation and was not satisfied with the female roles in this group.

**Application of science in engineering activities.** As the students worked to plan their electromagnet design, their teacher encouraged them to consider the results of their prior experiments in making decisions. The planning worksheets they completed required the students to justify their choices for their initial design and their redesign (see Figure 3.1).

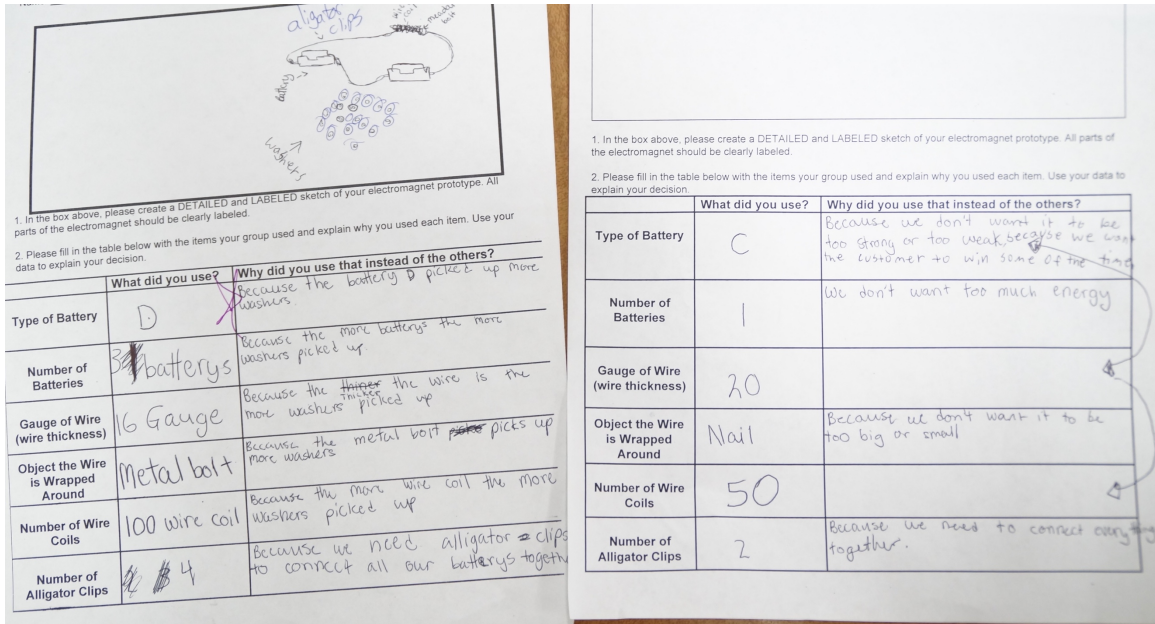


Figure 3.1 Students' initial engineering design plan (left) and redesign plan (right).

In Vignette 14, the students discussed the reasoning for their choices:

Vignette 14.

Ying: Type of battery?

Koob: C. Because, we don't want it to be too strong, or too weak. We don't want the battery to be too strong, or too weak.

Ying: [Writes.]

Cai: This is taking too long.

Koob: Yeah, hurry up.

Ying: Okay, I'm done.

Koob: Okay, number of batteries. One. Yeah, one.

Cai: One.

Ying: [*Writes.*]

Koob: Because we don't want it to be too weak or too strong.

While the students considered the results of their experiments in informing their design, they did not discuss science content beyond the outcomes of the investigations. In Vignette 14 and Vignette 5, Koob repeatedly reasoned that the group did not want their electromagnet to be “too strong or too weak,” demonstrating his knowledge of the design criterion that specified the electromagnet should pick up a toy on some, but not all, occasions. Although the students knew how the variables of battery size, number of batteries, and number of coils would affect the number of washers it could pick up, they did not discuss the scientific reason this was the case. In addition, students’ focus on engineering design criteria and constraints in some cases distracted them from applying science content knowledge in decision-making. For example, the group began looking for most economical solution (lowest “cost”), even when it did not align with what they learned in the science-focused lessons.

Although the students did not discuss science content in depth, their application of science content to the engineering design challenge revealed several misconceptions. In Vignette 10, Ying’s belief that the color of the plastic insulation on the alligator clips would affect the functioning of the electromagnet was revealed. Vignette 15 provides another example, when the students worked to troubleshoot their design on Day 13.

*Vignette 15.*

Koob: Okay, like this, and then where does this one [alligator clip] connect?

Cai: This is so not going to work, now start. Start. This is not going to work.

Ying: [*Uses electromagnet, does not pick up any washers.*]

Koob: I don't think we have enough energy. You got to warm it up first.

Ying: It's sticking, but it won't carry it up.

This interaction in the engineering design process revealed Koob's erroneous belief that the electromagnet had to "warm up" before it could be used.

## **Discussion**

### **Gender and Science Versus Engineering Engagement**

Despite the increasing popularity of integrated STEM instruction, prior research has not considered students' patterns of participation in the varying types of activities associated with integrated STEM units. Open-ended engineering activities, in particular, represent a departure from the types of activities common in the culture of school science. This study revealed important differences in student engagement between science and engineering lessons. Although the students suggested more ideas during engineering-focused lessons compared to science-focused lessons, they also experienced more frustration and disagreements in their team and attempted to control and direct their peers more often. The boys, in particular, became more competitive and controlling of the activities and less concerned with their female teammates' participation. The more open-ended nature of the engineering activities resulted in struggles to negotiate participation.

Although gender cannot be entirely disentangled from the other aspects of the sociocultural context, it is important to note that students in this study displayed gender-typical performance enactments. Drawing upon sociocultural theory, each student negotiated a sense of purpose in the group that was informed by prior socialization. Ying

and Maiv were well-versed in the typical classroom culture of note-taking, paying attention, participating in highly-structured activities, and assisting their peers. Previous research has found that girls are often socialized into rote learning models because of their desire to please their teacher (Fennema & Peterson, 1985; Novak & Musonda, 1991; Ridley & Novak, 1983). The girls in this study adopted “good student” performance enactments and behaved in ways that were consistent with the social norms of being a good student. Typically, these behaviors likely contribute to success in their science class. In fact, Brickhouse, Lowery, and Schultz (2000) found that identifying as a “good student” is more closely linked to girls’ success in school science than identifying as a person who does science. However, in the case of engineering lessons, the girls’ socialization as good students may have hindered their involvement because the engineering task requirements did not fit with their typical modes of engagement. Within the context of formal schooling, the culture of engineering is distinct from the general school culture. Engineering includes failure in the process of developing one of multiple viable solutions to a problem. Accordingly, students in this study, and the girls in particular, with their strong adherence to “good student” performance enactments, had less access to the cultural tools and discourse of engineering.

Koob often initiated activity and contributed the ideas that were taken up by the group, adopting a leadership role in moving the group forward. Although he displayed many “good student” performance enactments as well, Koob extended his participation beyond these enactments to more effectively participate in the open-ended engineering lessons. Boys are more likely to perceive their out-of-school science activities as risky (Archer et al., 2010), are more willing to take academic risks (e.g., Özer et al., 2009;

Ridley & Novak, 1983), and tend to have more extracurricular experiences related to physical science and engineering than girls (e.g., Adamson, Foster, Roark, & Reed, 1998; Dare & Roehrig, 2016; Jones, Howe, & Rua, 2000). Thus, Koob's socialization as a male may have prepared him to deal with the open nature of engineering.

Cai engaged with his peers via humor and entertainment, minimizing his efforts to complete the group's activities. Boys may use effort-minimizing strategies to disguise their low ability in areas typically viewed as masculine (Meece & Jones, 1996), such as STEM, so Cai's efforts to joke with and distract his peers with stories and drawings may reflect his perceived lack of ability in STEM, particularly when compared to his teammates. Although his performance enactments would not have contributed to academic success, Cai filled the social role of "class clown," being well-liked by his peers.

### **Gender Differences in Small Group Science Participation**

With small group activities accounting for nearly half of science activities (Baines et al., 2003) and purported to be especially beneficial for girls (e.g., Fredricks et al., 2018; Rivard & Straw, 2000; Wang, 2012; Zohar, 2006), it is of critical importance to consider whether and how these activities support STEM engagement among girls. Much of the research focused on gender differences in small group science activities was conducted in the 1990s and early 2000s. With new instructional methods, including integrated STEM approaches, it is unclear whether previous research findings are still representative of current classrooms. The four students in this study revealed important differences in the ways boys and girls engaged in the small group activities of an integrated STEM unit. In contrast to previous work, students of both genders were equally likely to manipulate the



materials in this study. Interestingly, students' rigid approach to conducting science experiments, largely influenced by their teacher's explicit instruction in experimental procedures, seemed to promote equitable small group interactions, with all of the students sharing in the responsibilities of the science-focused lessons. However, many of the girls' manipulations were in support of what the boys were doing (e.g., gathering washers into a pile) rather than related to taking charge of the activity. Thus, although girls in this study participated in the physical handling of materials more than girls in prior studies, equity-related issues remained.

### **Application of Science Content to Engineering**

This study also revealed potential affordances of engineering in revealing students' misconceptions related to science concepts. Discussion of science content is known to be important for students to develop more complex scientific understandings (Lemke, 1990), but students in this study displayed alarmingly little discussion of science content. Consistent with previous research (e.g., Jiménez-Aleixandre et al., 2000; Shepardson, 1996; Woods-McConney et al., 2016), they discussed procedures and lesson requirements but rarely negotiated shared meaning of science content or suggested new ideas related to science. With a school science culture that focuses on completing worksheets with correct answers (e.g., Hodson, 1999), deeper discussion of scientific phenomena is not required to be successful. The worksheets used in this curricular unit were not conducive to reasoning. As the students applied their science knowledge to the engineering design challenge, only a surface-level understanding of electromagnetism was required. Students needed to use their recollection of experimental results, but they did not need to understand the scientific phenomena of electromagnetism in order to

complete the design challenge. Evidence-based reasoning only occurred when the students were prompted, so the quality of the conversation in their group likely did not advance their scientific understanding.

Although the engineering design challenge did not require extensive science content knowledge, discussions during engineering design lessons did reveal several student misconceptions related to science. Because engineering requires students to apply their learning, it may offer rich potential for teachers to gain insight into student understanding of scientific concepts. Therefore, although intentional efforts must be made to ensure students discuss science concepts as they engage in engineering design, teachers should also attend to students' discussions throughout the engineering design process to help guide their ongoing instruction of science concepts.

### **Limitations**

While the results of this study are informative, there are several limitations that should be considered. First, students' performance enactments were analyzed and interpreted by researchers, who relied on observable performance enactments. Although the individual narratives were shared with the students' classroom teacher to increase their validity, member checking with the students was not included. It is possible that the students had different views of their own and their peers' participation than the researchers or teacher. Second, in addition to their experiences as girls or boys, their individual cultural backgrounds also would have influenced their participation in the activities. Students in this study were all of Asian descent and were first-generation immigrants to the United States. Their cultures, languages (Hmong and Karen), and background experiences likely intersected with gender in relation to their small group

participation. For example, the students spoke English as their second language. Although their language did not appear to hinder their participation in the activities, it is possible that their interactions may have differed if English were their first language. However, with limited information about students' cultural identities available, these aspects of culture were not included in this study. Rather, the study focused on the shared sociocultural context of school, which was common among the participating students. Finally, this study focused on one unit of instruction. The unit activities likely influenced students' performance enactments, and it is possible that the students would display different patterns of interaction if a different design challenge or different science content was the focus of the unit. Future research should examine task affordances and how they relate to student participation in integrated STEM.

### **Conclusion and Implications**

As integrated STEM instruction becomes increasingly common, it is necessary to understand how students, particularly those who are underrepresented in STEM fields, experience these integrated activities. Ongoing concerns about maintaining girls' engagement in STEM as they move from elementary into middle school and beyond necessitates the consideration of the affordances and limitations of small group STEM activities. With sociocultural theories holding that contextual factors influence the practices, values, and beliefs of science education (Lemke, 2001), this study fills a gap in the literature investigating girls' small group experiences by studying the current practice of integrated STEM instruction. In addition, this study provides new findings regarding shifts in student interaction between science and engineering.

This study suggests that students may experience epistemological conflicts when

science and engineering are integrated. While the current culture of science as practiced in schools, a “textbook science” (Jegede, 1997), prepares students to take notes and follow clear procedures in highly structured science investigations, it does not enculturate them into the practices associated with engaging in open-ended engineering design challenges. Students were relatively well-versed in the convergent thinking often emphasized in the culture of school science, but the divergent thinking required to generate multiple design solutions in engineering was less familiar to them. The girls, in particular, were more prepared to negotiate their involvement in the formulaic science tasks than in the open-ended engineering tasks. When performing science tasks, they were better able to anticipate next steps and become involved in the activities, likely due to their prior experience in similar science activities in school. Without clear rules and procedures, the girls struggled to participate in the iterative and open engineering design tasks. While the ambiguity of the engineering design challenge caused frustration for all students, the boys were able to take charge and ensure that they continued to participate. Within integrated STEM units of instruction, students, and girls in particular, recognize and may struggle with the differing purposes of science and engineering and have difficulty in flexibly applying science and engineering practices.

Several important implications are evident from this study. First, there is an ongoing need to consider students’ early experiences, both in and out of school, to ensure that girls have opportunities to engage in science and engineering practices. As students work toward more authentic approximations of expert practices in science and engineering (Lave & Wenger, 1991), increased opportunities to engage in such practices likely affects the degree to which students feel comfortable and confident engaging in

small group activities. The girls in this study displayed initial hesitancy to get involved in hands-on activities, and increased opportunities to participate in science and engineering activities will increase student comfort and preparation to do so. Second, students must be supported in understanding how the disciplines and goals of science and engineering are both similar and different, including how to navigate back and forth between science and engineering challenges. Third, in order to ensure that they are equipped with strategies for equitable participation, students need additional practice and support in engaging in less structured small group activities like open-ended engineering design challenges. In this study, the boys limited the girls' involvement and did not accept their ideas; over time, this has the potential to quash girls' desire to participate, so students must be guided in productive group work in school. Both teachers and curriculum developers should consider how to build this support into activities, perhaps by including rotating assigned student roles based on task requirements. Finally, the culture of school science must be carefully considered to determine whether it is meeting the needs of students. A "textbook culture" in which correct answers are reached after following a defined series of steps limits students' preparation for more authentic science and engineering challenges that do not have a clearly defined path to success.

Although this study reveals important patterns in students' STEM interactions, further research is needed. Small group size, the ratio of girls to boys in the small group, and students' choice of their teammates will likely affect group interactions and should be investigated. In addition, the intersectionality of students' identities (e.g., identifying as both a female and a student of color) must be considered in small group settings. Large-scale studies that examine interactions of boys and girls in small group, integrated

STEM activities would also promote greater understanding of whether the patterns of interaction revealed in this study are common across contexts and curricular units. As integrated STEM instruction becomes more popular, it is imperative that additional research investigate how to structure learning opportunities to promote girls' involvement in STEM.

## **Chapter 4 - “There are Other Ways to Help Besides Using the Stuff”: Group Gender Composition and Students’ Participation in Small Group STEM Activities**

Despite increasing demand for science, technology, engineering, and mathematics (STEM) workers (e.g., President’s Council of Advisors on Science and Technology [PCAST], 2010; U.S. Department of Commerce, 2012; Vilorio, 2014), women continue to be underrepresented in STEM fields (e.g., Corbett & Hill, 2015; Economics and Statistics Administration [ESA], 2017; National Science Foundation [NSF], 2017). Personal interests have a significant impact on future career choices, surpassing the influence of earning potential, parental influence, course enrollment, and achievement (Hall, Dickerson, Batts, Kauffmann, & Bosse, 2011; Holmegaard, Ulriksen, & Madsen, 2014; Maltese, Melki, & Wiebke, 2014; Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006). Although girls and boys both tend to have high levels of interest in science throughout elementary school (Murphy & Beggs, 2005), their STEM interest tends to decrease as they transition from elementary to middle school (Capobianco, Yu, & French, 2015; Pell & Jarvis, 2001); this is especially noteworthy among girls (e.g., Archer et al., 2010; Eccles & Harold, 1992; Riegler-Crumb, Moore, & Ramos-Wada, 2011; Sadler, Sonnert, Hazari, & Tai, 2012; Xie & Shauman, 2003). By the end of high school, 39.7% of boys versus only 12.7% of girls are interested in STEM careers (Sadler et al., 2012).

With rapid decreases in girls’ science interest between the ages of 10 and 14 (Archer et al., 2010) and research demonstrating that positive school STEM experiences in the elementary and middle school grades are critical for developing girls’ STEM interest (e.g., Maltese & Cooper, 2017; Mosatche, Matloff-Nieves, Kekelis, & Lawner, 2013; Shapiro & Sax, 2011), it is necessary to consider how to support girls’ ongoing

interest in STEM. STEM integration seeks to merge the disciplines and is promoted as a means of increasing the number and diversity of students who are interested in and prepared to pursue STEM careers (Honey, Pearson, & Schweingruber, 2014; Stohlmann, Moore, & Roehrig, 2012). Teamwork and small group activities are key components of integrated STEM instruction (e.g., Brown, Brown, Reardon, & Merrill, 2011; Kennedy & Odell, 2014; Moore, Glancy, et al., 2014; Moore, Stohlmann, et al., 2014; Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016), yet little is known about how students participate in the small group portions of integrated STEM activities. For example, in their review of 94 studies related to small group participation in science, Bennett, Hogarth, Lubben, Campbell, and Robinson (2010) identified that the majority of studies focused on student understanding of science content. Wieselmann, Dare, Ring-Whalen, and Roehrig (accepted) found that girls and boys working in a mixed-gender small group displayed varying patterns of participation in STEM activities depending on whether the tasks were science-focused or engineering-focused. This study builds on our previous work (Wieselmann et al., accepted) to explore how the gender composition of small groups relates to students' participation in integrated STEM activities by addressing the following research question: *How, if at all, does students' participation in small group science and engineering activities within an integrated STEM unit vary based on group gender composition?*

## **Literature Review**

Researchers have consistently found that students working in small groups display different patterns of interaction based on their gender. Throughout this literature review, students in K-12 settings will be referred to as girls and boys; those in undergraduate



settings or beyond will be referred to as women and men. Women and men often display distinct communication patterns within small groups, with women attending to socioemotional aspects of group functioning, such as including their teammates (Hawkins & Power, 1999; Savicki & Kelley, 2000). Girls show higher rates of interaction with group members (Lee, 1993) and tend to focus on interactive, cooperative, and people-oriented interactions in their group work (Fenwick & Neal, 2001). While undergraduates of both genders ask questions at similar rates, women ask significantly more probing questions than men, suggesting that they encourage interaction among their peers and focus on the details needed to move the group forward (Hawkins & Power, 1999). In contrast to girls' modes of participation, boys tend to focus on tasks more than group processes (Johnson & Schulman, 1989), spend more time off-task (Harskamp, Ding, & Suhre, 2008), and display more strategies to maintain control of resources while working in small groups (Green & Cillessen, 2008). These distinct tendencies result in different interaction styles for girls and boys working within small groups, which have consequences when those groups are mixed-gender.

### **Mixed-Gender Groups**

A number of studies have investigated student participation in small group activities based on the gender composition of the group. Some researchers (e.g. Herschel, 1994; Meadows & Sekaquaptewa, 2011; West, Heilman, Gullett, Moss-Racusin, & Magee, 2012) have found no relation between group gender composition and participation in group activities. For example, in an exploration of undergraduate engineering design presentations, Meadows and Sekaquaptewa (2011) found that group gender composition did not significantly affect participation in small groups. However,

regardless of the group gender composition, men consistently presented more technical information and spoke longer; in contrast, women spoke for shorter periods of time and presented significantly more non-technical material.

Other studies have found that mixed-gender groups are more beneficial than single-gender groups. For example, Gnesdilow, Evenstone, Rutledge, Sullivan, and Puntambekar (2013) found that middle-school students participating in a design-based physics curriculum performed better on assessments of content and practices if their prior group work had occurred in mixed-gender groups. Matthews (2004) concluded that middle school students working in mixed-gender groups were more likely than those in single-gender groups to enjoy science lessons and consider future study of science. Schnittka and Schnittka (2016) found that girls learned more science and engineering content in mixed-gender engineering groups.

However, a variety of studies have suggested that mixed-gender groups are especially beneficial for boys and may actually be detrimental to girls. For example, Myaskovsky, Unikel, and Dew (2005) found that women in mixed-gender groups were less task-oriented than women in single-gender groups; in contrast, men were more task-oriented when their group included women. Mixed-gender groups may enhance boys' performance on computer-based problem-solving tasks, but the performance of girls paired with boys is lower than that of girls placed in all-girl groups (Light, Littleton, Bale, Joiner, & Messer, 2000). In a study of undergraduates taking an introductory biology course, Sullivan, Ballen, and Cotner (2018) found that an increase in the percentage of women in small groups was associated with improved course performance for all students, regardless of gender. In addition, women evaluated their peers more

positively when they were in groups with higher proportions of women. This finding aligns with previous research in business in which the number of women in a group was positively related to performance (Fenwick & Neal, 2001). Monereo, Castelló, and Martínez-Fernández (2013) found that female-majority groups were more productive than male-majority groups at working toward task objectives while fostering a cooperative, positive group climate, and the most significant predictor of group success was having a female-majority group. Thus, although the presence of girls may be beneficial to both female and male members of a small group, the presence of boys may negatively impact girls within a given group.

Providing further evidence of potential issues for girls in mixed-gender groups, studies (e.g., McCaslin, Tuck, Wiard, Brown, LaPage, & Pyle, 1994; Myaskovsky et al., 2005) have found group gender composition to be related to differences in interpersonal interactions. Among upper elementary students working in mixed-gender small group science activities, girls often have lower rates of participation than boys (Rennie & Parker, 1987). Boys often take on leadership roles within mixed-gender groups and direct their peers' involvement (Jovanovic & King, 1998; Wieselmann et al., accepted). In mixed-gender groups, girls tend to be less verbally active compared to boys, who dominate speech (Schnittka & Schnittka, 2016) and provide more task-related help to their peers (Lee, 1993). These patterns are problematic because within mixed-gender dyads, boys learn significantly more than girls (Ding & Harskamp, 2006). Mixed-gender group interactions are further complicated by boys' differential treatment of their peers based on gender. For example, men interrupt women more often than they interrupt other men, whereas women interrupt both men and women equally (Smith-Lovin & Brody,

1989). In addition, girls experience high levels of frustration and often have to conform to male-generated group norms within mixed-gender groups (Schnittka & Schnittka, 2016). These research findings suggest that students' participation in mixed-gender small groups is inequitable and cause for concern.

### **Single-Gender Groups**

A variety of studies have suggested that single-gender small groups are especially important for enabling girls to have equitable levels of participation in STEM activities. Even among six-year-olds, all-girl groups have high rates of collaboration, whereas all-boy groups often have “onlookers” who do not assist with the task (Green & Cillessen, 2008). This pattern of greater collaboration in all-girl groups compared to either mixed-gender or all-boy groups continues in both middle school (e.g., Asterhan, Schwarz, & Gil, 2012) and high school (e.g., Ding & Harskamp, 2006). Girls working in single-gender engineering groups tend to use language that refers to their collective group (we/us) and focus on group-oriented interactions (Schnittka & Schnittka, 2016). In contrast to the collaborative benefits for girls working in single-gender groups, the experience of working in mixed-gender groups may cause girls to adjust their interactional style to be more competitive in nature as they seek to have input in the group activities (Schnittka & Schnittka, 2016).

With greater collaboration and a focus on the group, girls working in single-gender groups may feel intellectually and emotionally safer than their female peers working in mixed-gender groups. For example, in a study of undergraduate engineering students, Dasgupta, Scircle, and Hunsinger (2015) found that women felt less threatened, more positively challenged, and more confident and ambitious in their engineering career

aspirations when working with other women. Single-gender groups allow girls to avoid the dominance of boys and have the support of friends, so unsurprisingly, girls often prefer to work in such groups (Dare, 2015; Parks, 2006). This desire to work in all-girl groups is consistent for students in elementary school (e.g., Adamson, Foster, Roark, & Reed, 1998), middle school (e.g., Barbieri & Light, 1992), and college (e.g., Zhan, Fong, Mei, & Liang, 2015). Single-gender, out-of-school engineering programs for elementary students are also particularly powerful in influencing girls' perceptions of engineers and attitudes toward engineering careers (Hirsch, Berliner-Heyman, Cano, Carpinelli, & Kimmel, 2014).

### **Single-Gender Versus Mixed-Gender Groups**

With the goal of fostering girls' interest and participation in STEM and issues associated with equitable participation in mixed-gender groups, the potential benefits of single-gender groups in STEM education must be considered. Some researchers (e.g., Bennett et al., 2010; Monereo et al., 2013; Underwood, Underwood, & Wood, 2000; Zhan et al., 2015) have found a positive association between single-gender groups and equitable participation. For example, in a systematic review of 94 studies of small group discussions in high school science classrooms, Bennett et al. (2010) found that single-gender groups functioned more purposefully than mixed-gender groups. Underwood et al. (2000) found that single-gender pairs of elementary students had more verbal interactions, were more task-focused, and were more likely to share the materials than mixed-gender pairs. In a study of 11-12-year-old students working in pairs, Barbieri and Light (1992) found that all-girl pairs shared the computer mouse with short and frequent turns; in contrast, within mixed-gender pairs, boys displayed significantly more control of

the computer mouse than their female partners. Further, elementary students' self-efficacy in engineering increased significantly if they participated in single-gender engineering programs but decreased significantly if they were in mixed-gender programs (Hirsch et al., 2014).

In addition to exploring participation among group members, additional research has found that single-gender groups are associated with more positive learning outcomes, such as test performance and problem-solving abilities, particularly among girls. For example, female high school students working on physics problem-solving tasks in single-gender groups scored higher on assessments of content knowledge than their peers in mixed-gender groups (Ding & Harskamp, 2006) and had higher levels of problem-solving performance than girls in mixed-gender groups (Harskamp et al., 2008). All-girl groups tend to outperform boys in constructing strong arguments (Asterhan et al., 2012). In sum, these findings suggest that single-gender groups may support increased learning of STEM content, likely because of the more equitable and purposeful participation within these groups. With no research of integrated STEM group participation within middle school classrooms, this study fills a gap in the literature to explore whether students' participation in STEM activities varies based on the gender composition of their small group.

## **Theoretical Framework**

Because this study focuses on how students participate in small group activities, activity theory was selected as a lens to guide our work. Activity theory originated in the work of Vygotsky (1978) and Leontiev (1981), who expanded upon behaviorist learning theories to consider how individuals' goals and the tools available to them influence

learning and development. Vygotsky (1978) considered how the participant, objective or goal, and tools interacted to explain human activities. While Vygotsky's model was useful in explaining individual actions, Leontiev (1981) focused on the collective nature of human activity and distinguished between object-oriented activity, which is durable and more collective, and goal-directed activity, which is temporary and more individually focused. Engeström (1987) integrated aspects of Vygotsky's and Leontiev's frameworks and expanded activity theory to include elements of community, rules, and division of labor. In this way, it is possible to examine the collective activity system of people doing some type of work together. Within the holistic activity system, interactions are mediated by the instruments, rules, community, and division of labor, allowing for insight into the complex and social nature of human learning (Engeström, 1987).

Engeström (1987; 2000) identified key elements of an activity system (see Figure 4.1). The *participants* or subjects are the actors doing the activities. These participants have an *objective* or motive for doing the work. The participants rely on *tools* or instruments to support their work. These tools can include physical, mental, psychological, symbolic, or abstract instruments. The *division of labor* must be negotiated by the participants working within the activity system to determine how the activities are divided among participants. *Rules* or norms are the expectations and practices, either explicit or implicit, that guide interactions within the activity system. As participants work on a given activity, they also interact with those in the *community* around them. Finally, the *outcome* is the end result of an activity.

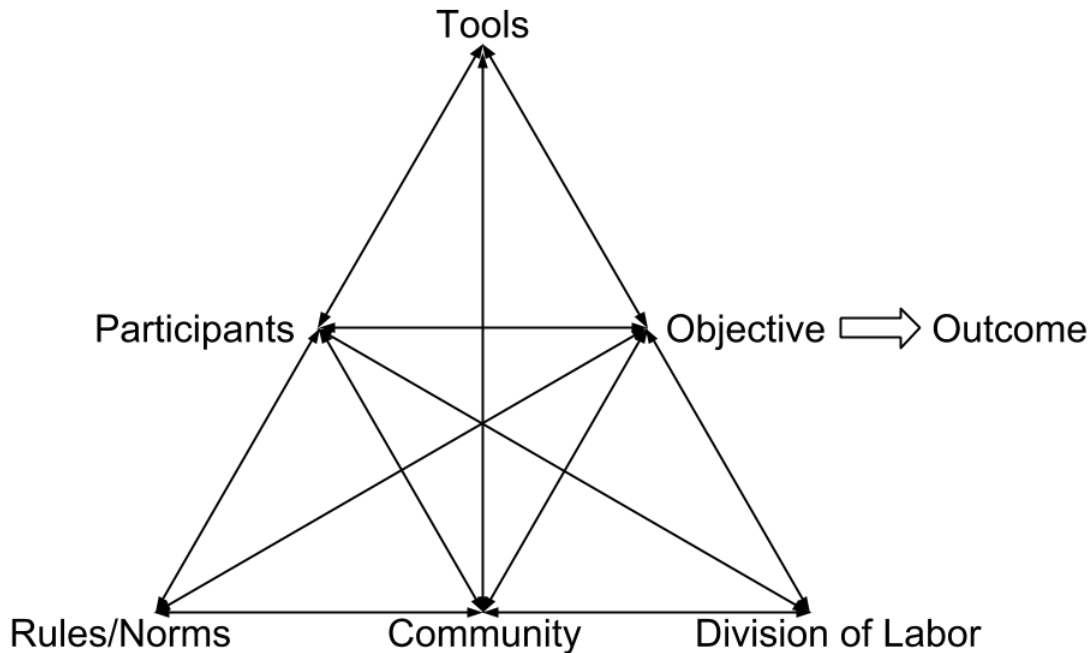


Figure 4.1. Activity theory elements.

Within an activity system, it is possible to distinguish between short-lived actions and more durable actions oriented toward the objective. In addition, the collective activity system may evolve over time (Engeström, 2000). Disturbances, or “deviations from standard scripts,” often arise from contradictions within a system and can drive change and development (Engeström, 2000, p. 964). For example, a new tool that is introduced may cause frustration and imbalances in the activity system, resulting in shifts. Although these disturbances or contradictions may serve as obstacles, they can also be helpful in developing the activity system, even expanding an activity through “expansive transformation,” which occurs when “the object and motive of the activity are reconceptualized to embrace a radically wider horizon of possibilities than in the previous mode of the activity” (Engeström, 2001, p. 137).

Activity theory is a productive theoretical framework because it allows for the analysis of learning within a particular social setting, such as small group work (Murphy



& Rodriguez-Manzanares, 2008). It can help in making sense of complex data sets (Yamagata-Lynch, 2010) while helping researchers recognize the social and material resources that are most important in a given activity (Roth & Lee, 2007). When considering STEM activities, activity theory can be used to better understand how activity systems differ depending on the gender composition of the small group and how the activity system in which small group learning occurs may shift based on the focus of the activity (science or engineering).

## **Methods**

### **Research Design**

This study utilized a multiple embedded case study to explore the phenomenon of student participation in the small group activities of an integrated STEM unit based on their group's gender composition. A case study method was selected to provide an in-depth exploration of the social phenomenon of small group activity (Yin, 2014). In this study, three small groups of students each represent a case. One small group is composed of all girls, one group is all boys, and one group is mixed gender (two girls and two boys). Case-level and cross-case analyses were used to compare the participation patterns of students across the three groups in both science and engineering activities within the STEM unit.

### **Context**

This study was situated in the fifth year of a five-year, NSF-funded research project that focused on developing in-service K-12 teachers' understanding, development, and implementation of integrated STEM units based on the framework for integrated STEM instruction (Moore, Stohlmann, et al., 2014), which includes six key

tenets: 1) a motivating and engaging context; 2) an engineering design challenge; 3) opportunity to learn from failure through redesign; 4) inclusion of mathematics and/or science content; 5) student-centered pedagogies; and 6) an emphasis on teamwork and communication. During the first three years of the grant, teachers attended a three-week professional development (PD) summer institute focused on teaching engineering and data analysis, integrating engineering in science instruction, and creating integrated STEM units. Teams of teachers worked together and with a graduate student coach to write integrated STEM units during the PD. They then piloted, revised, and implemented their units with their students during the school year.

During the final two years of the grant, teachers field-tested edited versions of the curricula that had been developed by teachers in the initial three grant years. Field-test teachers had participated in at least one of the first three years of the grant, attending the full three-week PD and writing an integrated STEM unit. In year 5, when this study occurred, they attended a one-week summer PD focused on the unit they would be implementing. The first author served as the curriculum development and PD lead for the unit explored in this study.

### **Curricular Context**

The curricular unit, *Laser Security System*, was written for students in grades 6-8 and focused on science content related to properties of light, including reflection, refraction, absorption, transmission, the wave model of light, and the electromagnetic spectrum. This unit was selected via purposive, criterion-based sampling (Miles, Huberman, & Saldaña, 2013) because of its inclusion of all six tenets of integrated STEM instruction (Moore, Stohlmann, et al., 2014). Throughout the unit, students worked to

meet the needs of a client to develop a laser security system to protect valuable artifacts in a museum exhibit. After learning the foundational science content, small groups of students were tasked with using a single laser, mirrors, and lenses to design a system that reflected and refracted light such that a thief would have to cross the laser light at least three times in walking from the exhibit entrance to the artifacts on display. After planning their designs, groups tested their designs, identified problems or ways to improve their initial designs, and redesigned their laser security systems. Evidence-based reasoning was emphasized in the curricular materials to ensure that students applied their content knowledge related to the properties of light, rather than “tinkering” with the materials when creating their designs. For example, one of the suggested activities in the curricular unit required students to evaluate their design ideas in relation to the problem’s criteria and constraints, providing data as supporting evidence and justification of how the data and evidence support their design. The unit was composed of eight lessons, each of which was intended to take at least one 50-minute class period (Table 4.1). In this study, the unit was implemented during 20 class periods.

*Table 4.1. Laser Security System Lessons*

Lesson	Days of Implementation	Lesson Focus	Lesson Summary
Lesson 1	1-3	Engineering	Design Challenge Introduction: Students work in small teams to review the Engineering Design Process (EDP). They complete a card-sorting activity to demonstrate their knowledge of the EDP stages and how each stage corresponds to real-world engineering. Students read a client letter that introduces them to the context of their engineering design challenge, a security company that needs a laser security system to protect valuable museum displays.
Lesson 2	4-5	Science	Waves and Electromagnetic Spectrum: Students explore why the light that shines from a flashlight looks different than the light that comes from a laser pointer. Students learn about the wavelength, amplitude, and frequency of waves and how these relate to the energy of the wave. They discuss the color spectrum and relationships between the wave properties and the color of light seen. Students connect their learning to the engineering problem of creating a laser security system.
Lesson 3	6-7	Science	Light Propagation: Students explore some of the basic properties of light. They observe that light travels in a straight line, spreads out as it moves away from its source, and interacts differently with different surfaces. Students explore absorption and transmission of light using different materials and relate their learning to the engineering design context.

Lesson 4	7-8, 10	Science	Intro to Reflection and Refraction: This lesson introduces students to reflection and refraction of light. Through hands-on activities, students observe light as it interacts with mirrors and lenses. They learn that light behaves differently depending on the medium with which it is interacting. Students consider how mirrors and lenses can be of use to them in the engineering design challenge of creating a laser security system.
Lesson 5	9, 11	Science	Reflection/Refraction Simulation: In this lesson, students read an email from the client with responses to their questions. Students complete a guided exploration of a simulation. By manipulating variables within the simulation, they discover the law of reflection. They also learn that the angle of refraction is dependent upon the medium through which light is passing, which affects the speed of the light. Students connect this learning to the engineering design challenge, noting how their new content knowledge can help them plan a successful laser security system design.
Lesson 6	12-13	Science	Reflection/Refraction Experiments and Data Collection: Students apply their learning from the reflection and refraction simulation to a hands-on activity. They conduct controlled experiments to measure angles of reflection and refraction of mirrors and lenses. As they work through a guided lab, students record data they will need for their laser security system prototype design and reflect on how the lab activities will inform their designs.

Lesson 7	14-18	Engineering	Plan/Build/Test: Students apply their previous learning to make a plan for their laser security system. Students individually brainstorm potential design ideas, then work with their teammates to compare ideas and create at least two team plans using precise measurements from their previous labs. To decide between their team plans, students complete evidence-based reasoning graphics to examine their designs in relation to the criteria and constraints of the design challenge. Students make a physical prototype of their laser security system using the design plan they developed in the previous lesson. They test their own security system as well as other teams' designs, then provide feedback to the other teams. Based on their own observations and the feedback they receive from their peers, teams of students identify ways to improve their security system design based on the client's criteria and constraints.
Lesson 8	18-20	Engineering	Redesign: In this lesson, students utilize their reflections from the previous lesson to improve their laser security system prototypes. They work as a team to create a new design plan, then build, test, and evaluate their prototype. Students compose letters to the client to justify why their design fulfills the criteria and constraints. They also reflect on how their understanding of the design challenge has evolved throughout the course of the unit.

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## Participants

Participants in this study were 11 students working in teacher-assigned small groups. All students were sixth-graders, aged 11-12 years, at a suburban middle school in

the Midwest United States. Within the district, 31.3% of students identified as students of color, 20.5% qualified for free or reduced-price lunch, 13.9% received special education services, and 6.2% had limited English proficiency. The participants experienced the *Laser Security System* unit in their science class. Their teacher, Ms. Baker (all names are pseudonyms), participated in the aforementioned PD during years 1 and 3 of the project to learn about STEM integration and develop integrated STEM units, and again during years 4 and 5 to field-test revised versions of curricula. The class had a total of 27 students (nine girls and 18 boys), who were divided into small groups for the unit activities. Within the class, there were two all-girl groups, three all-boy groups, and three mixed-gender groups. One group of each gender composition was selected for this study based on the group members' consent to participate and comfort with the video camera and audio recorder. Participants' pseudonyms and demographics are shown in Table 4.2. All 11 participants in this study were native English speakers. Brian, a student in the all-boy group, received special education services.

*Table 4.2. Participant Demographics*

Group Gender Composition	Pseudonym	Gender	Ethnicity
All-girl	Elsa	Female	White
	Kiera	Female	White
	Kelly	Female	White
All-Boy	Charlie	Male	White
	Adam	Male	Asian American
	Brendan	Male	White
	Brian	Male	White
Mixed-Gender	Madison	Female	White
	Amanda	Female	White
	Umar	Male	African American
	Alan	Male	Asian American

## **Data Collection**

Data were collected each day of the 20-day unit implementation. A video camera and audio recorder were focused on each small group at any time they worked together. This resulted in 256 minutes of data for the all-girl group, 237 minutes for the all-boy group, and 258 minutes for the mixed-gender group. All of the small group audio was transcribed. Each student maintained an individual worksheet packet, which was copied for analysis. In addition, daily field notes taken by the first author during unit implementation served as another data source.

## **Data Analysis**

Data were analyzed in two phases. During the first phase, each of four researchers focused on one student within each small group throughout the duration of the unit to develop a thorough understanding of that student's particular patterns of participation. Researchers focused on their target student while watching the small group videos and took detailed memos to capture their observations of the student's participation. At the end of the unit, each researcher wrote a report for their focus student that highlighted the student's participation throughout the course of the small group activities. Researchers met to discuss overall patterns in group functioning and develop a case report, and this process was repeated for the remaining cases.

During the second phase of data analysis, the elements of activity theory were used to better understand students' patterns of participation across activity type (science versus engineering) as well as across cases (all-girl, all-boy, mixed-gender groups). Researchers used deductive coding methods (Miles et al., 2013) based on the elements of activity theory to code their memos, first coding all of the science activities, then all of



the engineering activities. Constant comparative analysis strategies (Corbin & Strauss, 2015) were used to look for consistencies and differences between activities and groups as researchers referred to memos, transcripts, field notes, and videos in this phase of analysis.

## **Findings**

Because this study is focused on understanding students' participation in STEM activity systems based on the gender composition of their small group, the findings are presented in relation to the elements of activity theory. The first element of activity theory, participants, is described in the Methods section above. For the remaining elements of activity theory, the activity system for each group is described for both science and engineering, with differences across groups and across task focus (science versus engineering) emphasized throughout. Student quotations and vignettes are used throughout the findings section to provide examples of student interactions.

### **Objectives**

**Science objectives.** Within the mixed-gender group, the purpose of doing the small group science activities varied across students. For the girls in the group, the purpose was worksheet-oriented, with a focus on task completion. They sought to complete the required tasks as efficiently as possible, relying on the guidance of worksheets to shape their participation. In contrast, boys in the mixed-gender group viewed the purpose of the science activities as providing them with opportunities to socialize and occasionally engage in hands-on activities. However, because the boys were only interested in participating on occasion, they struggled to negotiate their involvement. Because the girls prioritized efficiency, they controlled the activities and were hesitant to

allow their male peers to participate. These differing objectives were a source of conflict within the mixed-gender group. Vignette 1 is from Day 7, when the students explored absorption and transmission of light by observing light in relation to a variety of materials. This vignette illustrates the girls' preoccupation with efficiency and their frustration with the boys' intermittent involvement.

*Vignette 1.*

Amanda: What time is it? 1:15? We only got three done.

Madison: It's too bad because those dumbos [boys] were messing off. We should tell [Ms. Baker] that all they do is mess around.

Amanda: So, light reflects off the aluminum.

Ms. Baker: Are you guys done?

Amanda: We're not done. Can we have the flashlight please?

Madison: Yeah, because all you guys are doing is shining it everywhere.

Umar: Can I? I wanna use it for the aluminum foil.

Amanda: Stop.

Madison: Stop. You're not doing it right.

Ms. Baker: [Umar], are you getting stuff done?

Madison: No.

Umar: Yeah, I'm trying to grab the...

Madison: No, you're not. You guys have been messing around the entire time.

Alan: I'm done.

Similar to girls in the mixed-gender group, those in the all-girl group were also motivated to complete the worksheets associated with the curricular unit. They frequently compared responses with one another before recording answers on their worksheets. Although they discussed efficiency less frequently than the girls in the mixed-gender group, they remained focused on progressing through the assigned tasks.

Participants in the all-boy group focused on different objectives throughout the science activities, with social motivations shaping their participation. Charlie's primary focus was learning the science content and getting a good grade, although he was also interested in developing social relationships with his teammates, especially Brendan. Adam's social and academic motivations were in competition throughout the science activities, with his frequent off-task socializing in contrast to the occasions when he discussed his desire to get good grades and needing to focus on the task at hand. Both Brian and Brendan were primarily focused on social opportunities within the classroom, with academics having lower priority. For example, Vignette 2 is from Day 8, when the students used a flashlight, lenses, and mirrors to explore reflection and refraction. While Charlie explored how light was affected by the concave and convex lenses, Adam and Brendan socialized.

*Vignette 2.*

Charlie: Okay so this is the convex.

Adam: Hey guys, does anybody wanna sing a song with me? Does anybody still wanna sing Wrecking Ball?

Brendan: I came in like a wrecking ball [singing].

Adam: I came in like a wrecking ball [singing]. That was beautiful.

Brendan: Thank you. Dude, I should sing babies to sleep.

Adam: Dude I'll come with you too.

Charlie: So, my prediction was correct, this does get smaller.

Across the three groups, girls maintained a primary focus on worksheet completion. While boys had a greater variety of objectives in the science activities, social motivations factored into their participation. Within the mixed-gender group, these differing objectives resulted in struggles to negotiate participation and conflict when the boys expressed a desire to be more involved in the activities than they had previously been.

**Engineering objectives.** As the unit focus shifted to engineering, students' objectives for completing the small group activities also shifted. For girls in the mixed-gender group, the primary objective of completing the tasks efficiently remained consistent. For example, as the students developed their design plans on Day 15, Madison was concerned about their lack of efficiency. She exclaimed, "You realize every other group has a plan for their laser security system except for us?" The students in this group struggled to make progress on the open-ended design activities. Although they were unsure about how to proceed in the engineering tasks, the girls remained hesitant to let the boys in their group take an active role. They sought to maintain power, only occasionally taking up ideas from the boys that might lead them forward. Boys in the mixed-gender group again sought opportunities to engage in hands-on activities, particularly when novel materials like laser pointers were available for their use.

Students in the all-girl group also struggled in knowing their objective in the open-ended engineering activities, which did not require worksheet responses. They had

frequent off-task conversations throughout the engineering lessons and were unsure when they had completed the task. They had several design iterations that met the criteria and constraints, but rather than recording the details of their design, they continued to tinker with the materials and were less focused than they had been in the science lessons. For example, as the girls developed their design plan on Day 15, they shared ideas and tinkered with the materials, but recorded no information about possible designs. This is demonstrated in Vignette 3, when the students continued to make adjustments to their design despite already having a successful iteration.

*Vignette 3.*

Elsa: So how do we set up our mirrors? Do we want to make our mirrors a little smaller this time? Like set them up a little smaller?

Kiera: I don't think that we need the flat mirror.

Kelly: No. We're supposed to use the flat lens.

Kiera: The flat lens.

Kiera: This one [binder clip] just doesn't want to stay on here [lens].  
That's just going to have to go here.

Elsa: [*moving lenses around*]

Kiera: Where does it go?

Elsa: I don't know where it goes.

Kiera: Should we even put the clips on the flat mirror? Or no?

Elsa: I don't know.

Kelly: [*shrugs*]

Kiera: I don't think we should. Wait, does the flat mirror, I mean the flat lens reflect?

Kelly: [*moving mirrors around*]

Elsa: Do any of the lenses reflect?

Kiera: Yeah. So, this is the flat mirror. The flat mirror reflects.

Elsa: Then we can use this. Do you want to put the mirrors on the outside and those [lenses] all in the middle?

Kelly: Well, I mean, we need it to reflect.

Elsa: Because it goes through...

Kelly: But then we only have three mirrors.

Elsa: And it reflects. We don't need four.

Kiera: I don't think that matters. What was I going to say?

Elsa: Oh, gosh...

Elsa: [*moving binder clips around to keep mirrors standing in place*]

Kelly: [*moving mirrors around*]

Elsa: And just to remind you, we have another mirror.

Kelly: I thought we weren't using it.

Elsa: It reflects though, so we can use it.

In the all-boy group, Adam, Brendan, and Brian became more oriented toward the objective of using the hands-on materials in the open-ended design activities. However, this interest ebbed and flowed throughout the engineering activities. In contrast to the rest of his teammates, Charlie focused on the objective of designing a laser security system to solve the real-world problem and meet the criteria and constraints of the client. He

integrated his knowledge of the design context as well as the science content of reflection and refraction as he considered how to solve the problem. For example, as his teammates considered their design, Charlie reminded, “When you shine it at an angle, it reflects at the exact same angle,” and when their design was not working as intended, Charlie retrieved a protractor to refine the measurements.

## **Tools**

**Science tools.** For both girls and boys in the mixed-gender group, the physical materials associated with the lesson served as tools in working toward the objectives. However, the girls in this group also relied heavily on science worksheets as tools for moving the group forward. The structure of the worksheet guided their participation and engagement in the science activities. In addition to the physical tools, the girls also utilized psychological tools related to confidence and task management. Within the mixed-gender group, the girls were very confident and comfortable in progressing through the worksheet-based activities. They used their confidence and familiarity with school science as a way to maintain superiority over the boys because they knew what needed to be done. Because the girls had a better idea of what was expected and how to go about achieving it than their male peers, they were able to dictate the boys’ involvement. For example, on Day 8, the students explored reflection and refraction of light using mirrors and lenses. Vignette 4 is from this class period and demonstrates how the girls in the mixed-gender group used the boys’ lack of understanding of the task to restrict their involvement.

### *Vignette 4.*

Amanda:        Can I have the flashlight?

Umar: Wait, can I try it? I wanna try it [testing one of the mirrors] once.

Madison: Do you even know how we're supposed to do it?

Girls in the all-girl group also relied on the worksheet as their primary tool for meeting the activity objectives, with the physical materials associated with the lesson serving as supporting tools. With their agreement on the objective of the lesson, they seamlessly used their worksheets to guide participation within their group. In contrast, the physical materials took precedence over the worksheets in the all-boy group. These physical tools included a flashlight, mirrors, lenses, protractors, and assorted materials for comparing the absorption and transmission of light. For boys in the all-boy group, there was less concern about “correct” answers, and each boy recorded as much or as little on his individual worksheet as he desired, with little influence of his peers. For example, in Vignette 5 on Day 7, the students explored the absorption and transmission of light by observing its interactions with different materials. Brian and Brendan maintained complete focus on the physical materials, ignoring their worksheets. In contrast, Charlie recorded notes on his worksheet throughout the investigation and sought to complete one set of notes before testing the next material, whereas Adam recorded only at the end of the vignette.

*Vignette 5.*

Charlie: Alright, so first the black paper.

Charlie: [*writing*]

Adam: Black paper?

Charlie: Oh yeah, there's the black paper.

Brian: [*shines flashlight on black paper*]



Adam: You want to do aluminum foil first?

Charlie: Wait, no.

Brian: [*shines flashlight on black paper*]

Charlie: Okay so it doesn't go through black paper.

Charlie: [*writing*]

Brendan: [*picks up aluminum foil, shines flashlight on aluminum foil*]

Brian: [*picks up wax paper, shines flashlight on wax paper*]

Brendan: It doesn't go through tin foil.

Charlie: Oh, we're not there yet. We're still doing the black paper.

Charlie: [*writing*]

Adam: [*writing*]

**Engineering tools.** Without a worksheet to guide their participation in the engineering-focused activities, the physical materials became a primary tool for those in the mixed-gender group. In particular, the laser pointer became a tool for wielding power in the group, with the student in control of the laser largely in control of the group's activities. The girls sought to maintain this control through their ongoing task management and by restricting the boys' access to the materials, as illustrated in Vignette 6.

*Vignette 6.*

Alan: At least let us help you by using the stuff.

Madison: You guys aren't any help.

Alan: We're trying to but you --

Amanda: Okay, okay, okay.

Madison: Is Umar trying too?

Umar: I'm waiting for you guys to give us the stuff.

Madison: You guys aren't helping though.

Umar: We're trying.

Madison: You're trying to turn on the water [at the lab station].

Alan: No, we're not, we're trying to help, but you guys won't let us use the stuff.

Madison: There are other ways to help besides using the stuff.

Umar: Do what then?

Despite the girls' attempts to maintain dominance in their group, the tool of confidence shifted in favor of the boys during engineering. With increased confidence related to the open-ended design activity, the boys were more active in sharing ideas and manipulating the materials associated with the laser security system design.

Similar to girls in the mixed-gender group, those in the all-girl group demonstrated less confidence in the open-ended engineering design activities. The students were provided with a large piece of grid paper with no questions or instructions to guide their participation, as well as the physical lesson materials, including a laser, mirrors, lenses, and binder clips to hold the mirrors and lenses in place. In addition to the provided materials, girls in the all-girl group also used the flashlight on their phones as a tool. Without concrete steps guiding their participation, the girls resorted to off-task conversation and tinkering, using their phone flashlights to see the path of light rather than using their knowledge of light to develop their laser security system.

In addition to the physical materials associated with the engineering design activities, boys in the all-boy group also drew upon plans they had individually developed and sketched in their notebooks as tools in designing a laser security system. Unlike the other groups, the boys accessed their individual ideas related to the design context as they considered how to move forward. After sharing their individual ideas, the boys negotiated a group design by incorporating multiple students' ideas, illustrated in Vignette 7 from Day 15.

*Vignette 7.*

Adam: Should the entrance be around here?

Charlie: I don't know. I'm going to figure out... I'm just going to see where it's going to refract.

Adam: Then, do you want to do Brian's idea, where you do an M or something?

Brian: Yeah. I'm trying to do the M idea. I'm trying to figure out how do we...

Charlie: I don't know what happens when you do that at a 15-degree angle. What angle would it refract act, at a 15-degree angle?

Adam: I'm not sure. We could just make an educated guess.

Charlie: Good idea. If it's concave, I guess it's going to refract around 20. Yeah, I guess.

Adam: Yeah.

## Division of Labor

**Science division of labor.** The mixed-gender group included distinct divisions of labor. Madison was the group leader and dictated how other students could be involved. Amanda assisted Madison and sometimes acted as a liaison between Madison and the boys, attempting to provide ways for the boys to be involved in the group activities. Alan and Umar were largely off-task, socializing with each other and other students in the classroom, though Alan tried to contribute ideas and be involved on various occasions.

The division of labor was less distinct in the all-girl group. The students placed an emphasis on taking turns and discussed who should do each task at different points in the science activities. In Vignette 8, the girls discuss how they will use the materials as part of their exploration of how light interacts with mirrors and lenses as part of Day 8.

### *Vignette 8.*

Kelly: [writing]

Elsa: So, do you want to do it where someone is holding it [the lens], and the other person has the flashlight, and the third person is writing? Then after that we can rotate?

Kiera: Sure.

Elsa: Okay. Because then I feel like everyone can do something.

Kelly: Yeah.

The leadership role was fluid in the all-girl group, with each girl having at least a brief turn as the group leader. Elsa was the most vocal leader, whereas Kelly led the group through actions with the materials. Kiera tended to follow her teammates' lead

more often than she took on an active leadership role, but status and power distinctions were not readily apparent among girls in this group during science activities.

Within the all-boy group, Charlie was the clear leader throughout the science activities. He attempted to engage his teammates in the activities at different points, but they were not always interested in participating. Charlie maintained intellectual power and attempted to leverage this status to increase his social status within the group. For example, on day 5, Charlie asked, “Do you guys want answers?” Adam occasionally assisted in leading the team forward academically, although he also sought to entertain and maintain his social status in the group. In contrast to Charlie’s intellectual status, Brendan had the greatest social status in the group, with his peers seeking his recognition and approval. Brian sought this approval by mimicking his teammates’ actions, whereas Charlie discussed shared experiences as a way to gain Brendan’s recognition. For example, Vignette 9 occurred on Day 1, as the students considered how to keep track of whom they were referring to in the group, with Brendan and Brian sharing the same real first name. Charlie used his recollection of past interactions with Brendan to make a social connection.

*Vignette 9.*

Brendan: Call me [Brendy] boy.

Charlie: We're just gonna call you, you're [Brendy] Haha. There's a story for [Brendy] Haha. [to Brendan]

Brendan: How'd you know that?

Charlie: We went to the same school. You were called that in fourth grade.

Brendan: It's cause...you know [Jacob]?

Charlie: [Jacob], yeah.

Brendan: It's because his dad calls me that.

Charlie: We were in the same fourth grade class.

Brendan: Oh yeah.

**Engineering division of labor.** As was the case in science lessons, Madison sought to maintain her role as team leader in engineering. However, she seemed less equipped to lead her team in the open-ended engineering activities. At times, this resulted in frustration and aggression. For example, as the students tinkered with their design on Day 17 to try to get the light to reflect as they desired, Madison said, "I give up. This is too hard." In this case, Madison decided her team was done for the day and started cleaning up even as Alan and Umar requested to use the materials. On some occasions, Madison's uncertainty with the open-ended activities resulted in the boys being allowed to contribute. While Madison did allow for some contributions from her teammates in engineering, as soon as the group was back on track with the design activity, Madison attempted to regain control of both the physical materials and the conversation in the group. Thus, her teammates largely acted as assistants. Amanda willingly accepted this role and continued working on the engineering activity even when Madison had given up, whereas Alan and Umar were less satisfied to be relegated to doing only what Madison asked of them.

The division of labor became less equitable in the all-girl group in engineering activities. Kelly tended to take on the bulk of the work, making measurements and recording their design plan. Elsa and Kiera spent more time off task than they had in the

science lessons. For example, Vignette 10 occurred on Day 15, as the girls developed their initial design plan.

*Vignette 10.*

Kelly: [sketching group design plan]

Elsa: What's your dominant hand? Right or left?

Kiera: My left.

Elsa: Mine's right.

Kelly: [using protractor and sketching group design plan]

Kiera: Do you know that some people, some parents, if they see their kid using their left hand, they'll switch it. Let's say that you write like this, holding with their left hand, they'll switch it to the right hand.

Elsa: Why?

Kiera: I don't know. Because they want their kid to be right-handed.

Kelly: Guys, it's starting to look very good.

While power distinctions were not apparent in this group, Elsa and Kiera seemed to have a stronger social connection, which they utilized as they had off-task conversation. As Elsa and Kiera socialized, Kelly was solely responsible for sketching their group's engineering design plan.

The division of labor remained consistent in the all-boy group. Charlie continued to do the majority of the design activities. However, Charlie also became frustrated with his peers and their intermittent involvement on several occasions. On Day 15, Adam and Brendan failed to acknowledge Charlie's suggested design ideas. In less than one minute, Charlie made three separate requests to share an idea, saying, "So guys, can I tell you

what I'm thinking quick?" and "Guys, can I give you my idea quick?" Charlie became frustrated and walked away from the table, though his position as the group leader was again apparent by the end of the class period.

## **Rules**

**Science rules.** Within the mixed-gender group, the girls had an implicit understanding that efficiency in completing the worksheets was the top priority in their group. Because of this norm, the girls made efforts to manage the behavior of their male teammates by keeping them out of the way of their activities. In addition, there was a norm of doubting opposite-gender peers within this group. The boys did not trust that the girls would share information with them, and the girls did not trust the boys to clarify science content. For example, Vignette 11 occurred on Day 8 when the students were testing lenses and mirrors to see how they affected the path of light. Alan and Umar correctly questioned the girls' description of concave lenses, but their input was not trusted, and they were told to be quiet.

### *Vignette 11.*

Madison: Wait, what are we doing next? Concave ones?

Amanda: Yeah, I'll do the next one.

Madison: Okay, I'm just gonna write concave lens.

Amanda: So, it should be...

Umar: What lens are we doing?

Madison: I'll write all the lenses; I'll write all the type of things we're doing.

Amanda: Thicker in the middle. Wait, thinner in the middle.

Umar: Thicker in the middle?



Amanda: So, the concave is thicker in the middle.  
Madison: Thicker in the middle?  
Amanda: Yeah.  
Umar: Thicker in the middle?!  
Alan: Guys, that's not the concave lens! You know that, right?  
Amanda: Be quiet!  
Madison: Stop!

Those in the all-girl group also maintained the norm of completing the worksheets, but their norms extended to include neatness and quality of completion as additional factors guiding their participation. With these additional norms, the girls frequently checked in with each other to compare responses before recording anything on their worksheet. For example, Vignette 12 took place on Day 12, when the students were conducting controlled trials to measure the angle of reflection.

*Vignette 12.*

Kelly: What'd you get for number five?  
Elsa: I haven't done five. What was number four?  
Kelly: How do the angle of incidence and the angle of reflection compare for each of your trials? They are the same degree. Yeah, they're the same degree. Like the angle of incidence comes out as the same degree.  
Kiera: And each part is really, really close to get it, to get it to show [*shining light at mirror to measure angle of reflection*].  
Elsa: Yeah.

Kiera: See, like if I put it on 15, it somewhat goes to 15.

Elsa: I think it's about the same because

Kiera: Yeah, yeah. It's hard to line up.

Kelly: [*writing*]

Elsa: So, what?

Kelly: We're writing it has the same degree.

All girls: [*writing*]

In addition to norms guiding worksheet completion, the girls also established norms related to participation. They believed each student should be involved in the activities, so they explicitly discussed who would take on the different responsibilities (e.g., see Vignette 8).

In contrast to the cooperative approach the all-girl group took, the all-boy group developed a different set of norms. The boys implicitly agreed that Charlie would lead the group and take on any responsibilities not adopted by others in the group. The rest of the boys participated intermittently, but they maintained the expectation that they could be off-task at their discretion and that neither Charlie nor Ms. Baker would require their participation.

**Engineering rules.** Within the mixed-gender group, the rules and norms guiding the students' participation shifted during engineering activities. Competition became more of a norm within the group, with increased frustration apparent, particularly for girls. This frustration was manifested in both physical and verbal aggression, with conflict over the physical materials and who would be allowed to participate. The lack of trust with opposite-gender peers continued to be the norm in engineering, although this

dissipated somewhat as the engineering-focused activities progressed. On Day 14, the students worked to develop plans for their laser security system. As they considered the criteria and constraints, the girls were uncertain about the meaning of criteria, and they asked for clarification from the boys in their group. This was the first time in the unit that the girls actively sought the boys' opinions, although Madison still wanted confirmation from Ms. Baker, as illustrated in Vignette 13.

*Vignette 13.*

Amanda: Okay so... What is criteria?

Madison: I don't really know. Criteria is the expectations, I think.

Amanda: Wait, criteria is that the expectation? [to Umar]

Umar: Yeah.

Amanda: Are you sure?

Umar: I'm sure.

Alan: Yeah it is.

Amanda: Okay, criteria is expectations, so the musts. It must reflect at least three times.

Amanda: [*writing*]

Madison: What is criteria? [to Ms. Baker]

Ms. Baker: Criteria, things that need to be included.

Without a worksheet to guide their progress, those in the all-girl group struggled to develop productive norms in engineering activities. Their norms included finishing at the same time as other groups in the class and unnecessarily tinkering with their design, even after they had a viable solution. The girls experienced a pronounced lack of norms

or expectations about what they should record and how they could decide when their design was complete.

Interestingly, students in the all-boy group maintained the same rules and norms across science and engineering. Charlie held primary responsibility for the team and their progress, and his teammates continued to follow the norm of participating only when they desired.

### **Community**

Across all three groups, certain aspects of their community were shared throughout the entire curricular unit. The community was composed of other small groups of students, the classroom teacher, an educational assistant, and the first author, who was minimally involved with the students. Despite the seemingly consistent community, each group had unique experiences with the co-participants in the classroom context. These unique aspects of community, particularly related to the role of the teacher, are described in the following sections.

**Science community.** Throughout the science lessons, Ms. Baker was a presence in the groups' community through both whole-class instruction and group-level interactions. She provided a significant amount of structure, starting each science class period by discussing what students should be doing that day and how they should make use of the available materials. She utilized direct instruction to ensure that students were aware of underlying science concepts and vocabulary (e.g., concave versus convex lenses) before they transitioned to small group activities and maintained a central role in the science community.

Within the mixed-gender group, group-level interactions with the teacher served to maintain the girls' position of power within the group. Ms. Baker appeared to view the girls as responsible and diligent students, thus giving them the benefit of the doubt when considering their actions. For example, on Day 7, she thanked the girls when they offered to remain at their lab table during whole group instruction to finish their group's worksheet, not even questioning why the work had not been completed in the first place. Ms. Baker seemed to echo the girls' mistrust of the boys in the group, assuming that the boys were at fault for any conflicts in the group. As the students worked to measure angles of reflection and refraction of mirrors and lenses on Day 12, Ms. Baker stopped at their lab table to redirect the boys' involvement, as illustrated in Vignette 14.

*Vignette 14.*

Ms. Baker: We shouldn't be making the girls do all the work. You guys are all collaborating together to...

Umar: They said no, don't help us.

Amanda: That's not true!

Umar: Yes, it is!

Alan: Yeah, it is!

In this exchange, Ms. Baker failed to acknowledge that the girls were contributing to the problem by restricting the boys' access to the materials, as shown in Vignettes 4 and 6.

Ms. Baker's interactions with students in the all-girl group focused on monitoring their progress on the worksheet. She checked in with the students to see how much remained for them to do and how much more time they needed. Like the girls in the

mixed-gender group, those in the all-girl group were trusted by the teacher to remain on-task and complete the expected activities.

In contrast, Ms. Baker's approach to the all-boy group largely focused on behavior management, particularly related to Brian. Because Brian maintained much of Ms. Baker's focus in this group, she had fewer interactions with the other students. Brendan and Adam largely avoided interacting with Ms. Baker, shifting their off-task behavior whenever they sensed she was nearby. Ms. Baker's interactions with Charlie demonstrated her respect for his diligent focus on classroom activities, as well as his knowledge related to science. For example, Charlie approached her to talk about a famous astrophysicist unfamiliar to her.

**Engineering community.** In the engineering portions of the curricular unit, the focus of Ms. Baker's interactions with the students shifted away from providing information about the activities. She utilized whole-class instruction rarely, often starting the class period by telling students to continue working on their engineering projects with little additional detail or guidance. Rather, her interactions with the students largely focused on managing the materials as the students worked in their small groups. In particular, she carefully distributed the laser pointers, both as a way to manage students' safety with the lasers and to deal with a shortage of laser pointers. This primary interaction was true across all three groups.

In addition to Ms. Baker's primary interactions related to the lasers, she had distinct patterns of interaction with the different groups. In the mixed-gender group, these interactions shifted to clarifying engineering-specific ideas, such as criteria and constraints. In the all-girl group, she conducted brief check-ins to see how the students

were doing and whether they had any questions. In the all-boy group, she continued to manage Brian's behavior.

Throughout the engineering activities, students had increased interactions with peers beyond their small group, resulting in a sense of increased chaos in the classroom as they participated in the open-ended tasks. They engaged in off-task activity that crossed group boundaries, but they also compared designs with one another. For example, as the all-boy group tested their design on Day 19, students from the other groups gathered around their table to observe whether or not their design was successful.

### **Outcomes**

**Science outcomes.** During the science activities, the primary outcome for the mixed-gender group was completing their worksheets. Worksheet completion was also the outcome for the all-girl group, although these students also ensured that their worksheets were completed neatly and with attention to detail. The outcome differed by student within the all-boy group. Charlie, Brendan, and Adam all completed their worksheets, though not with the same level of care as the girls in both of the other two groups. Whereas Brendan and Adam focused on exerting the minimal effort to satisfy Ms. Baker's expectations, Charlie was genuinely interested in learning the science content. For example, even as his peers engaged in off-task conversation on Day 8 when they had completed the assigned activity, Charlie said, "I'm just gonna keep on working." His focus on learning was apparent in his conversations with Ms. Baker and the researcher, as well as in his application of the science content to engineering.

**Engineering outcomes.** Creating a physical design was the primary engineering outcome for all three groups, although their level of success varied. The mixed-gender

group created a solution in which the reflection of the laser light was successful, but their design did not meet the full set of criteria and constraints. In addition, they did not create a permanent representation of their ideas by recording their design on paper, so there was little evidence of their understanding of the engineering context or whether their design could be considered successful. The all-girl group created a design that was successful in meeting the criteria and constraints, but they also failed to record the details of their design.

The all-boy group created a successful design much earlier than the other groups, and they also created a diagram of their design. For Brian, the social benefit of sharing a design idea that was valued by his teammates seemed to be the most significant outcome. Charlie maintained his focus on the context of the lesson, considering whether their design met the criteria and constraints. For example, on Day 16 as the boys considered their design plan, Charlie alerted their attention to the requirement that the design include refraction. He explained to his teammates, “Well, the thing is, it doesn't matter when we have it refract. It just has to have refract at least once. It doesn't matter when. So, for all we care, we could have it refract at the last second.” He had internalized the design criteria and considered the simplest way to fulfill them. However, Charlie’s desire to get a good grade caused him to question whether a simple design would be sufficient. In considering their design, Charlie said, “We’re trying to get a good grade, so it has to be complicated.” Thus, he considered ways to increase the complexity of the design in the interest of getting a good grade.



## **Discussion**

This study contributes new insights into how middle school students participate in small group integrated STEM activities (see Table 4.3 for summary of findings).

Students' patterns of participation vary based on the gender composition of their small group, as well as whether they are participating in science-focused or engineering-focused activities. In the following sections, the key findings are discussed in relation to the existing literature as well as the elements of activity theory to highlight the novel findings of this study.

Table 4.3. Summary of Findings by Activity Theory Element

Activity Theory Element	Mixed-Gender Science	Mixed-Gender Engineering	All-Girl Science	All-Girl Engineering	All-Boy Science	All-Boy Engineering
Participants	2 girls, 2 boys	2 girls, 2 boys	3 girls	3 girls	4 boys	4 boys
Objectives	Efficient worksheet completion; Socialization; Hands-on activities	Efficiency; Socialization; Hands-on activities	Worksheet completion	Using materials to stay occupied	Learning; Grades; Socialization	Solving real-world problem; using materials; socialization
Tools	Worksheet; physical materials; confidence; task management	Physical materials; task management; restricting others' access; confidence	Worksheet; physical materials	Physical materials; phone flashlights; tinkering	Physical materials; worksheet	Physical materials; individual design plans
Division of Labor	Madison as group leader; Amanda as assistant	Competition for leadership between girls and boys	Shared leadership	Kelly as leader	Charlie as leader	Charlie as leader
Rules and Norms	Efficiency; girls managing boys' behavior; distrust of opposite-gender peers	Competition; conflict over materials; distrust of opposite-gender peers	Worksheet completion; neat and quality work; inclusion of all teammates	Finishing at the same time as other groups; tinkering	Charlie as teammate who would take on all responsibilities not taken up by peers	Charlie as teammate who would take on all responsibilities not taken up by peers
Community	Teacher structuring activities; teacher viewing girls as worthy of trust and responsibility versus boys as responsible for conflict	Teacher managing materials; teacher clarifying engineering ideas; interactions across groups	Teacher structuring activities; teacher monitoring worksheet progress; teacher viewing girls as worthy of trust and responsibility	Teacher managing materials; teacher providing check-ins for questions; interactions across groups	Teacher structuring activities; teacher managing behavior; teacher viewing Charlie as worthy of trust and responsibility	Teacher managing materials; teacher managing behavior; interactions across groups

Outcome	Worksheet completion	Physical laser security system prototype that did not meet criteria and constraints; no permanent representation of ideas	Worksheet completion with attention to detail	Physical laser security system prototype that fulfilled criteria and constraints; no permanent representation of ideas	Differing levels of worksheet completion; learning science content for Charlie	Physical laser security system prototype that fulfilled criteria and constraints; diagram of design
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## **Group Gender Composition and Student Participation**

In contrast to previous research (e.g., Ding & Harskamp, 2006; Jovanovic & King, 1998; Lee, 1993; Rennie & Parker, 1987), boys in this study did not dominate the small group activities within the mixed-gender group. Rather, girls in the mixed-gender group dictated how their male peers could be involved. Although it is promising that girls were able to take on more active roles in the mixed-gender group, problematic patterns of interaction remained. Students in this group experienced higher levels of frustration and conflict than students in the other groups. Like previous researchers (e.g., Schnittka & Schnittka, 2016) have found, girls in the mixed-gender group were more competitive than students in either single-gender group. They sought to control their peers' participation and used the available tools and materials to wield power over the group. Much of the conflict in the mixed-gender group seemed to result from differences in the students' objectives for doing the activities. The girls' focus on efficiency and task completion contrasted with the boys' desire to socialize and use the hands-on materials for the purpose of exploring. These objectives were in direct contrast to one another, with the boys' attempts to manipulate the materials reducing efficiency and causing frustration among the girls.

In general, students in single-gender groups were more purposeful in their approach to the tasks and shared the materials more seamlessly, as other research has shown (e.g., Barbieri & Light, 1992; Bennett et al., 2010; Underwood et al., 2000). The more cohesive functioning within single-gender groups is likely because their objectives for participating in the task did not stand in direct conflict with one another. Participants in the all-girl group shared an objective of careful task completion, which provided a

context for cohesive group dynamics. Consistent with prior research (e.g., Asterhan et al., 2012; Ding & Harskamp, 2006; Fenwick & Neal, 2001; Green & Cillessen, 2008; Hawkins & Power, 1999; Monereo et al., 2013; Savicki & Kelley, 2000), participants in the all-girl group focused on including their teammates and developing positive group interactions.

Although boys in the all-boy group had different objectives from one another, their personal objectives for carrying out the activities did not conflict with others' purposes. Charlie, who wanted to learn the science content and apply that content to solve an engineering design problem, was still able to carry out this objective as his teammates focused on developing their social relationships and participating on occasion. The differing objectives in the all-boy group resulted in an inequitable division of labor with Charlie taking on the majority of the work in the activity system, but this work was in pursuit of his objective and did not seem to upset Charlie.

In addition to differing objectives, the three groups in this study also experienced different interactions with those in the surrounding community, particularly their classroom teacher. Ms. Baker's interactions with the students varied dramatically from one group to another. She seemed to trust the girls and Charlie to focus on the learning activities while believing that the other boys' behavior needed to be managed. Thus, many of her interactions with the all-girl group focused on general check-ins with the students. Ms. Baker's interactions with the all-boy group tended to focus on monitoring individual behaviors, with Brian receiving much of the behavioral attention. Many of Ms. Baker's interactions with the mixed-gender group related to managing group dynamics, which was not the case with the other groups. The higher rate of conflict in the mixed-

gender group attracted Ms. Baker's attention, but the group never reached an agreement about how to best manage the group tasks. Both the differing objectives and differential teacher involvement with the groups guided their participation within the integrated STEM activity system.

### **Science Versus Engineering Participation**

Like the elementary students in Wieselmann et al. (accepted), middle school students in this study also displayed different patterns of participation in science versus engineering activities. After developing group norms focused on science instruction, engineering, with its new tools and norms, served as a disturbance of the activity system (Engeström, 2000). Girls in both the mixed-gender and the all-girl groups relied on the structure of worksheets to guide their participation in science. Other researchers (e.g., Oliviera & Sadler, 2008) have also found that college-age women continue to focus on worksheets and other tangible products, rather than the concepts being explored. This reliance on the worksheet constrained how the girls in this study participated in science, with little room for exploration of the phenomenon beyond what was prompted. When this tool was no longer available in engineering, they struggled to determine how to participate and meet the task requirements. This resulted in time off-task or conflict within their group.

Consistent with prior research, during science-focused lessons, boys spent more time off-task (Harskamp et al., 2008) and were more likely to be "onlookers" (Green & Cillessen, 2008) compared to the girls. However, even those who were off-task during science activities contributed ideas and sought to be involved in engineering activities. They desired to handle the materials, particularly those materials that were novel, such as

the laser pointer. The objectives of most boys in the study included exploring the hands-on materials, and this purpose was better aligned to the type of participation that was necessary for success in the open-ended engineering activities. Boys in the mixed-gender and all-boy groups were less reliant on worksheets to guide their participation and thus experienced less of a disturbance to the activity system when that tool was no longer available. Interestingly, the all-boy group was the only group to maintain the same rules and ways of approaching the activities across both science and engineering, suggesting their modes of participating in science may be more closely aligned with open-ended engineering activities than girls' approaches to science. Although participation in the all-boy group was not equitable, this demonstrates that boys did not experience the same tensions between science and engineering as girls did.

Engineering also served as a disturbance of the community. Students engaged in more conversation with other groups during engineering, often comparing designs, sharing materials, and observing as other groups tested their designs. While other students in the classroom became more active community participants in engineering-focused activities, Ms. Baker became less involved. Throughout the engineering lessons, she gave very few whole-class instructions with specific directions to guide students. In addition, Ms. Baker focused on managing the engineering materials, so she was less available to students for providing feedback and guidance. The disturbance to the science activity system affected both the community and available tools and was therefore associated with different patterns of student participation during engineering activities.

## Limitations

While this study provides important information about how students participate in small group STEM activities and fills a gap in the literature, several limitations of the work must be considered. First, the all-girl group was composed of three students, while the other groups each had four students. It is possible that the tasks in this curricular unit were better suited to groups of three, so the number of students in each group may have shaped student participation. Second, participants in this study each had unique backgrounds and experiences beyond their gender that would have affected their interactions, and we did not have access to information to the full range of information about the intersectionality of their identities. For example, participating students had a range of ethnicities, academic abilities, cultures, and lived experiences both in and out of school, which were not included in this analysis. In addition, our treatment of gender as a binary construct, though consistent with the literature cited throughout this study, is an oversimplification that needs to be considered in more depth in future studies. Third, the participants in this study were from a single classroom, and their experiences were interpreted by researchers who relied on observable characteristics and patterns of participation. Thus, it is possible that the students' views of their own and peers' participation may differ from the researchers' views. In addition, these students' experiences may not be generalizable to all middle school students in all contexts. Although probabilistic generalization is not possible, the findings of this study can be applied via theoretical generalization (Eisenhart, 2009) to help inform educators of the unique experiences that some students will encounter as they participate in small group STEM activities.



## **Implications and Conclusion**

With an increasing focus on integrated STEM instruction and ongoing efforts to support girls' engagement and interest in STEM, this study fills a gap in the literature by considering how students' participation in small group STEM activities varies based on the gender composition of their small group. Compared to the mixed-gender group, single-gender groups had more cohesive functioning and less conflict, likely because the individual students' objectives and norms were compatible with one another. These consistent norms and objectives resulted in more productive work in single-gender groups, even when the norms and objectives shifted from science to engineering. Misalignment in students' objectives was a source of conflict and power struggles in the mixed-gender group.

In addition to the misalignment in students' individual objectives, it is important to consider the teacher's target objectives for students in selecting this curricular unit. Notably, Charlie was the only student whose objectives for the activities aligned with the objectives of the curriculum and teacher, namely learning science and applying it to an engineering design challenge. The other students lost sight of the real-world context and objective of the engineering design. Even Charlie, who maintained attention to design criteria and constraints as well as the real-world context throughout the unit, was unaware or unsure of how engineers would seek to optimize their designs. When his group had a successful design, he suggested making it more complicated to get a better grade, even though this is not authentic to real-world engineering. As integrated STEM curricular units may require more instructional time because of the additional components, it is

important for teachers to continually revisit the purpose of the activities to ensure that students are working toward common objectives in science and engineering.

Students' division of labor within their small groups also provided insight into how students navigate small group activities. Both the mixed-gender and all-boy groups displayed evidence of students negotiating task responsibilities based on the intersection of their academic ability and social position. Opinions and ideas that came from students who had higher academic or social status were taken up more seriously than those ideas that came from students of lower status. For example, Brian, who had lower academic and social status than his teammates, provided ideas on multiple occasions, but his idea was only incorporated in the group's design once. In considering equitable participation, teachers must attend to differences in students' academic and social status within the classroom and provide support to ensure that all students are accountable for participating in the small group activities.

As students in this study, particularly girls, shifted their focus to engineering design, it became readily apparent that the norms of school science were no longer sufficient in guiding their participation. Considerable support is needed to help students develop group norms around open-ended activities. In addition to negotiating the division of labor, students also need support in knowing how to track their progress on open-ended activities and determine when they have achieved the intended outcome. These supports must be put in place by the teacher, who has a significant role in supporting small group engineering activities. In order to promote equitable and productive participation, teachers must provide students with guidance related to the tools that are available to them. For example, the teacher in this study could have referred students

back to their list of criteria and constraints and suggested using this resource as a way of monitoring their progress. In addition to this type of task support, teachers also need to provide support related to teamwork and time management, as well as closure and assessment of students' final engineering designs. Without these supports in place, students in this study continued to tinker with their designs and struggled to know when their work was complete. Given the relatively recent addition of engineering to science standards in many states, professional development for teachers should include these strategies for supporting students' participation in small group STEM activities.

In addition to the need for professional development, further research is also needed to explore small group STEM participation. This study revealed the need for research related to the inclusion of students with special education needs, considerations of small group size in STEM activities, and explorations of students' intersecting identities within diverse classrooms. As integrated STEM instruction continues to become increasingly common in middle schools, researchers should consider these additional challenges related to equitable participation in small group STEM activities.

## **Chapter 5 - Participation in Small Group Engineering Design Activities at the Middle School Level: An Investigation of Gender Differences**

As demand for expertise in science, technology, engineering, and mathematics (STEM) continues to increase, STEM education is of growing concern in the United States and around the world. With ongoing calls for improvements to K-12 STEM education (National Research Council [NRC], 2011; NRC, 2012), pre-college engineering experiences are becoming increasingly common. The *Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) include engineering practices within the scope of science, indicating that teachers responsible for addressing science standards are also likely to be responsible for teaching engineering.

As efforts to improve the quality of K-12 STEM education continue, so too do efforts to increase the representation of women in STEM fields. Although women and men receive undergraduate degrees at about the same rate, women account for only 30% of all STEM degree holders and have particularly low representation in engineering (Economics and Statistics Administration [ESA], 2017), holding just 12% of engineering jobs (Corbett & Hill, 2015). STEM integration seeks to merge the disciplines and is promoted as a means of increasing the number of students who are interested in and prepared to pursue STEM careers (Honey, Pearson, & Schweingruber, 2014; Stohlmann, Moore, & Roehrig, 2012). As STEM integration becomes more common at the middle school level, it is important to consider key components of integrated STEM that are particularly supportive of young girls' interest and continued study in STEM.

While a variety of theoretical and practical conceptions of STEM exist (Breiner, Harness, Johnson, & Koehler, 2012; Brown, Brown, Reardon, & Merrill, 2011; Bybee, 2013; English, 2016; Herschbach, 2011; Johnson, 2012; Koehler, Binns, & Bloom, 2016; Ring, Dare, Crotty, & Roehrig, 2017), there is an emerging sense of agreement around the importance of teamwork in integrated STEM instruction (Brown et al., 2011; Kennedy & Odell, 2014; Moore, Glancy, et al., 2014; Moore, Stohlmann, et al., 2014; Rinke, Gladstone-Brown, Kinlaw, & Cappiello, 2016). Teamwork and collaboration are emphasized in educational reforms, including the Common Core State Standards and NGSS (NGSS Lead States, 2013; NRC, 2011; NRC, 2012; National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010) as well as the vision statement of The National Academy of Engineering (NAE, 2004). Within middle school classrooms, teamwork is often implemented through small group activities. Small group learning is particularly effective when the learning task is open-ended and has multiple solution paths (Cohen, 1994), which is often the case in engineering design tasks.

Despite the centrality of teamwork to integrated STEM and the high potential of engineering design activities within small groups, little is known about how students at the middle school level participate in small group engineering activities (Baillie & Douglas, 2014; Capobianco, French, & Diefes-Dux, 2012). Investigations of small group interactions in engineering tend to focus on the undergraduate level (Tonso, 2006; Wolfe & Powell, 2009). Schnittka and Schnittka (2016) explored small group gender dynamics in a design-based afterschool program for middle school students; however, their work was in a rural, primarily White setting, included cooperative group roles within self-

selected groups, and has not yet been extended to formal middle school classroom instruction of engineering-based integrated STEM. Compulsory coursework driven by a teacher's need to address specific academic standards in science and associated with grades for students is likely to create a different environment for student interactions than elective, non-graded, informal experiences. In addition, existing studies often use quantitative analyses to investigate associations between motivation, context, and engagement (Fredricks, Hofkens, Wang, Mortenson, & Scott, 2018). Since small group work is ubiquitous in STEM, the affordances and limitations of small group activities must be considered.

This study addresses the gap in the literature to explore the following research questions:

- 1) What differences, if any, are seen in the engineering practices middle school girls and boys display during an engineering design challenge?
- 2) How, if at all, is group gender composition related to students' participation in small group engineering design activities?

## **Literature Review**

### **Small Group Learning and Girls' STEM Interest**

Although a variety of factors, including stereotypes and biases, curriculum, and workplace environments, contribute to the underrepresentation of women in STEM (Corbett & Hill, 2015), many researchers point out low levels of STEM interest among girls as a particularly salient factor in influencing the career trajectories of young girls (Archer et al., 2010; Eccles & Harold, 1992; Martin, Way, Bobis, & Anderson, 2015; Riegle-Crumb, Moore, & Ramos-Wada, 2011; Sadler, Sonnert, Hazari, & Tai, 2012;

Wigfield et al., 2015; Xie & Shauman, 2003). In a survey of 7,970 individuals, Maltese and Cooper (2017) found that STEM interest was most often initiated prior to grade 6, and throughout the school years, STEM interest was fostered more through school experiences and coursework than out-of-school experiences. Positive school STEM experiences in the middle school grades are critical for developing students' STEM interest (Mosatche, Matloff-Nieves, Kekelis, & Lawner, 2013; Shapiro & Sax, 2011).

A variety of studies, including two meta-analyses (Lou, Abrami, Spence, Poulsen, & d'Appollonia, 1996; Springer, Stanne, & Donovan, 1999), have found that small group learning contributes to positive outcomes in achievement, motivation, persistence, attitudes, engagement, and problem-solving (Acar & Tarhan, 2008; Baines, Blatchford, & Chowne, 2007; Baines, Rubie-Davies, & Blatchford, 2009; Cohen, 1994; Fredricks et al., 2018; Fung, Hung, & Lui, 2018; Meece & Jones, 1996; Qin, Johnson, & Johnson, 1995). These benefits likely arise from the combination of hands-on activities and discussions that take place in small groups. Small group instruction is proposed as an effective strategy for engaging girls in STEM because of research that indicates that girls are more cooperative and less competitive than boys (Belenky, Clinchy, Goldberger, & Tarule, 1997; Brotman & Moore, 2008; Ferguson & Fraser, 1998; Jones, Brader-Araje, et al., 2000; Zohar & Sela, 2003). A variety of researchers have found that small group learning environments benefit girls (Brotman & Moore, 2008; Burkam, Lee, & Smerdon, 1997; Cavallo & Laubach, 2001; Fredricks et al., 2018; Heard, Divall, & Johnson, 2000; Lee & Burkam, 1996; Wang, 2012; Zohar, 2006). Hands-on activities that emphasize applications of knowledge in real-world contexts can meet girls' desire to know how their

learning can be applied (Baker & Leary, 1995; Geist & King, 2008; Lee & Burkam, 1996)

Despite a number of beneficial outcomes associated with small group learning strategies, well-documented problems with small group learning also exist. The social dynamics and organization of small groups can interfere with learning (Hammar Chiriac, 2014). It is often assumed that placing students in small groups will result in their learning of collaborative skills and teamwork (Singer, Hilton, & Schweingruber, 2006), but there is little research that supports this assumption (Sampson & Clark, 2009). Girls and boys working in mixed gender small groups often display different interaction patterns (Tolmie & Howe, 1993), with girls often participating to a lesser degree in the small group activities (Hansen, Walker, & Flom, 1995). Participation of girls often focuses on passive assistance and note-taking (Jovanovic & King, 1998; Mewborn, 1999), building positive relationships (Hawkins & Power, 1999; Savicki & Kelley, 2000), and following directions (Jones, Brader-Araje, et al., 2000). Girls show higher rates of interaction with group members (Lee, 1993) and tend to focus on interactive, cooperative, and people-oriented interactions in their group work (Fenwick & Neal, 2001).

In contrast, boys are more likely to actively lead a group and manipulate the materials (Green & Cillessen, 2008; Jovanovic & King, 1998; Mewborn, 1999), focus on tasks rather than group processes (Johnson & Schulman, 1989), express competitiveness with other group members (Jones, Brader-Araje, et al., 2000), and spend time off-task (Harskamp, Ding, & Suhre, 2008). In mixed-gender groups of fourth- and fifth-graders, boys were seen to have better ideas and be team leaders (Lockheed, Harris, & Nemceff, 1983), often dominating the small group activities and handling of equipment (Kahle,



Parker, Rennie, & Riley, 1993; Patrick & Yoon, 2004). In addition to boys' control of the physical materials in their small groups, researchers have found that middle school boys also dominated speech in terms of both frequency and volume (Schnittka & Schnittka, 2016). This pattern continues into college, when men are more likely to interrupt the women in their small group than they are to interrupt other men (Smith-Lovin & Brody, 1989). These interactional styles can further perpetuate gender stereotypes related to engineering.

### **Group Gender Composition**

With a significant body of research highlighting gender differences in group interactions and issues associated with mixed-gender small groups, the significance of group gender composition must be considered. Some studies have found the presence of girls to benefit both boys and girls in the group. For example, Monereo, Castelló, & Martínez-Fernández (2013) found that among high school students, female-majority groups were more adept than male-majority groups at breaking down task objectives, regulating progress toward reaching these objectives, interacting in a cooperative manner, fostering a positive group climate, providing support for one another, and remaining on task. Having a female-majority group was the most significant predictor of group success. However, additional research findings have been contradictory. Some studies (e.g., Herschel, 1994; Meadows & Sekaquaptewa, 2011; West, Heilman, Gullett, Moss-Racusin, & Magee, 2012) have found group gender composition to be unrelated to participation in group activities. Other studies have found that mixed-gender groups are associated with more positive outcomes than single-gender groups. For example, researchers found that middle-school students participating in a design-based physics

curriculum performed better on assessments of content and practices if they had worked in mixed-gender as opposed to single-gender groups (Gnesdilow, Evenstone, Rutledge, Sullivan, & Puntambekar, 2013). Schnittka and Schnittka (2016) found mixed-gender groups to be beneficial in engineering education, with girls learning more in such mixed-gender groups.

Although research findings related to the influence of group gender composition are mixed, a number of studies (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010; Monereo et al., 2013; Underwood, Underwood, & Wood, 2000; Zhan, Fong, Mei, & Liang, 2015) have found group gender composition to be significantly related to students' participation, with single-gender groups having more equitable participation patterns than mixed-gender groups. For example, in a systematic review of 94 studies of small group discussions, researchers found that single-gender groups had more purposeful functioning than mixed-gender groups (Bennett et al., 2010). Other studies have found that single-gender pairs of elementary students had more verbal interactions, were more task-focused, and were more likely to share materials (Underwood et al., 2000). In addition, students' self-efficacy in engineering increased significantly if they participated in single-gender engineering programs but decreased significantly for those in mixed-gender programs (Hirsch, Berliner-Heyman, Cano, Carpinelli, & Kimmel, 2014).

Single-gender small groups may be particularly effective in fostering girls' equitable engagement in STEM activities, with girls experiencing greater benefits of single-gender groups than males. Green and Cillessen (2008) found that all-girl groups of six-year-olds had high rates of collaboration, while all-boy groups were more likely to have "onlookers" who did not help with the task. Cooperation between girls in single-

gender groups is more balanced than either mixed-gender or all-male groups (Asterhan, Schwarz, & Gil, 2012; Ding & Harskamp, 2006). Within all-girl engineering groups, students tend to focus on group-oriented interactions, using we/us language more often than referring to self or others (Schnittka & Schnittka, 2016). In considering this difference as well as other differences in interaction patterns, Schnittka and Schnittka (2016) asserted that girls may adjust their interactional style depending on the gender composition of their group: collaborative and focused on group solidarity in all-girl groups, and competitive in mixed-gender groups. The same degree of interactional shifts was not seen for boys in all-boy and mixed-gender groups.

Girls' collaboration and group-oriented focus can provide a safe environment for girls who are working with their same-gendered peers. Girls often prefer to work in single-gender groups because they seek to avoid the dominance of boys and have the support of their friends (Parks, 2006). This preference for all-girl groups is consistent for students at a range of ages, including those in elementary school (Adamson, Foster, Roark, & Reed, 1998), middle school (Barbieri & Light, 1992), and college (Zhan et al., 2015).

## **Theoretical Framework**

As engineering is integrated in science instruction, engineering design activities are becoming more common at the middle school level. Design-based learning focuses on engineering design challenges as the context for learning (Mehalik, Doppelt, & Schunn, 2008). Engineering design activities that center on solving problems are emphasized as an effective means of promoting engineering skills and habits of mind in K-12 settings (NRC, 2011) while engaging students in practices that are authentic to engineering

(NGSS Lead States, 2013; NRC, 2012). While these activities have the potential to support student learning and achievement, they can also promote students' interest in STEM (NRC, 2011). For example, researchers found that students who were taught using an engineering design-based science curriculum showed more positive attitudes toward STEM following the unit of instruction (Guzey, Moore, Harwell, & Moreno, 2016).

This study is grounded in the work of Crismond and Adams (2012), who developed the Informed Design Teaching and Learning Matrix based on a meta-literature review. The matrix includes nine design strategies that are fundamental to informed engineering design and include: understanding the challenge, building knowledge, generating ideas, representing ideas, weighing options and making decisions, conducting experiments, troubleshooting, revising or iterating, and reflecting on the process. In addition to identifying these strategies, the authors describe learning progressions to highlight the range of design behaviors that develop from beginning designers to informed designers.

The design strategies in the Informed Design Teaching and Learning Matrix are intended to be used as an instructional tool for teaching design and were based on key performance dimensions of design (Crismond & Adams, 2012). In this study, the performance dimensions of design (see Table 5.1) are used to explore middle school students' participation in small group engineering activities as we seek to answer the research questions:

- 1) What differences, if any, are seen in the engineering practices middle school girls and boys display during an engineering design challenge?

- 2) How, if at all, is group gender composition related to students' participation in small group engineering design activities?

*Table 5.1. Performance Dimensions of Design*

Performance Dimension	Description
Learning while designing	Informed designers learn continually as they brainstorm, plan, prototype, troubleshoot, and revise their designs. Metacognition and reflection are central in this learning.
Making and explaining knowledge-driven decisions	Informed designers apply their understanding of science and how things work to their designs.
Working creatively to generate design insights and solutions	Informed designers use creativity and take productive risks in defining problems, developing potential solutions, and improving their solutions.
Perceiving and taking perspectives intelligently	Informed designers consider multiple perspectives in defining the goals and priorities in their work.
Conducting sustained technological investigations	Informed designers intentionally collect and use evidence as they consider their design.
Using design strategies effectively	Informed designers use a variety of design practices in their work and can work effectively with others.
Integrating and reflecting on knowledge and skills	Informed designers use knowledge from multiple disciplines and reflect on their design activity.

## **Methods**

### **Research Design**

This study utilizes a multiple embedded case study methodology to explore the phenomenon of students' experiences in small group, integrated STEM activities. This methodology was selected because it allows for an in-depth exploration of a social phenomenon (Yin, 2014). Three small groups of students represent three cases, and the individual students within each group serve as units of analysis.

## **Context**

This study is situated within the context of a five-year, federally-funded research project focused on developing K-12 science teachers' understanding of the engineering design process. The project was grounded in the STEM integration framework (Moore, Stohlmann, et al., 2014), which outlines six key tenets of high-quality integrated STEM curricula: 1) a motivating and engaging context; 2) an engineering design challenge; 3) opportunity to learn from failure through redesign; 4) inclusion of mathematics and/or science content; 5) student-centered pedagogies; and 6) an emphasis on teamwork and communication.

During the first three years of the project, participating teachers attended a three-week professional development (PD) summer institute, where they learned about approaches to teaching engineering and data analysis, integrating engineering in science lessons, and understanding how to create integrated STEM curricula. Teams of teachers wrote engineering design-based curricular units during the PD, piloted their units with summer camp students, made revisions to the units, and then implemented their units in their classrooms. They were supported by university faculty in STEM education and STEM fields during the PD and by STEM education graduate student coaches throughout the school year.

During the final two years of the project, graduate students in STEM education revised and polished curricula that had been developed during the grant's initial three years to strengthen their STEM integration and ensure the activities were purposeful and necessary for the engineering design challenge. These units were selected for field-testing because they had strong links or potential links to the STEM Integration Framework

(Moore, Glancy, et al., 2014). Participating teachers attended a one-week summer PD focused on the unit they would be implementing, then field-tested the revised versions of the curricula in their classrooms throughout the school year. The first author served as the curriculum development and PD lead for the unit explored in this study.

This study focuses on students experiencing Laser Security System, one of the teacher-developed, engineering design-based curricular units. This curricular unit was written for middle school students in grades 6-8 and focused on science content related to properties of light, including reflection, refraction, absorption, transmission, the wave model of light, and the electromagnetic spectrum. The unit was designed to have students work in small groups to meet the needs of a client who was developing a laser security system to protect valuable assets in a museum exhibit. Students are tasked with using a single laser, mirrors, and lenses to design a system that reflects and refracts light so that a thief would have to cross the laser light at least three times in walking from the exhibit entrance to the artifacts on display. The unit includes a planning phase, during which students apply their knowledge of properties of light to the design of their laser security system. During the testing phase, students identify problems or ways to improve their initial designs, and they have opportunities to make these improvements during the redesign phase. Evidence-based reasoning is emphasized throughout the curricular unit to ensure that students apply their content knowledge rather than “tinkering” with the materials when creating their designs.

This curricular unit was selected for this study via purposive, criterion-based sampling (Miles, Huberman, & Saldaña, 2014) due to its high-quality STEM integration based on the STEM Integration Curriculum Assessment (Guzey, Moore, & Harwell,

2016). The unit consisted of eight lessons, each of which was intended to take at least one 50-minute class period. In practice, this unit was implemented during 20 class periods, 10 of which focused on engineering.

### **Participants**

Participants were 11 students in grade 6 (aged 11-12 years) at a suburban middle school in the Midwestern U.S. The students' science class had a total of 27 students (nine girls and 18 boys), and their science teacher had received PD related to both STEM integration and the unit itself. Their teacher had participated in the grant project for three years, and she assigned the participants to either a single-gender or mixed-gender small group for the duration of the Laser Security System unit. Within the class, there were two all-girl groups, three all-boy groups, and three mixed-gender groups. One group of each gender composition was selected for this study based on the group members' consent to participate and their comfort levels with the video camera and audio recorder. These three groups serve as the cases and are the primary focus of this study. Within these three target groups, three girls participated in the all-girl group, four boys participated in the all-boy group, and two girls and two boys participated in the mixed-gender group. While the range of gender identities are associated with a range of complex issues in STEM education, this study is limited in focus to the binary categories of female and male, which aligns with the literature cited throughout.

Participants' pseudonyms and demographics are shown in Table 5.2. These students were representative of the school district in which they were enrolled. All 11 participants in this study were native English speakers. Brian, a student in the all-boy group, received special education services.



*Table 5.2. Participant Demographics*

Group Gender Composition	Pseudonym	Gender	Ethnicity
All-Girl	Elsa	Female	White
	Kiera	Female	White
	Kelly	Female	White
All-Boy	Charlie	Male	White
	Adam	Male	Asian American
	Brendan	Male	White
	Brian	Male	White
Mixed-Gender	Madison	Female	White
	Amanda	Female	White
	Umar	Male	African American
	Alan	Male	Asian American

### **Data Collection**

Data were collected throughout the 20 days of unit implementation, and this study focuses on the 10 days of engineering-focused instruction. A video camera and audio recorder were trained on each small group each time they worked together, resulting in seven hours and 57 minutes of small group video available for analysis. All of the small group audio was transcribed, and additional data sources included the first author’s daily field notes from the unit implementation and researcher viewing memos (described in more detail below).

### **Data Analysis**

During the first phase of data analysis, each researcher focused on one student in each small group throughout the duration of the unit to better understand individual patterns of participation. While viewing the videos, researchers wrote detailed memos about their target students. In addition, researchers used a coding protocol based on Jovanovic and King’s (1998) protocol that examined student participation in small group

science activities. The science-focused protocol was modified and expanded upon to include performance enactments of integrated STEM and engineering activities (Wieselmann, Dare, Ring-Whalen, & Roehrig, accepted). The final coding protocol consisted of 33 performance enactments, including both verbal and non-verbal modes of participation (see Appendix C).

Once interrater reliability was established, this coding protocol was applied to each three-minute segment of small group engineering activity throughout the unit to generate frequency counts of the performance enactments for each student. The 33 performance enactments were coded using a binary system: within each three-minute segment, 1 indicated the presence of a performance enactment and 0 indicated its absence. As this phase of data analysis was completed for each group, the researchers met and discussed both the code frequencies and their researcher memos to capture details about the participation patterns, overall interactions, and cohesiveness of each group.

During the next phase of data analysis, researchers focused on cross-case analysis (Yin, 2014) to identify similarities and differences across the three small groups in the study. Constant comparative analysis strategies (Corbin & Strauss, 2015) were used to look across data sources (coding protocol, researcher memos, and field notes) and across groups to explore how group gender composition was related to students' participation.

## **Findings**

As students participated in the engineering activities of the Laser Security System unit, they displayed differing patterns of performance enactments. These patterns varied both by gender and by group gender composition. In the following sections, individual case summaries are shared to describe each group's interactions. These findings focus on

overall group cohesion and interactions based on data from both researcher memos and the coding protocol. Table 5.3 provides frequency counts by individual, by gender, and by group for the most salient codes from the coding protocol. These data are discussed in more detail throughout the findings. Following the individual case descriptions, cross-case analysis findings focus on the seven performance dimensions of design (Crismond & Adams, 2012).

Table 5.3. Performance Enactment Frequency Counts by Student, Gender, and Group

Group	Student	Student Gender	Agreeing	Directing	Elaborating	Frustration: Person	Frustration: Task	Judging: Person	Manipulating	Metacognition	Off-Task	Peer Checking	Reasoning	Record Keeping	Referring to Prior Material	Suggesting Idea	
All-Girl	Kiera	F	13	12	3	0	1	0	34	1	19	11	6	28	2	36	
	Kelly	F	14	16	4	1	1	0	28	3	9	7	7	20	1	19	
	Elsa	F	31	34	5	2	4	0	39	3	33	17	7	27	4	34	
	SUM - Group			58	62	12	3	6	0	101	7	61	35	20	75	7	89
Mixed-Gender	Madison	F	6	28	3	14	11	6	39	0	22	3	11	19	2	21	
	Amanda	F	12	8	0	8	4	4	23	0	2	11	6	7	1	16	
	Umar	M	0	4	0	6	2	0	33	0	21	0	0	8	1	19	
	Alan	M	2	6	1	6	4	5	14	0	39	1	4	6	0	16	
	SUM - Girls			18	36	3	22	15	10	62	0	24	14	17	26	3	37
	SUM - Boys			2	10	1	12	6	5	47	0	60	1	4	14	1	35
	SUM - Group			20	46	4	34	21	15	109	0	84	15	21	40	4	72
All-Boy	Charlie	M	9	31	4	14	4	4	35	0	2	0	17	15	3	18	
	Adam	M	2	5	1	2	3	9	11	0	29	3	5	9	1	16	

Brendan	M	5	3	0	1	0	4	16	0	27	0	0	5	0	17
Brian	M	6	0	2	11	3	1	5	2	38	0	4	2	0	5
SUM - Group		22	39	7	28	10	18	67	2	96	3	26	31	4	56

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## Case Summaries

**All-girl group.** Overall, the all-girl group had highly cohesive group dynamics. Leadership responsibilities in the all-girl group were somewhat fluid, with different students taking primary leadership at different points in the design activities. Although Elsa acted as the primary group leader, directing on 34 occasions, the leadership responsibilities were distributed across the group members. Kiera and Kelly both gave verbal directions to their teammates (12 and 16 occasions, respectively) at points in the lesson when they adopted temporary leadership responsibility. The cohesiveness of the all-girl group is also evidenced by the distribution of responsibilities (such as manipulating and record keeping), frequent peer checking and elaborating, and low occurrences of frustration and judging. Students in the all-girl group expressed frustration with their peers on only three occasions and frustration with the task on six occasions. They did not express judgement about a person on any occasion.

Girls in this group appeared familiar with the more structured aspects of engineering design, such as record keeping and developing initial plans guided by a worksheet. However, the open-ended design activities seemed to cause them to struggle to stay focused when they did not have a worksheet to use as a tool for moving forward. As a result, they resorted to tinkering to make adjustments to their design, not explicitly drawing upon their scientific knowledge, and they had multiple successful designs that they did not record. Although the students in the all-girl group did not apply scientific understanding to their engineering design as the unit intended, they were able to work in a supportive environment free from conflict with their same-gendered peers.

**Mixed-gender group.** In general, girls in the mixed-gender group dominated the activities. Madison took primary responsibility as the group leader. These leadership responsibilities can be seen in the frequency with which the students gave verbal directions to their peers; Madison directed her teammates on 28 occasions, compared to the eight directions by Amanda and only 10 total directions by both boys combined. In addition to directing, the girls in this group were more active than their male peers in almost all performance enactments related to their participation in the activities: agreeing, elaborating, manipulating, peer checking, reasoning, record keeping, and referring to earlier material. The single performance enactment where boys in the mixed-gender group had a higher frequency than girls was off-task behavior. The boys' off-task performance was especially prevalent in the initial design planning activities structured by worksheets.

When the activities shifted to less structured engineering activities that were not guided by worksheets, the boys attempted to become more involved. They suggested ideas and were interested in using the physical materials to design their laser security system. However, given the boys' past lack of participation in the more structured activities, the girls were reluctant to shift any responsibility for the design to the boys, and this became a source of frustration and conflict within the group. Students in this group expressed frustration with their peers on 34 occasions. This type of frustration was more common among girls (22 occasions) than boys (12 occasions). As the students dealt with conflicting ideas about who should be involved and in what manner, they also expressed judgment about their peers. Judgment was more commonly expressed by girls (10 occasions) than boys (5 occasions). Together with judgment and frustration directed

toward peers, students in this group expressed frustration related to the task on 21 occasions. Again, as they took primary responsibility for the group tasks, girls in the mixed-gender group expressed frustration with the task more frequently than their male teammates (15 versus 6 occasions, respectively). Throughout the less structured design activities, the laser pointer became a tool for wielding power in the group, with students attempting to control the laser pointer to ensure their ideas were acknowledged. The mixed-gender composition of the group was associated with conflict and tension.

**All-boy group.** Within the all-boy group, students' levels of participation varied widely. Charlie was the clear group leader and took responsibility for the bulk of the design activities. Charlie directed his team on 31 occasions, compared to the next most frequent 5 directions by Adam. Charlie also dominated manipulating, reasoning, and record keeping within the group. He was off-task on only two occasions, while the rest of his teammates were off-task for at least 27 occasions each. The other boys in the group were generally less involved throughout the unit, although they occasionally became interested in the design activities, both manipulating the materials and suggesting ideas.

Although Charlie was able to produce an effective design for his group, he also experienced frustration. Students in the all-boy group expressed frustration with their peers 28 times, and Charlie accounted for 14 of these instances, often growing frustrated in attempts to manage his teammates' participation and behavior. Brian, who was receiving special education services and was frequently marginalized by his peers, expressed frustration on 11 occasions. Together, Charlie and Brian accounted for 25 of the 28 total instances of frustration in the all-boy group. Frustration with the task was more evenly distributed across the group, with 10 total occasions and no single student



accounting for more than four occasions. The students in the all-boy group expressed judgment of each other on 18 occasions. Many of these judgments were directed at Brian. While the all-boy group was ultimately successful in the engineering design activities, they did not equitably share in the responsibility or have cohesive group dynamics. The single-gender composition of this group was associated with one boy taking the lead on completing the group activities while his teammates were non-participatory.

### **Cross-Case Analysis Based on the Performance Dimensions of Design**

**Learning while designing.** Learning while designing is a key performance dimension of informed design, and students displayed evidence of learning throughout the design process to different degrees across groups. Metacognition is indicative of learning while designing, and the all-girl group was the only group to have a metacognitive discussion throughout the unit. This conversation was unprompted by the teacher, and the girls talked about which decisions were more difficult for them to make and why. In the all-boy group, Brian made two metacognitive comments, but his teammates did not engage in conversation with him.

Although learning while designing is not observable in all instances, students' record keeping offers one means of observing this learning, as they recorded details of their design ideas and tracked their revisions to these designs. Record keeping was most common in the all-girl group (75 occasions) and least common in the all-boy group (31 occasions). Students in the mixed-gender group engaged in record keeping on 40 occasions, with girls doing so more frequently than boys (26 versus 14 occasions, respectively). It is also important to note that in addition to keeping records throughout the design process most consistently, the all-girl group also showed the most even

distribution in adopting this responsibility, with each student record keeping on at least 20 occasions. Although a formal measure of student learning was not included as part of this study, students in the all-girl group displayed performance enactments indicative of learning while designing more consistently than the other groups.

**Making and explaining knowledge-driven decisions.** As students sought to design their laser security systems, many opportunities for data- and knowledge-driven decisions existed, although they were not emphasized by the teacher. Students' use of knowledge-driven decisions is most clearly evidenced by the reasoning code, which requires students to explain the reasoning behind their decisions. Although reasoning was evenly distributed across girls in the all-girl group (6-7 occasions of reasoning per student), their overall frequency of reasoning (20 occasions) was lowest. Students in the mixed-gender group provided reasoning on 21 occasions, while those in the all-boy group provided reasoning on 26 occasions. The distribution of these reasoning performance enactments is also important to note. Within the all-boy group, Charlie accounted for 17 of the 26 instances of reasoning, largely dominating this performance enactment in his group. While students in other groups relied on "tinkering" to make adjustments to their designs, Charlie explicitly used his knowledge of the law of reflection to inform his design decisions. In the mixed-gender group, Madison and Amanda accounted for 17 of the 21 instances of reasoning, with their male peers showing evidence of reasoning on only four occasions.

**Working creatively to generate design insights and solutions.** Informed design relies on creative design solutions, and students in this study displayed their creativity when suggesting ideas for their laser security system design. Students suggested ideas

most often in the all-girl group (89 occasions) and least often in the all-boy group (56 occasions). No single student within a group clearly dominated the suggestion of ideas, but some interesting patterns were evident. In the all-boy group, Brian only suggested ideas on 5 occasions, markedly fewer than the other students on his team. Among students in the mixed-gender group, ideas were suggested in almost equal numbers between girls (37 suggestions) and boys (35 suggestions). In general, boys in this group were less involved than their female teammates in the engineering activities, as evidenced by their lower frequencies of agreeing, elaborating, manipulating, peer checking, reasoning, record keeping, and referring to earlier material. Given their general low level of participation in the group's activities, it is interesting to note that the boys in the mixed-gender group actively suggested design ideas.

**Perceiving and taking perspectives intelligently.** As informed designers work to create innovative designs, they consider a number of perspectives: those of other designers as well as the end users of the product. Evidence of considering others' perspectives was most apparent in the all-girl group. Students in this group expressed agreement with their peers most often (58 occasions in the all-girl group versus 22 occasions in the all-boy group and 20 occasions in the mixed-gender group). In fact, each student in the all-girl group expressed agreement at least 13 times (and up to 31), which was greater than the maximum number of agreements in either the mixed-gender or all-boy groups. Participants in the all-girl group also elaborated on their teammates' ideas most often (12 occasions in the all-girl group versus seven occasions in the all-boy group and four occasions in the mixed-gender group). In addition, they verbally compared ideas and answers before deciding on a response (peer checking) more often than students in

other groups (35 occasions in the all-girl group versus 15 occasions in the mixed-gender group and three occasions in the all-boy group).

While the mixed-gender group did not show evidence of agreeing, elaborating, or peer checking on as many occasions as the all-girl group, girls in the mixed-gender group displayed these performance enactments more frequently than their male teammates. Girls expressed agreement on 18 occasions (versus two for boys), elaborated on three occasions (versus one for boys), and checked with their peers on 14 occasions (versus one for boys).

**Conducting sustained technological investigations.** Sustained technological investigation is a key performance dimension of informed design, and students in this study displayed varying levels of sustained investigation. All groups investigated the properties of light that could be beneficial in their laser security system designs, and they frequently engaged with the materials available for use in their designs. Manipulating the materials was particularly frequent in the mixed-gender (109 occasions) and all-girl (101 occasions) groups. Within these groups, all students had opportunities to manipulate the materials, although the all-girl group displayed the most even distribution of this responsibility. In contrast, students in the all-boy group manipulated the materials on only 67 occasions, and Charlie accounted 35 of these instances.

Focused, on-task engagement is also important to consider in relation to sustained investigations. The all-girl group was off-task least often (61 occasions), and these occasions often occurred when the girls clearly felt confident they would have time to complete the necessary tasks. Off-task performance enactments were more common in the mixed gender group (84 occasions), and within this group, boys were off-task more

frequently than girls (60 versus 24 occasions). The all-boy group was off-task most frequently (96 occasions). Within this group, Charlie was only off-task on two occasions, while the other three students were off-task more frequently (27-38 occasions each).

**Using design strategies effectively.** Throughout the engineering design activities, all of the groups developed effective design solutions to the laser security system challenge. The way they went about reaching these solutions differed, however. Within the all-girl and mixed-gender groups, after developing an initial plan on paper, the students eventually relied on “tinkering” to make adjustments to their design. In contrast, the all-boy group, led by Charlie, consistently used measurement and application of scientific knowledge to develop their design; for example, in making adjustments to the group’s design, Charlie stated known angles based on the law of reflection and used a protractor to make precise adjustments to the design. The all-boy group also switched between design strategies more seamlessly than the other groups, transitioning between hands-on design activities and paper-based planning.

**Integrating and reflecting on knowledge and skills.** Informed designers use knowledge from multiple disciplines and reflect on their design activities. In this unit, students planned, tested, and redesigned their laser security systems after learning science content that would support informed design decisions. They had access to their previous learning related to the design challenge and had opportunities to refer to that material to integrate science learning into their designs, although this was not explicitly encouraged by the teacher. As previously mentioned, Charlie led the all-boy group to apply the law of reflection to their group’s design. However, Charlie was largely silent in integrating this knowledge. He explicitly referred to earlier material on only three occasions throughout

the design process, and his team referred to earlier material on a total of four occasions. The mixed-gender group also referred to earlier material on four occasions (three occasions for girls and one for boys). The all-girl group referred to earlier material slightly more frequently, on seven occasions, and they also incorporated metacognitive discussions that included reflection on their activities.

## **Discussion**

### **Gender and Small Group Participation**

With much of the literature around students' small group interactions dating back to the early 2000s, the present study provides important information about how students navigate engineering and integrated STEM activities. This study confirmed previous research findings that girls and boys tend to participate in small group activities in unique ways, with boys spending more time off-task (Harskamp et al., 2008) and focusing more on tasks rather than group processes (Johnson & Schulman, 1989). However, the present study also offered new insights into middle school students' participation in small group engineering activities. A number of prior studies found that boys tend to act as leaders, dominate the physical materials, and be more involved in small group activities (Green & Cillessen, 2008; Hansen et al., 1995; Jovanovic & King, 1998; Kahle et al., 1993; Lockheed et al., 1983; Mewborn, 1999; Patrick & Yoon, 2004), but that was not confirmed in the present study. In the mixed-gender group, girls were primarily responsible for leading their team, taking on additional responsibilities to drive their group forward.

Girls' modes of participation were more extensive in this study than in prior work. While the girls in the present study were still involved in note-taking (Jovanovic & King,

1998; Mewborn, 1999), interacting with group members (Fenwick & Neal, 2001; Lee, 1993), and building positive relationships (Hawkins & Power, 1999; Savicki & Kelley, 2000) to a greater degree than boys, they *also* adopted performance enactments that previous researchers have found to be more characteristic of boys, such as manipulating materials and leading their team. This finding is significant because it suggests that perhaps these patterns have changed, with girls' modes of participating in small group activities broadening since the early 2000s.

Despite girls' overall greater involvement in the mixed-gender group activities, the boys in this group became distinctly more interested and involved when the activity shifted from worksheet-based planning to open-ended design that included materials. This pattern of increased involvement was also seen within the all-boy group, with those students who had previously been onlookers expressing new ideas and engaging with the materials. In contrast, students in the all-girl group became less focused and more frustrated in the open-ended design activities. Their rate of off-task behavior increased dramatically, and their work was less purposeful. With no teacher expectations related to how long the engineering tasks were expected to take and a seemingly unlimited amount of time available to work, the girls did not make efficient use of their time, as they had in prior activities.

### **Group Gender Composition**

In exploring student participation related to their group's gender composition, several interesting patterns emerged. Consistent with prior research findings (Bennett et al., 2010), both of the single-gender groups had more purposeful functioning than the mixed-gender group. However, problematic patterns of interaction were evident in the

all-boy group. Similar to all-boy groups in other studies (e.g., Green & Cillessen, 2008), this group faced more challenges in equitably distributing tasks. Some boys were rarely involved in the activities, and there were particular problems surrounding Brian's involvement. Brian, who was receiving special education support, was often marginalized by his teammates and limited in his participation. His teammates did not listen to his ideas and managed his behavior negatively, often telling him he was not allowed to do certain things without suggesting alternative activities.

Consistent with previous research (Asterhan et al., 2012; Ding & Harskamp, 2006), the all-girl group was more cohesive than either the mixed-gender or all-boy groups. Students in this group developed positive relationships and worked together on the engineering activities. Each girl in the group acted as the leader at different points, demonstrating fluidity in leadership responsibilities that was not apparent in the mixed-gender or all-boy groups. The single-gender environment was supportive of girls' participation in the engineering activities within a safe, judgment-free zone. Because the students established this supportive group environment, they were able to suggest many ideas related to their design without fearing judgment.

Students in the all-girl group expressed agreement and elaborated on one another's ideas more often than students in the other groups. Interestingly, they provided reasoning for their design decisions less often than those in the mixed-gender or all-boy groups. Because of their high rates of agreement, girls in the single-gender group were met with less skepticism and questioning, which resulted in fewer situations where they had to defend their ideas. Although this resulted in low levels of conflict, these girls also had fewer opportunities to justify and explain their reasoning in the face of potential



disagreement, a process that is known to be particularly effective in promoting conceptual understanding of STEM content (Howe et al., 2007).

While both of the single-gender groups faced unique challenges, the mixed-gender group was fraught with frustration and conflict throughout the activities. Interactions between girls and boys in this group were competitive in nature, with students using the physical materials such as the laser pointer to maintain control of the group's activities. The mixed-gender composition of this group was associated with challenges and direct conflicts not found in the all-girl group. The high rates of frustration among girls in the mixed-gender group is problematic when considering the goal of fostering ongoing interest and engagement in engineering among girls.

### **Limitations**

In considering the findings of this study, it is important to recognize that this case study focused on three small groups of students experiencing one curricular unit. Thus, probabilistic or statistical generalization is not possible, given that the students cannot be assumed to represent the whole population of middle school students. However, despite the fact that these findings do not represent the experiences of all students, it is possible to make theoretical generalizations from qualitative inquiry (Eisenhart, 2009). That is, in understanding the general process of engineering education, findings from this study help to develop a refined understanding of the unique experiences some students will encounter as they participate in small group engineering activities.

This study also focused on the binary gender categories of female and male, when there is much more complexity related to students' gender identities and the intersectionality of gender identity with other identities (e.g., identifying as both a female

and a student of color). Thus, the students in this study do not represent the full range of students who are experiencing small group engineering activities. Diversity in students' cultures, languages, socioeconomic status, and background experiences likely intersect with their gender in relation to their participation in small group engineering activities.

## **Implications**

Investigating small group activities and the potential impact of group functionality on girls' ongoing participation in engineering, this work fills a gap in the literature around small group engineering activities in formal middle school settings. As engineering becomes increasingly common in pre-college education, students will need additional practice and support in equitably engaging in open-ended engineering design challenges. Several key findings emerged from this study with implications for instructional strategies, curriculum development, and future research.

### **Teacher Role in Facilitating Small Group Engineering Activities**

The role of the teacher cannot be underestimated in supporting students' meaningful and equitable engagement in engineering design activities. In this study, small groups received no guidance from the teacher and were left to determine how the tasks would be divided amongst group members. With no discussion of the division of labor or how to keep all teammates involved, participation was inequitable, particularly in the mixed-gender and all-boy group. In designing engineering activities for implementation at the middle school level, explicit instruction in how to engage in teamwork should be included. Group roles may offer a practical solution to helping all students engage in small group activities more equitably. These roles should be fluid, offering different students opportunities to experience different roles. In addition, they

should be authentic to the engineering tasks, rather than general group roles often seen in middle school teaching (e.g., materials manager, time keeper). With the support of the teacher, groups of students should have opportunities to break down tasks, identify action steps in completing the tasks, and divide those responsibilities among group members. Ongoing and explicit discussion of effective teamwork will help support students in equitable engagement in engineering design activities and be better prepared for ongoing collaboration in engineering contexts.

### **Supporting Productive Student Participation in Engineering Activities**

Students also require additional support to ensure the engineering design process is moving forward productively. Clear expectations about how long activities should take and ongoing checkpoints would be helpful in ensuring that students are making the most productive use of their time. In this study, students were not given clear time guidelines, so they felt they had unlimited time to complete the engineering activities. In some cases, this resulted in boredom and off-task behavior, while in other cases, this resulted in students redesigning an already effective solution without purpose. In addition to checkpoints related to timing, there is a need for increased teacher involvement in encouraging students to make evidence-based decisions and integrate knowledge from all of the unit's lessons. Two of the groups (all-girl and mixed-gender) in this study largely relied on tinkering to improve their designs, despite having access to previously explored data that would have allowed them to make more informed decisions. Additional teacher guidance would assist students in applying previous learning to their design decisions.

## **Preparing Students for Open-Ended Small Group Activities**

While some students, particularly the girls, struggled with the open-ended nature of the engineering design activities, other students attempted to engage in the open activities to a greater degree than their previous participation would predict. The boys in the mixed-gender group and select boys in the all-boy group became markedly more interested and involved in the design activities when they had access to physical materials and could make design suggestions without being constrained by a worksheet. Despite their interest, however, they still faced challenges in shifting to more active participation in their teams, with the team leaders reluctant to listen to or grant new responsibilities to those who had been previously been less involved. While engineering activities may serve as an opportunity for students who are typically less engaged in group activities to take on new roles and responsibilities, additional teacher support is needed to help students, particularly girls, navigate these open activities without the structure of a worksheet and remain open to the process of failing and redesigning.

## **Conclusion**

Working in a mixed-gender group was a source of frustration for girls, who had difficulties managing their male peers' involvement. While this study suggests that the most positive group dynamics and equitable participation were found in the all-girl group, there is a need for further research regarding group gender composition in middle school engineering activities. Future studies should explore strategies for supporting girls in open-ended engineering activities that are not guided by worksheets. Additional research would also be beneficial in determining whether the pattern of boys in mixed-gender groups becoming more engaged in the less structured activities is consistent; if so,

future work could address the challenges of supporting all students in meaningful engagement in both highly-structured and less-structured activities.

## **Chapter 6 - Conclusions, Implications, and Future Directions**

### **Key Findings**

This dissertation contains three distinct but related studies that explore elementary and middle school students' participation in small group, integrated STEM activities. The first study (Chapter 3) focused on a mixed-gender group of fifth-grade students to determine whether participation varies based upon student gender and the focus of the activity (science versus engineering). This study revealed that students displayed gender-typical performance enactments (e.g., Hansen, Walker, & Flom, 1995; Jones, Brader-Araje, et al., 2000; Jovanovic & King, 1998; Kahle, Parker, Rennie, & Riley, 1993; Mewborn, 1999; Patrick & Yoon, 2004), with boys often leading the team and directing their peers' involvement. In contrast, girls adopted "good student" performance enactments and took notes, followed directions from their peers, and observed the activities more frequently than the boys in the group. While the students were able to navigate highly-structured school science activities while attending to equitable participation (i.e., turn-taking), they struggled to negotiate equitable participation in open-ended engineering activities. Frustration and disagreements were more common in the engineering activities, and the boys became more controlling of the activities. This study demonstrated that students may experience epistemological conflicts when science and engineering are integrated, with students largely unprepared for open-ended engineering activities.

The findings from the first study necessitated further investigation, so the second study (Chapter 4) built upon the findings to explore student participation in single-gender versus mixed-gender small groups in a sixth-grade classroom. In contrast to previous

research, including the first study, this study indicated that girls in the mixed-gender group dominated the activities and dictated their peers' involvement. However, students in this group experienced higher rates of frustration and conflict than the all-girl and all-boy groups, largely due to conflicting objectives within the group. The girls' focus on efficiency stood in contradiction to the boys' desire to explore the materials, resulting in conflict within the mixed-gender group. Students in the all-girl and all-boy groups had compatible objectives, so their interactions were less contentious. However, as was the case in the first study, students in this study experienced a shift in modes of participation between science and engineering activities. The girls in both the single-gender and mixed-gender groups relied on worksheets as their primary tool in science activities, but without that tool to guide their participation in open-ended engineering activities, they struggled to determine how to participate and meet the task requirements. Each group navigated the shift from science to engineering differently, and the all-boy group was the only group that maintained a similar approach to both science and engineering.

With both of the first two studies highlighting equity issues in open-ended engineering activities, the third study (Chapter 5) focused specifically on the engineering practices students employ in small groups of different gender compositions. Within the mixed-gender group, girls tended to take on primary responsibility for their team's progress in the engineering design challenge. However, the boys in this group became distinctly more interested and involved when the activity shifted from planning to open-ended design with materials. A similar pattern was also evident in the all-boy group, with those students who had previously been onlookers expressing ideas and engaging with

the engineering materials. In contrast, students in the all-girl group became less focused and more frustrated in the open-ended activities.

### **Conclusions and Implications Across the Three Studies**

In examining the set of three studies, several conclusions can be drawn. These conclusions include the need to facilitate equitable student participation in small group STEM activities, support students in open-ended STEM activities, and design STEM curricula with students' needs in mind. In the following sections, the key conclusions and their implications for teaching strategies, professional development, and curriculum development are described.

#### **Facilitating Equitable Student Participation in Small Group STEM Activities**

While the high rates of conflict and frustration in mixed-gender groups may seem to suggest that single-gender groups are preferable in integrated STEM instruction, unique challenges related to equity emerged in the single-gender groups as well. For example, students in the all-girl group agreed with each other and did not challenge each other's ideas often; although this resulted in a more positive atmosphere among the group, it also may have hindered the co-construction of deeper conceptual understanding because challenging others' ideas did not fit within the group norms. Students in the all-boy group did not experience as much conflict as those in the mixed-gender groups, but they also divided the labor inequitably, with one student performing the bulk of the tasks.

Given that challenges related to equitable and purposeful participation were present across the different groups, rather than considering the ideal group gender composition, a more productive approach focuses on facilitating equitable participation in all group types. Students will require explicit instruction related to teamwork and



collaboration, as well as monitoring, feedback, and self-reflection throughout STEM units. By helping students develop language and strategies to ensure their own and their peers' participation in small group activities, teachers can prepare students for the variety of group compositions they will encounter throughout life. Particularly as women remained underrepresented in STEM fields, it would be a disservice to educate young girls only in single-gender groups when they will likely encounter male-majority groups if they continue into STEM careers. However, as these studies demonstrate, teachers do not naturally include this type of teamwork-focused instruction in their STEM units. Thus, professional development and intentional curricular design are needed to support the aim of fostering equitable student participation in small group STEM activities.

### **Supporting Students in Open-Ended STEM Activities**

Open-ended engineering activities disrupt students' routine modes of participation in science activities and create new challenges related to equitable engagement in STEM. The mixed-gender groups across the studies navigated the shift between science and engineering differently, with boys taking control in one group and girls taking control in the other. This difference may be attributable to the students' home cultures, age, or other factors that were beyond the scope of the studies. However, despite this difference, the students in the mixed-gender groups consistently experienced increased conflict and frustration in engineering-focused activities compared to science-focused activities. Girls in the single-gender group also struggled to navigate the shift from science to engineering, but their struggle resulted in greater frequency of off-task performance enactments and less purposeful functioning rather than conflict. Across all three studies, only the all-boy group moved seamlessly between science and engineering, suggesting

that their approach to school science is more compatible with open-ended engineering activities.

Students' struggles to develop effective strategies in open-ended engineering design challenges suggests a need to consider the types of activities students have the opportunity to engage in within the context of school science. Although the science activities with clear procedures resulted in more equitable participation among students in this study, this type of convergent thinking is not authentic to the work of STEM professionals. Students need additional opportunities to participate in open-ended activities, but they also need support in doing so. When worksheets are unavailable to guide participation, students require explicit instruction in breaking down a task into its component parts, developing a plan for completing it, and monitoring their progress. With modeling and scaffolding, students can become more reflective about their own task progress and engage in metacognitive thinking and discussion within their group to maintain purposeful participation in open-ended activities.

In addition to the need for self-monitoring, students also need to be held accountable for their participation in open-ended engineering design activities. Mechanisms for monitoring progress, ensuring that students are applying science content knowledge to their designs rather than tinkering, and evaluating final designs based on students' ability to justify their design decisions with evidence will help ensure that engineering activities move beyond playing. With the increasing addition of engineering to science standards, teachers will likely require professional development in these areas to ensure they are offering sufficient supports to their students.

## **Designing STEM Curricula with Students' Needs in Mind**

As integrated STEM curricula continue to be developed and implemented, a variety of factors must be considered. These curricula should attend to the suggestions highlighted in the previous sections to include explicit discussion of teamwork and support students' participation in open-ended activities. In addition, gender-inclusive curricula and pedagogies should draw upon students' interests and experiences and use real-life contexts that are engaging to girls. In particular, the societal relevance of what is being learned should be emphasized to help girls connect to the potential significance of what they are learning. Notably, these elements of gender-inclusive instruction align closely with the key features of quality integrated STEM instruction.

In addition to the previously described features of gender-inclusive curricula and pedagogy, there is a particular need to consider the length of integrated STEM units and how to maintain student engagement throughout the unit. In both curricular units included in this dissertation, an introductory engineering lesson provided the context for learning, followed by a series of science-focused lessons before the unit culminated in an engineering design challenge. While this is an effective way to add engineering into existing science units, it can also result in lengthy units of instruction. For example, the *Laser Security System* unit was taught over the course of 20 class periods from February 14 to March 21. Although lengthy units are not inherently problematic, they pose the additional challenge of maintaining students' focus on the problem and tasks at hand over the course of several weeks. Students who experienced the *Laser Security System* unit largely lost sight of the purpose of their learning, as well as the criteria and constraints for their engineering designs. Maintaining students' focus on the objectives in long STEM

units will require frequent discussion of the learning context, goals for learning, and progress monitoring. Even within shorter STEM units, these recurring discussions will also be important as the focus shifts between science and engineering activities.

### **Future Directions**

This dissertation explored students' participation in small group, integrated STEM activities and revealed patterns in student engagement based upon student gender, group gender composition, and the type of activity (science versus engineering). Case study methodologies were utilized to provide a more thorough understanding of the phenomenon of study. While the qualitative analyses provided rich descriptions of student interactions, future studies should employ quantitative research methods to determine whether the findings hold across a variety of small groups. Quantitative studies would allow for greater generalization of findings to better understand what is typical of students' small group STEM experiences. With more participants, it would also be possible to consider equity from additional lenses to include the study of race/ethnicity, socioeconomic status, native language, and special education classification, as well as the intersectionality of different identities (e.g., being both a female and a student of color).

As this research expands, studying a greater variety of classrooms would also be beneficial. For example, the small groups featured in this dissertation were composed of students in the fifth and sixth grades. Students' STEM participation at additional grade levels should also be considered. Further, the teachers of students in this dissertation participated in the same professional development project. Future studies should include teachers who have not had STEM-specific professional development or who have participated in different STEM professional development experiences to determine

whether the findings of this study are unique to the particular professional development project.

Finally, with the ultimate goal of supporting more equitable participation in small group STEM activities, future studies should explore teacher professional development interventions specifically focused on supporting equitable small group STEM participation. Exploring whether these professional development supports are effective could result in recommendations for best practice in small group STEM instruction to broaden the participation of students who have historically been less engaged in STEM activities. Findings from the studies in this dissertation suggested that open-ended engineering activities may engage students who are less engaged in the highly-structured activities that are common in school science. However, professional development is needed to help teachers structure small group STEM activities and support student participation throughout these activities.

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## Appendix A: Coding Protocol for Study 1

Code Category	Code	Code Description
Verbal		
	Explaining Procedure	Explaining the task/activity procedure to another student
	Reading Directions	Reading directions to others in the group or referring group members back to directions
	Elaborating on Another Student's Statement	Building on another student's response verbally
	Reasoning	Explaining the reason for a certain decision (i.e., evidence-based reasoning)
	Directing	Verbally leading the group to move forward
	Suggesting Idea	Verbally raising a new idea for how to complete the task/activity
	Expressing Uncertainty	Verbalizing uncertainty about how to conduct the activity/task
	Requesting Explanation from Student	Verbally asking another student for an explanation of the task or content
	Encouraging	Encouraging another group member to participate or to have confidence in their participation
	Disagreeing	Expressing disagreement with something that another student has explicitly said
	Judging: Task	Expressing verbal judgment about something related to the task at hand (could be judging an idea)
	Judging: Person	Expressing verbal judgment about an individual (could be self or other)
Mixed		
	Referring to Earlier Material	Looking back (in notebooks, classroom artifacts, etc.) to earlier material for use in the current task/activity
	Expressing Frustration: Task	Showing signs of exasperation (verbal or physical) related to a task
	Expressing Frustration: Person	Showing signs of exasperation (verbal or physical) related to another student
	Distracting Other Students	Actively distracting other students by talking to them about off-task subjects or physically interfering with their on-task behavior

	Off Task	Failing to do something they should be doing (do not code as off task if the students are between activities and waiting for the next step)
	Avoiding	Refusing to participate (verbally or nonverbally)
	Requesting Help from Teacher	Asking the teacher for help related to task or content (verbal or through raised hand)
Non-Verbal		
	Manipulating	Handling the materials/equipment
	Record Keeping	Taking notes or writing down results
	Assisting	Helping a student who is directing the activity, unprompted by the student who is directing
	Following	Following another student's direction when prompted
	Observing	Passively observing the activity
	Initiating: Non-Verbal	Using materials to move the group forward
	Forcefully Controlling: Non-Verbal	Controlling the task through non-verbal means

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## Appendix B: Small Group Performance Enactment Frequency Counts from Study 1

Performance Enactment	Girls		Boys	
	Science	Engineering	Science	Engineering
Explaining Procedure	0	2	0	6
Reading Directions	1	4	0	9
Elaborating on Another Student's Statement	0	1	0	5
Reasoning	0	2	6	21
Directing	17	17	3	26
Suggesting Idea	7	24	6	36
Expressing Uncertainty	12	9	1	10
Requesting Explanation from Student	6	13	4	16
Encouraging	4	7	7	10
Disagreeing	8	13	2	7
Judging: Task	0	0	0	7
Judging: Person	9	13	8	12
Referring to Earlier Material	2	4	0	6
Expressing Frustration: Task	4	14	8	13
Expressing Frustration: Person	3	13	3	3
Distracting Other Students	2	1	8	24
Off Task	8	25	13	34
Avoiding	4	6	0	3
Requesting Help from Teacher	0	3	0	5
Manipulating	35	36	28	42
Record Keeping	29	45	18	23
Assisting	18	15	19	20
Following	11	20	0	4
Observing	34	59	20	35

Initiating: Non-Verbal	1	5	6	17
Forcefully Controlling: Non-Verbal	2	6	3	13

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## Appendix C: Coding Protocol for Study 3

Code Category	Code	Code Description
Verbal	Explaining Procedure	Explaining the task/activity procedure to another student
	Explaining Content	Explaining the science or engineering content to another student
	Elaborating on Another Student's Statement	Building on another student's response verbally
	Reasoning	Explaining the reason for a certain decision (i.e., evidence-based reasoning)
	Metacognitive Thinking	Describing thinking about the learning process and/or understanding of the task
	Directing	Verbally leading the group to move forward
	Suggesting Idea	Verbally raising a new idea for how to complete the task/activity
	Expressing Uncertainty: Task	Verbalizing uncertainty about how to conduct the activity/task, including spelling questions
	Expressing Uncertainty: Content	Verbalizing uncertainty about the science or engineering content
	Requesting Explanation from Student	Verbally asking another student for an explanation of the task or content
	Encouraging	Encouraging another group member to participate or to have confidence in their participation
	Agreeing	Expressing agreement with something that another student has explicitly said
	Disagreeing	Expressing disagreement with something that another student has explicitly said
Judging: Task	Expressing verbal judgment about something related to the task at hand (could be judging an idea)	

	Judging: Person	Expressing verbal judgment about an individual (could be self or other)
	Peer Checking	Verbally comparing answers to confirm or verify response
Mixed	Reading Directions	Reading directions to others in the group or referring group members back to directions
	Referring to Earlier Material	Looking back (in notebooks, classroom artifacts, etc.) to earlier material for use in the current task/activity
	Expressing Frustration: Task	Showing signs of exasperation (verbal or physical) related to a task
	Expressing Frustration: Person	Showing signs of exasperation (verbal or physical) related to another student
	Distracting other Students	Actively distracting other students by talking to them about off-task subjects or physically interfering with their on-task participation
	Off Task	Failing to do something they should be doing (do not code as off task if the students are between activities and waiting for the next step)
	Avoiding	Refusing to participate (verbally or non-verbally)
	Requesting Help from Teacher	Asking the teacher for help related to task or content (verbal or through raised hand)
Non-Verbal	Manipulating	Handling the materials/equipment; MUST be part of hands-on activity (i.e., not just handling worksheet) for the purpose of completing the task, observing, or collecting data
	Record Keeping	Taking notes or writing down results
	Assisting	Helping a student who is directing the activity, unprompted by the student who is directing; MUST be a clear distinction in the type of participation between leader and other students
	Following	Following another student's direction when explicitly prompted
	Observing	Passively observing the activity

Initiating: Non-Verbal	Using materials to move the group forward
Managing Materials	Using materials in support of the task, but not while doing the actual task
Forcefully Controlling: Non-Verbal	Controlling the task through non-verbal means
Copying	Looking at another student's paper and copying what was written

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