Dyadic Collaborative Problem Solving on Engineering Tasks in a First Grade Classroom

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Abstract

Current research in engineering education often focuses on students in high school or college; at these ages many students have often already decided that they are "science and math types" or not. Thus, it may be "too late" to encourage or change their perspectives. Research on engineering education with young children is needed to understand better how these decisions are made and to encourage females to enter engineering fields. Furthermore, integral components of engineering, such as problem solving—as stated in the Massachusetts Curriculum Frameworks for Technology/Engineering—and the ability to work with others, are skills that transcend all disciplines.

This research had four main goals: (1) to understand how first graders approach and complete an engineering activity when working in dyads (pairs); (2) to inform engineering curriculum design for early childhood; (3) to provide a tool to help researchers and teachers assess engineering learning in classroom; and (4) to suggest that there is a need for early introduction to engineering in education. For this research, a custom tool was developed to allow for "real time" data collection of student behaviors. Using the data from this tool, two techniques—interactions graphs and task-event networks—for visually showing and quantifying students' interactions when working alone, with each other, and with teachers were created. In addition, a classification system was developed for describing collaborative problem solving on engineering tasks in a first-grade classroom and this system allowed for analysis of the distribution of dyads in a first-grade classroom among these classifications. Preliminary analysis suggests that the "friendship status" of the pair, the social problem-solving skills of the students relative to grade-level expectations, and the gender composition of the pair impacts the type of collaboration that occurs. Also discussed are suggestions for teachers when pairing students to work on engineering tasks, the limitations of this research, and the need for additional research in the area of engineering education with young children.

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Next, I would like to thank Professor Chris Rogers of the Mechanical Engineering Department for having the foresight to realize that engineering in education *is* important, the creativity to develop a tool for teaching engineering, and the persistence to lobby for its presence in schools. I want to also thank Marina and Chris together for recognizing the power of interdisciplinary work in higher education and providing me a unique niche in which to occupy.

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I consulted many scholars in problem solving when working on this research; I not only gained valuable guidance regarding my research, but also insight into new areas of the field that I had yet to explore. I would like to thank Nira Granott, a visiting scholar at the Eliot-Pearson Department of Child Development, for meeting with me to discuss my research when I was feeling the most lost. Without her gentle suggestions, I would not have had such a strong basis for my analysis. I would also like to thank George Scarlett for his insight and enthusiasm into young children's play.

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Chapter One: Introduction and Literature Review

Introduction

In the academic year of 1969 to 1970, only 0.7 percent of bachelor's degrees in engineering were earned by women; in 2000 to 2001, women earned 19.9 percent of bachelor's degrees in engineering (2004). While certainly a large increase, women are still minorities in the field of engineering. In a study by McIlwee and Robinson (1992), as discussed in their book, *Women in Engineering*, they interviewed men and women engineers to find what factors were most influential in their decision to become engineers. The top three answers for men were: (a) they had been "tinkerers" during their youth, (b) they had been encouraged by their father or other family member to enter the profession, and (c) they were interested in mechanics/electronics. In contrast, women responded that their top three reasons for becoming an engineer were: (a) they were good at math and science, (b) engineering was a practical field (in terms of number of jobs and salary), and (c) they had been encouraged by a father or other family member. McIlwee and Robinson went on to explain:

> For a man entering the profession of engineering, the process is a "natural" one. It is as if society, their families, and their own personal orientations conspire them to point in this direction. . . . As boys they were in love with machinery or electronics. These boys were by and large bright kids, but that was not what distinguished them as a group. Rather, it was their passion for tinkering and

> technology. . . . They loved taking things apart and putting them back together again. It was their tinkering orientation and compatibility of engineering with their developing gender identity that paved such a smooth path for them. . . . For women the story was quite different. The path to engineering was less obvious and less "natural" for them. Few were tinkerers, and fewer yet had rebuilt a car engine or taken apart a television set. But when it came to school work, they excelled. They were more than just competent in school; they were outstanding. It was their academic skills more than anything that made engineering a possibility for them, despite its male-identified image. (p. 25–26).

While there is, of course, no one "right" path to an engineering profession, for women, the path is not always as clear as it is for men. In order to have a diversified workforce, there is a need for more women in engineering, and a need to understand how and when children, and in particular girls, decide that engineering is or is not a field they wish to pursue.

When I began the research for this thesis, I set out to look at gender differences in problem solving on engineering tasks. In my pilot research, I attempted to design a methodology to meet this goal. As revealed in more detail in Chapter 2, this initial task was too broad, and I realized I needed to re-formulate my goals in order to have a more solid methodology. I also considered that research in engineering education traditionally has focused on older children, those in middle school through college, which may in fact be "too late"—these students may have already "made up their mind" about whether they are "better at" math/science or the humanities. There needs to be a better understanding of what causes some children to decide early on whether they are "little scientists" or "little humanists" (Bers & Portsmore, 2005) and why so many girls seem to chose the "little humanist" route. This new area of research is unique and thus needed a unique methodology that blended traditional psychological techniques for examining problem solving with innovative methods for classroom research. Using my engineering and developmental psychology backgrounds as well as the experience from my pilot research, I developed a methodology for examining social collaboration in young children when working on engineering tasks. Thus I shifted slightly from a focus purely on gender differences in problem solving in young children, as even that was too broad, to one in which an important aspect of both problem solving and engineering, social collaboration, was observed for gender differences. This research will focus on the role of dyadic (two students) social problem solving on engineering tasks in a first-grade classroom in an attempt to better understand how children learn to engineer. While only a small sample size (24 students in 12 dyads) was used in this research and the results only hint at gender differences in young children, I hope that this methodology will set the groundwork for future research. In the remainder of this chapter I will provide a general background of problem solving as well as an overview of the domain of engineering for children in order to set a theoretical framework for the research.

Background: Problem Solving

Definition of Problem Solving

The history of problem solving is, for obvious reasons, closely tied to research about reason and logic; Wason and Johnson-Laird (1972) wrote,

> It is obvious . . . that when an individual draws a conclusion from premises according to traditional Aristotelian laws of logic, he is engaging in reasoning. It

> is also feasible to assert that an individual solving a crossword puzzle, planning to buy a new house, or determining the best route from one town to another, is also engaging in reasoning. (p. 1)

The quotation above represents the two major forms of reasoning and logic: formal and informal. Formal logic is based only on logical truth—one is only asked to draw a conclusion based on a situation or question. A classic example of a question aimed at formal logic might be: "(1) If A is true, then B is true. (2) A is true. What follows?" Informal logic, on the other hand, is based in reality and context, resulting in more possible answers and solutions and thus more uncertainty. In both informal and formal logic, however, there are two important concepts that carry over to problem solving: goal-directed cognitive activity and inference. Due to the scope of this research, logic and reasoning as fields unto themselves will not be discussed further; rather, they will be alluded to throughout the following discussion of problem solving.

Before delving too much into the specifics of the problem-solving literature as it relates to my research, I feel it is important to have a definition of the term in order to ground understanding. *The Handbook of Child Psychology*, one of the most respected and eminent publications in the field, devoted an entire chapter to the development of general problem solving in children; within this chapter, Deloache, Miller, and Pierroutsakos (1998) define problem solving as a situation consisting

> . . . of a goal, one or more obstacles that make achieving the goal not immediately possible, one or (typically) more strategies that can be used to solve the problem, other resources (knowledge, other people, etc.) that can affect which strategies are used, and the evaluation of the outcome of the problem-solving process. (p. 826)

Extracting from this definition, there are four key components to how problems are actually solved—recognition of the problem, identification of the end goal, creation of a plan to get to the end goal, and recognition that the end goal has been achieved (Deloache, Miller, & Pierroutsakos, 1998; Thornton, 1995). Engineering is a field that is based on the ability to solve problems, both formally and informally, as is reflected in the engineering design process (to be discussed in more detail in Chapter 3).

Children's Development of Problem-Solving Strategies

In general, the development of problem solving is described by changes in four areas: (a) the problem-solving strategies that children use, (b) the resources children can use to solve problems, (c) the ability of the child to plan and manage the process of solving a problem, and (d) the influence of the social contexts where problem solving occurs. Overall, changes in these four areas help make problem solving more reliable, systematic, and efficient as cognitive limitations due to developmental stage and age are overcome (Deloache, Miller, & Pierroutsakos, 1998). Each of these four areas will be discussed below, though I would like to note that the first three areas are provided as background and the fourth area is the focus of the analysis of this research.

The Problem-Solving Strategies that Children Use

Problem solving strategies can be classified into two major categories: "knowledge-lean strategies"—general problem-solving strategies that cut across domains—and "knowledge-intensive strategies"—problem-solving strategies that are specific to a domain (such as math and science). Because knowledge-intensive problem-solving strategies rely on the context of the situation to organize the strategies used, they cannot be generalized to other domains, and thus problem-solving strategies that have been found in math and science cannot be generalized to engineering (and hence where this research falls) (Deloache, Miller, & Pierroutsakos, 1998).

More specifically, knowledge-lean problem-solving strategies are usually one of two major types: forward searching or problem-reduction. The most common forward-searching strategy is “trial-and-error,” which is defined as trying all possible solutions until one works. In trial-and-error, one only needs to recognize that the goal has been achieved (i.e. one does not have to find the best strategy to get to the solution). The use of trial-and-error strategies has been seen in infants as young as six months of age, though it has been found as a common strategy in two and three year-olds. In addition, research has suggested that while twelve year-olds also use trial-and-error, their sequence of trials is more coherent than that of younger children (i.e. they are capable of becoming more focused in what they try). (Deloache, Miller, & Pierroutsakos, 1998)

One of the most common problem-reduction strategies is “means-end analysis.” In means-end analysis, one is required to observe and process the difference between the current state and the goal state, and then to develop steps to reduce the differences between them. However, if the goal cannot be achieved directly, mini-goals can be created to move closer to the end state. Means-end analysis requires an understanding of the domain in which the problem solving is occurring, but it is a strategy that has been found to be generalizable across domains. Means-ends analysis, however, is difficult because of the “cognitive load” required—one must be able to generate goals, order the goals, remember the goals, use the goals to regulate one’s actions, and finally, repeat these steps. Thus, only as one’s “cognitive load capacity” increases through development can means-end analysis be used efficiently. Nine-month olds have been shown to demonstrate means-end analysis, but most growth with this strategy occurs during the toddler years. (Deloache, Miller, & Pierroutsakos, 1998)

Another common problem-reduction strategy is “hill-climbing,” which is a combination of trial-and-error and means-end analysis. In hill-climbing, one chooses strategies that will bring one closer to the end goal, but one does not have to have the entire path to the goal planned out. Hill-climbing has been shown to be a problem-solving strategy in children as young as four years-old. (Bjorklund, Muir-Broaddus, & Scheider, 1990; Deloache, Miller, & Pierroutsakos, 1998; Thornton, 1995)

In general, the major difference between the two categories of knowledge-lean strategies is that one is not planned (forward-searching) and the other is planned (problem-reduction). On a given problem, individuals may use a wide array of strategies, which makes it difficult to identify one particular strategy as the main method of solving (Bjorklund, Muir-Broaddus, & Scheider, 1990; Deloache, Miller, & Pierroutsakos, 1998; Thornton, 1995).

Role of Knowledge and Context

In addition to understanding the types of strategies that might contribute to the solving of a problem, it is important to recognize the role that familiarity and knowledge plays in problem solving. Bjorklund, Muir-Broaddus, and Schneider (1990) wrote,

> Children display high levels of performance and apparently use sophisticated strategies, but only under specific conditions. The environment must be supportive to the extent that it provides prompts or cues for children to use a particular strategy or to the extent that task-relevant information is well known to

> the children, presumably permitting them to process that information efficiently (p. 93).

Thus problems that are unfamiliar are harder to solve, even if the logic is the same as other problems that are familiar and have been successfully solved previously. For example, returning to the problem previously given as an example of formal logic, the question is: "(1) If A is true, then B is true. (2) A is true. What follows?" This question is difficult for both children (and adults) to answer, mostly because the terminology and phrasing of the question is unfamiliar. If it is rephrased, however, and written as: "(1) If you are good on the shopping trip, then you will get a piece of candy. (2) You were good on the shopping trip. Now what?" The question now has a more familiar context for most children, and they are better able to answer the question even though the logic between the two problems was the same. Knowledge about a particular task changes the concepts and reasoning used to come to a solution, and new ways of reasoning results in new tools for problem solving (Thornton, 1995). In fact, the amount of knowledge and how they organize it is one method by which experts in a particular domain are often recognized, and thus experts in a particular field have the ability to use their understanding of the domain in problem solving (Deloache, Miller, & Pierroutsakos, 1998).

Development of Planning in Problem Solving

The third important factor in how children complete tasks is how well they can plan their strategies to reach an end goal, an essential component of means-end analysis. Children's ability to plan is affected by the complexity of and child's familiarity with the problem (Brown & DeLoache, 1978): the amount of planning that occurs increases as the knowledge and complexity of the task decreases (and vice versa—planning decreases as the complexity and unfamiliarity of the tasks increases). Young children often plan on simple tasks, but not on more complex ones, illustrating the variable nature of planning across different situations. Thornton (1995) summarized the role of knowledge in planning when she wrote,

> Each step forward in planning depends on a step forward in what you know about the specifics of the task. . . . You cannot planfully decide between several alternative courses of action if you do not know that different options exist or if you do not know the relative advantages and disadvantages of each alternative (p. 59).

In addition, the amount of participation in the project and the particular goals to be reached can influence planning (Deloache, Miller, & Pierroutsakos, 1998; Thornton, 1995). Case (1978) has also suggested that the amount children plan is related to memory capacity—one of the most complex features of the process of solving problems is regulation and planning, and thus as children grow and increase their memory capacity, their ability of how to plan and use this ability also increases.

Social Context of Problem Solving

The role of peer learning in education.

The social context in which problems are solved is another important piece of children's development of problem solving. De Lisi and Golbeck (1999) wrote,

> Peer learning is an educational practice in which students interact with other students to attain educational goals. One reason for growing popularity of peer learning in schools is a shift away from traditional views of the teaching-learning process that stress knowledge transmission from teacher to pupil, in favor of

> constructivist approaches than emphasize discovery learning and view knowledge acquisition as a social activity. Collaborative work between students has become an important means of implementing constructivist educational practices (p. 3–4).

In this research, collaborative problem solving between pairs was the focus of the analysis because of the important role that learning to work with others plays in early elementary education. The other pieces of problem solving as described above—such as the specific strategies that children use, the role of planning, and the role of context and knowledge—are each important in their own right, but in order to narrow the scope of the research, I only focused on the social context of problem solving. I would like to note that like the area of problem solving, the area of peer learning is quite broad in its history and the amount of literature available. Thus, I will focus this portion of the literature review on the role of social problem solving from a Piagetian perspective and research done from this viewpoint with young children.

Peer learning from a Piagetian perspective.

It is possible to look at the role of peer learning on cognitive development from a variety of perspectives, including those of Piaget, Vygotsky, and Bandura (DeVries, 1997; Granott, 1993); each perspective has its own conceptions and beliefs regarding the nature and impact of collaboration with others on cognitive development. In order to guide this research, I felt that it was important to focus on social theory from only one perspective in order to ground the research in theory. After consulting with David Henry Feldman, an expert in cognitive development, I decided to choose Piaget's theory of social development. DeVries (1997) wrote that,

> According to Piaget, peer interactions are crucial to a child's construction of social and moral feelings, values, and social and intellectual competence. . . . Reciprocity in peer relations can provide the psychological foundation for perspective-taking . . . and decentering . . . Children are more easily able to think and act autonomously with other children than with most adults. (p. 4–5; also supported by De Lisi & Golbeck, 1999).

Peers play an important part in classroom learning and in the context of this research, it is central to understand the extent of role of peer learning on engineering tasks. However, it is important to note that according to Piaget, it is at the age of 7 or 8 years (the age range of the students in this research) when children are said to be in the "concrete operational stage." In this stage, operations and co-operations for working with others become developed. At 11 or 12 years, these operations continue to grow as children enter the "formal operational stage." (DeVries, 1997)

In collaborative problem solving, there is a notion of "two wrongs make a right": essentially if two people working together both have incorrect strategies, they can use pieces of each in order to find a correct solution, and thus a pair working together is more likely to develop a new and better strategy then someone working alone (Deloache, Miller, & Pierroutsakos, 1998; Thornton, 1995). Piaget believed that it was this conflict that allowed for change and development of collaborative operations (De Lisi & Golbeck, 1999; DeVries, 1997; Thornton, 1995). However, this is not always the case, as students' strategies can be in such conflict that they are unable make joint decisions, and thus will not gain anything from the experience. In addition, if one student dominates the activity to the point that the other student can only watch passively, then that student will also not learn anything from the interaction. However, there are situations in which unequal dominance between the partners can be beneficial for learning; Thorton (1995) wrote, “The key factor seems to be whether passive partners have a chance to work out conflicts between the understanding and expectations that come from their own strategy and the feedback that comes from the strategy the dominant partner is pursuing” (p. 96). Thus, if a dominant partner is able to explain his/her strategy and allow the passive partner to gather feedback from the task, there is more likelihood that both partners will learn from the task.

DeVries (1997) developed a list and description of five principles, based on Piaget’s social theory and her work with teachers, for classroom teachers in what she terms “constructivist education”:

(1) Relate to children in co-operative ways.

(2) Promote peer friendship and cooperation, including conflict resolution.

(3) Cultivate a feeling of community and the construction of collective values.

(4) Appeal to children’s interests and engage their purposes.

(5) Adapt to children’s understanding. (p. 14–15)

These five principles, in particular the second and the fourth, are important to this research in order to understand better how children work together on engineering tasks. In sum, the component of Piaget’s theory regarding social learning is important for this research in that it (a) emphasizes the importance of peers for learning and development, (b) highlights the role of conflict in peer learning, as it relates to friendship and motivation, (c) suggests a need to adapt to the child’s needs and understandings of the materials in order for the child to be a successful learner.

Background: Engineering in Childhood

Domain of Engineering for Children

The domain of engineering for children is a new and exciting area of research, raising the simple question of "What does engineering for children look like?" In Massachusetts, the passing of the state frameworks for science and technology/engineering in 2001 helps to answer this question, painting a picture of engineering in elementary through high school, at least in Massachusetts. For this research, the definition of engineering will be that of the Massachusetts Frameworks (Massachusetts Department of Education, 2001):

> Technology/engineering seeks different ends from those of science. Engineering strives to design and manufacture useful devices or materials, defined as technologies, who purpose is to increase our efficacy in the world and/or our enjoyment of it. . . . Each technology represents a designed solution, usually created in response to a specific practical problem. (p. 4)

Problem solving is an important component of engineering; the fifth of the ten guiding principles of the MA Frameworks states: "Investigation, experimentations, and *problem solving* [emphasis added] are central to science and technology/engineering education." Thus without a clear understanding of how children problem solve engineering tasks, an educator will not be able to develop appropriate curriculum to support children's learning.

Children's Problem Solving in Engineering and Technology

Some research has been done regarding children's technological problem solving—Gustafson and Rowell (1998) looked at elementary school children (5 to 13 years) and how they began problem solving on a technological task. They suggest that children need time to "figure out" a way to get to the goal state, and that teachers should be flexible and allow for this time. Over three years, Roden (1999) researched young children's technology and design problem-solving strategies in Key Stage 1 (early elementary school in the United Kingdom, ages 5 to 7). Roden created a taxonomy of 10 problem-strategies for this key stage, which included "sharing and co-operating" (p. 23) and found that the frequency of some strategies increased with age (e.g. "negotiation" and "sharing and co-operating) while others decreased (e.g. "talking to self" and "personalization"). McCormick, Murphy, and Hennessy (1994) looked at 13-year-old students' problem-solving processes on a technological task, finding that the design process is complex and relies on the context of the situation. Other researchers have examined problem solving at the college level, however, due to the scope of this paper, they will not be discussed (see: the engineering design process and problem solving, Von Der Weth & Frankenberger, 1995; Defeyter & German, 2003; problem solving with mechanics, Hegarty, 1991; technological and personal problem solving, Wu, Custer, & Dyrenfurth, 1996).

Engineering in Early Childhood with Robotic LEGO© Bricks

For this research, the toolset used to bring engineering to young children was that developed by the LEGO© Group in the form of robotic LEGO bricks. The use of hands-on materials in learning engineering concepts supports constructivist learning theory

(Bers, Ponte, Juelich, Viera, & Schenker, 2002; Resnick, 1998) and it allows children to explore "real" engineering pieces, such as motors and gears, in a safe and inexpensive manner.

The toolset used in the pilot research.

The toolset used in the pilot study of this research was a commercially available robotics kit, called LEGO Mindstorms™ Robotic Invention Kits and ROBOLAB™ software. Each kit contains a variety of pieces in different sizes and shapes, though many are standard pieces that would be familiar to those who have previously played with LEGO products. These familiar pieces include beams, bricks, and plates (Figure 1.1).

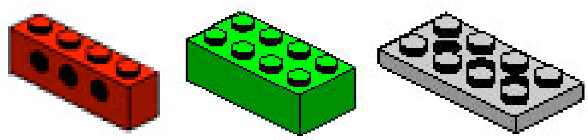


Figure 1.1: Traditional LEGO beams, bricks, and plates.

However, the Mindstorms Robotic Invention Kits contain several additional pieces, including motors, light sensors, touch sensors, wires, axles, and gears. Perhaps the most interesting and unfamiliar piece in the kit is the "RCX"—a large yellow and gray brick (measuring 2.5" wide, 3.75" deep, and 1.5" high) that contains a micro-computer. The RCX has three input connections (for the touch and light sensors) and three output connections (for motors and lamps). In addition, a LCD display provides information about the input and output connections as well as data that are stored in the processor. The RCX communicates information to and from a computer through infrared (the kit contains a USB infrared "tower" that connects to a computer) (see Figure 1.2).

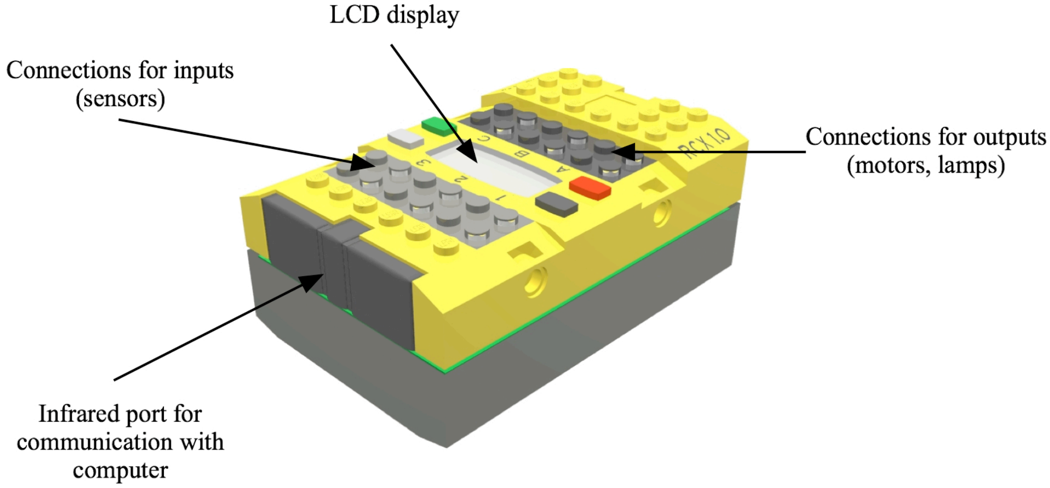


Figure 1.2: The RCX.

This kit was used in the pilot research, along with the software that can control the brick, ROBOLAB.

The ROBOLAB software was developed through a partnership with the Tufts University Center for Engineering Educational Outreach (CEEO), the LEGO Group, and National Instruments Corporation. ROBOLAB is a drag-and-drop graphical interface that has several levels of difficulty, so the user can tailor the functions that are available to their personal skills (Portsmore, 1999) (Figure 1.3). ROBOLAB has been used with pre-kindergarten students to college engineering students to adult teaching professionals. Currently, ROBOLAB and LEGO Mindstorms are used in 30,000 to 50,000 schools worldwide, making it a widely used teaching tool.

Figure 1.3: Sample ROBOLAB program. This program tells a car (built around the RCX) to go forward for two seconds then to go backwards until the touch sensor is pushed, and then stop.

The toolset used in the second phase of research.

In the second phase of research, the LEGO "Motorized Simple Machines Set" was used instead of the "Mindstorms Robotic Invention Kit." (Figure 1.4).

Figure 1.4: Components of the LEGO Motorized Simple Machines kit. Adapted from http://www.legoeducation.com.

This kit contains many of the same basic pieces (i.e. beams, bricks, plates, etc.) as well as some of the more advanced pieces (i.e. motors and gears), but does not have an RCX nor sensors. Instead, the kit contains a simple battery pack that can drive one motor forward or backward.

The curriculum used in the second phase of research.

In the second phase of the research, the curriculum taught was entitled "Engineering by Design," (Green et al., 2002) which is available for downloading from the CEEO website.[1] Experienced first-grade teachers as well as experts in the technology from the CEEO developed this curriculum, and it has been used in many classrooms since it became formalized in 2002. The curriculum contains lessons to teach vocabulary (the proper names of the pieces), engineering concepts, building concepts, and beginning programming concepts.

In this chapter, I began by summarizing the state of women in the field of engineering and suggesting the need for research into engineering in early education. I then provided a background for problem solving, including a definition and a discussion of the four areas that describe development of problem solving: the strategies that children use, the role of knowledge and context, the ability of a child to plan, and the role of the social context. I then discussed the domain of engineering as it pertains to children, including a description of the toolset and curriculum used in this research. In the next chapter I will discuss the methodology for and results from the pilot research that set the groundwork for the final research methodology.

[1] The curriculum used in this research can be downloaded from: http://www.ceeo.tufts.edu/robolabatceeo/k12/curriculum_units/Engineering%20by%20Design.pdf

Chapter Two: Pilot Research

Introduction

As shown in Chapter 1, research about young children in engineering is still in its infancy. To provide a starting point for my thesis, I developed and completed pilot research during the spring of 2005, in partial fulfillment of requirements for the course "Qualitative Research Methods," taught by Professor Jayanthi Mistry of the Department of Child Development at Tufts University. For this pilot research I formulated two major research questions: (1) How do girls of different ages plan and get started on the task of solving engineering problems? and (2) What do girls of different ages actually do when they are engaged in creating the solution to the problem? The research design for the pilot work was based upon these two questions and incorporated active interviews with participant observation. Throughout this pilot research, I followed the guidelines for the recursive nature of qualitative research (Denzin & Lincoln, 1998; J. Mistry, personal communication, January 31, 2005) in which the researcher continuously cycles through the following steps: (1) defining the theory and frameworks within which the research will be grounded, (2) determining the purpose of the research and the subsequent research questions, (3) planning the research design, (4) collecting the data, and finally (5) interpreting the data. Thus, my pilot research was a dynamic process, and I will explain where this was pertinent in the following sections.

Selecting a Sample

For this pilot research, I thought the best course of action was to have girls of different ages complete the same robotics task so that I could observe developmental differences in their problem solving. I also had wanted to use this pilot research to test the robotics task to see if it was an appropriate means to gauge problem solving and to evaluate the types of questions I would be asking the girls (for example, how best to word a particular question so that the first grader would understand) for the next phase of research. I had planned on recruiting girls in kindergarten/first grade, third/fourth grade, middle school, high school, and college, but due to time constraints, the girls had to have already learned the robotic LEGO brick materials. For this pilot research, I recruited girls in a variety of ways.

Recruiting of First- and Second-Grade Students

I applied for permission to do research at the Eliot Pearson Children's School located on the Tufts University campus, and permission was granted after my proposal was reviewed and the criminal record offender information ("CORI") check, as required by Massachusetts, was approved. However, the teacher in charge of research at the school told me that only three girls in the first- and second-grade classrooms fit the criteria. I contacted the parents of all three girls by letter sent through their classroom teachers, but only two of the parents agreed to let their daughter be part of the research (one six-year-old first grade student and one seven-year-old second grade student). I arranged a time with them to meet me after-school with their daughters at the Children's School. In order to make the students feel comfortable, I invited their parents to stay with them during our session; one mother did, and one mother worked in a room down the hall.

Recruiting of Fourth-Grade Students

A professor who works with the CEEO has a daughter in fourth grade, and both the daughter and her parents agreed to take part in my research. I arranged with her mother to work with the student at her home one afternoon after school. I had originally intended to interview a friend of this student as well, but I was unable to coordinate a time to meet because of the student's schedule.

Recruiting of Middle School Students

I had taught a four-day mini-course on LEGO robotics for students in middle school at Lexington Christian Academy (LCA, a private school) in March of 2005. In my course of twelve students, I had six girls. I asked the Dean of Student affairs if it would be possible for me to recruit some of the girls for my research at the conclusion of the course I was teaching. After reviewing my proposal and consent/assent forms, she approved, and I gave all six of the girls the opportunity to volunteer (though the forms were not due until after I submitted the grades for the course so that the girls would not feel pressured to participate). Two girls, one twelve-year-old sixth grader and one twelve-year-old seventh grader, agreed to be part of the research. The dean arranged a time for me to meet with the girls individually during the "Activities Block," an hour at the end of the day when students can participate in drama, sports, music, etc.

Recruiting of High School and College Students

For this pilot research, I was not able to recruit high school students, as at the time, the CEEO was not working with high school students using the robotic toolset. In terms of college students, I asked three of the undergraduate engineering students who also work at the CEEO if they would be willing to volunteer for this research. Only one was able to help me, and thus I had one college junior for this research. I met with her one Friday afternoon when it was convenient for her schedule.

In total, I had six girls participate in my research: one first grader, one second grader, one fourth grader, one sixth grader, one seventh grader, and one college junior. In order to protect their privacy, all references to the girls in the following sections are pseudonyms.

Data Collection

I collected data for this research in two ways: through interviewing the participants and through participant observation. In general, I asked each girl to meet with me for one 45-minute session, either after school or during the day, depending on which was most convenient for them (for the younger girls, I arranged meeting times with their mothers).

Active Interviews

During the first ten minutes and the last five to ten minutes of the session I interviewed the girls. During the first interview I asked the girls questions about their backgrounds (i.e. age, grade, familiarity with LEGO bricks) and questions related to problem solving and group work. During the second interview I asked questions regarding the task they had just completed.

As I was just learning not only how to interview, but also what questions to ask, each interview had slightly different questions than the previous one, though many of the topics remained the same. I also had to learn to how interview a participant in a manner that was appropriate and would elicit the best responses. Luckily, we had practiced interviewing during my coursework, and I tried to keep in mind Spradley's suggestions for ethnographic interviews (1979), such as remembering that turn-taking should be less balanced in favor of the interviewee (i.e. allowing the girls opportunity to talk), repeating back what the interviewee said, and expressing both ignorance and interest to illicit rich responses.

Participant Observation

Between the two interviews each participant had approximately thirty minutes to create a robotic music box. They had available to them a LEGO Mindstorms kit (which included all the robotic pieces), a bin of extra LEGO pieces (such as decorative pieces, bricks, beams, plates, etc.), white computer paper, a pencil, a ruler, a laptop computer (with a mouse and the ROBOLAB software installed). They were told that I did not care what they made or if they finished in the time allotted (so that they would not feel stressed), and that they could stop at any time during the course of the task.

Because of the age range of the girls, I had to decide beforehand whether I was going to interact with them during their completion of the music box. As discussed by Spradley (1980), I could have chosen nonparticipation, in which case I would have just sat and watched the girls complete the task, asking no questions or interacting with them. On the opposite extreme, I could have chosen complete participation, which would have meant that I was actively involved in helping them create their music box, including making decisions about the task. I choose somewhere in the middle (while not a perfect term, moderate participation may best characterize it)—I told the girls at the beginning of the task that I would help them if they wanted it, but that they would have to ask me (e.g. if I saw them struggling, I would not "jump in" and tell them the solution) and that I might have to ask them questions about what they were doing (I told them I had to do this because I "couldn't see into their heads to see what they were thinking").

Documentation: Videos, Field Notes, and Photographs

Because I was actively involved in helping the girls when asked and because I wanted them to feel as comfortable as possible, I decided not to take notes during the sessions. Instead, I videotaped each session, setting up the video camera on a tripod in a location that best captured the situation. At the end of each session, I also took pictures of their projects. As soon as possible after the sessions, I transcribed the videos, including transcribing what was said and describing the actions of the girls during the sessions as they were building their music boxes. During the last few transcriptions, I realized that I should “capture” frames of the video as images to better show what the girls were doing while they were building, as trying to describe what is occurring while building with LEGO bricks can be difficult. In each set of field notes, I included a description of the setting, added my personal comments where appropriate (“observer comments”), and inserted the pictures of their projects at the end of the document (a sample of these field notes can be found in Appendix A).

Coding

Once each of the sessions was transcribed and the field notes were complete, I imported them into the research software program *Atlas.ti* as primary documents. I created a start list of codes (as suggested by Miles and Huberman, on whose method I based my analysis) prior to coding, and this list included six major categories (“families”) of codes. The six categories related to the interviews were: (1) “Participant Background,” to understand where each participant is coming from; (2) “Knowledge of Materials,” as according to the problem-solving literature, the amount of knowledge one has about a topic is one of the most important components of problem-solving; (3) “Group Work,” to understand the importance of the social environment in problem solving; (4) "Problem-Solving Conceptions," to get a sense of what they understand about problem solving; (5) "Post-Task Questions," related to how they reflect upon the task, and; 6.) "Task Strategies," related to how they actually completed the task. The codes in the first five families were based on the questions that I asked the girls during the interviews (i.e. the code "GW: Gender of people" corresponded to the question, "When working in a group, do you prefer to work with boys or girls?"). Because I knew, for the most part, what categories of questions I would be asking, there was not much change between the start list of codes and the final codes for these four families.

However, the last family of codes, "Task Strategies," was much more dynamic. The codes in this family corresponded to actions that the girls did during the task. For example, "TS: Asks a question" was used if the girl asked me a question, "TS: Assembles" was used when the girl put pieces together, and ""TS: Pauses to look at project" was used when the girl stopped working to look at her project. I also decided that while the amount of time that the girls spent programming their projects on the computer varied, it was not a significant aspect of the creation of the music box—the girls spent most of the time building the music box. Thus, all programming was captured under the code "TS: Programs," and the analysis is mostly in reference to the building. I had created a start list of the codes for this family, but as I was going through the field notes, I added ones when necessary; thus, my initial seven codes in this family blossomed into twenty-three (see Appendix B for a complete list of the codes used and their definitions and Appendix C for a sample of coded field notes).

Analyzing Data

Overview of Miles and Huberman's Approach to Qualitative Analysis

For analysis of this pilot research, I used Miles and Huberman's methods, dubbed "soft-nosed" positivistic, as I felt the use of a case-by-case approach and visual displays—two assumptions their method is built upon—were the best way for me to analyze my data considering the very small sample size. They summarized their approach best when they wrote, "valid analysis requires, and is driven by, displays that are focused enough to permit viewing of a full data set in the same location, and are arranged systematically to answer the research questions at hand" (1994, p. 91–92). In their approach, displays can serve several purposes, including to aid in data reduction, in creation of a coding paradigm, in pattern analysis, in verification of patterns, and in presentation of results. Because I wanted to see the patterns that developed between both the girls' answers to the interview questions and how they completed the task, I felt that this method— in comparison to the other major qualitative analysis strategies available, including Spradley's ethnographic approach (1979), Strauss and Corbin's grounded theory approach (1990), and Reissman's narrative analysis approach (1993)—best suited my data.

Across-Case Charts

To create across-case charts, I used *Atlas.ti* to filter one of the coding families, and then I exported the codes for that family and the linked quotations into a text file, which I then copied into charts that I created in Microsoft Word. I repeated this for the four remaining coding families that corresponded to the interview questions. Thus, I produced five across-case charts that reduced my data a great deal and made analysis easier. In addition, I used some of the charts for pattern analysis, which resulted in an even more generalized chart. For example, one of the initial across-case charts was based on the girls' responses to the number and gender of people they prefer to work with in a group (see Appendix D). Using this chart, I created a chart that indicated the patterns of the girls' responses (see Appendix E).

Task Event Networks

The more complicated piece of analysis was creating task event networks for each of the girls (I should note that I randomly selected one of the middle school students to use in the analysis so that every grade level would only have one case). After coding the task using the "Task Strategy" codes, I used *Atlas.ti* to filter that family, and I then exported the document, including the codes in the margins, to a Portable Document Format (PDF). I then printed out only the pages of the PDF that had codes for the task (i.e. I did not include the interview codes). Finally, I created task event networks in Microsoft Excel based on the order of the codes (for an example of a document with the task codes, see Appendix F; for an example of a task event network, see Appendix G).

Presentation of Findings

Background of the Girls

Before starting the analysis, it is important to understand the background of each of the girls, particularly their age (related to their developmental level) and their knowledge of the materials. I should also note that because I only created task event networks for four of the girls, I am including only those four girls in my analysis. Based on my interviews with each of the girls, observing her complete the task, and my personal knowledge about the materials, I classified each girl at a "level" with the materials relative to the other girls, as shown in Table 2.1.

Table 2.1: Age, grade, and level with the materials for each of the participants in the pilot research.

Student	Age	Grade	Level with the Materials
Amanda	6	1	Beginner
Kaylee	10	4	Novice
Chloe	12	7	Intermediate
Leah	21	College Junior	Expert

In addition, I asked each of the girls about their favorite class in school, and "what they wanted to be when they grew up" (Table 2.2). The three younger girls choose traditional "liberal arts" classes as their favorites and also chose non-math, science, technology, or engineering (MSTE) fields for potential future careers (two actresses and "something with dogs"), while the oldest girl chose both an engineering class and an engineering field (which is unsurprising because she is studying engineering). While only four girls, their answers support other research that indicates younger girls are not interested in MSTE fields for careers (McIlwee & Robinson, 1992).

Table 2.2: Each participant's (in the pilot research) favorite class and "what they want to be when they grow up."

	Favorite Class		**What She Wants to "Be When She Grows Up"**	
Age of Student	Traditional "Liberal Arts" Class	MSTE Class	Non-MSTE occupation	MSTE occupation
Early Elementary	✓		✓	
Late Elementary	✓		✓	
Middle School	✓		✓	
College		✓		✓

Girls Conceptions of Problem Solving

In order for me to know how each girl understood problem solving, I asked her to define the phrase "problem solving."

Table 2.3: Girls' definitions of the phrase "problem solving."

Student	**Definition of Problem Solving**
Amanda	"It means like there is a problem and then you solve it."
Kaylee	"How to solve a problem".
Chloe	"Well, you have something you need to overcome, and use steps to overcome this thing…that you need to overcome...basically."
Leah	"I would say coming up with a variety of solutions to any type of question in any kind of field."

As shown in Table 2.3, the younger two girls gave answers that were simply a rephrasing of the words. The middle school girl's definition started to become more abstract, but she was not quite sure how to finish her thought, though the college student was able to articulate a little more clearly, suggesting a development in their understanding of problem solving.

I also asked each girl to imagine they were sitting in math or science class, and the teacher gave them a problem to solve. I then asked them if they thought that the person next to them was going to answer the problem in the same way as they would. All four of the girls responded with some variation of "it depends." For example, Amanda said,

> Because if, let's say, how...what other ways can you make 10 besides 5 plus 5? I may do 6 plus 4, and someone else might do 7 plus 3. . . . It depends what day it is. 'Cause some days you're thinking different things from your friends, and some days you're thinking the same thing.

while Chloe said,

> I possibly could but, um, the way that we interpret the problem may be different so if um, so if you are going through the problem, maybe it is a word problem and you need to figure out this (gestures with her hand) and the other person thinks you need to figure out that (gestures with her other hand) instead of this (gestures with her first hand again) then the answer would be slightly different.

This is one of the only areas where all the girls had similar responses to the question, suggesting that even at early ages girls are able to understand that people solve problems in various ways that may or may not be different than how she solves the problem. The youngest girl's answer reflects that she is beginning to be able to take the point of view of another person, i.e. that she is moving away from an egocentric mode of thinking. This transition is typical at her age (six years), as she moves from the stage Piaget called "pre-operational" to the "operational" stage, in which her thinking becomes more advanced, including the ability to take the perspective of another (Marvin, Greenberg, & Mossler, 1976; Piaget & Inhelder, 1956).

The Social Context of Problem Solving

A major component to problem solving is the social context in which it occurs, including the people one works with as well as the help one seeks. In terms of group work, I asked the girls if they preferred to work in a group or individually on projects as well as their preferred gender composition if they had to work in a group (Table 2.4).

Table 2.4: Participants' preferences for group work.

	Preferred Working Situation			**Gender of People in Group**	
Age of Student	Individually	In a Group	It Depends	Prefer to Work with Girls	Will Work with Boys or Girls
Early Elementary			✓		✓
Late Elementary		✓		✓	
Middle School	✓			✓	
College	✓				✓

The two older girls preferred to work by themselves, both citing speed of task as important: "'Cause then you can usually work a lot faster, like um, usually when you have a group you have to talk and sometimes there are disagreements and that slows you down," (Chloe) and "I guess now I would prefer to work by myself. Basically because I know what work needs to be done and when you work with a group you don't always know who is going to put in as much effort as you will" (Leah).

In terms of their preference for gender composition of a group, the youngest and oldest said they would work with boys or girls ("It doesn't matter. . . .I'd work with anybody" and "It wouldn't matter in college—I think it's kind of whoever in the class you get along with best," respectively), while the late elementary and middle school student preferred working with girls. To explain herself, Kaylee said, "They [boys] do it all themselves and they don't really ask you anything.... and they are loud," and Chloe said, "It is easier to work with a girl rather than a boy because you probably know them better than a boy. And it is easier for you to communicate 'cause you are going through...it is just easier." Dunphy (1963) found this same pattern of group gender preference, in which groups remain single-gender in early adolescence.

In this pilot research, I considered the role that adult (or expert) help might play in how the girls completed the engineering task; to do so, I looked at the codes in order to count the number of times that each girl either asked me a question, asked for help, received help from me, or I gave her a LEGO piece. Like the other task strategy codes, these codes also decreased as the girls' age increased. For Amanda, the sum of these "helping" codes was 58, for Kaylee, 11, for Chloe 2, and for Leah 0. Thus, it seems that a major component to completing an unfamiliar engineering problem, especially for younger girls, is the amount of help that they need to complete the task. However, this may also be due to the differences in knowledge level between each of the girls, as the youngest girl was a beginner and the oldest girl was an expert (in fact, she often teaches the material herself).

In addition, Amanda had 22 instances of the code "unsuccessful assembly" which meant she tried to assemble the pieces but was unable to (usually resulting in my helping her or her changing her plan for an easier action)—this was mostly a fine-motor issue, as she struggled with physically putting the pieces together. For the older girls, however, the physical difficulties with the materials were not a large issue, suggesting that the development of fine motor skills that comes with age can influence how an engineering task is completed. In terms of designing engineering curricula and planning personnel support for activities for various ages, this pilot research suggests that younger children need to have adequate adult/expert support when working on engineering tasks (perhaps especially those requiring fine-motor abilities).

How Girls Complete an Engineering Task

In order to better understand how girls complete an engineering task, I examined the task event networks of four girls, looking at both the number of their steps and behaviors as well as patterns in their behaviors.

Number of steps and number of behaviors.

Each of the "Task Strategy" (TS) codes represents an action completed by the girl. Thus, the total number of TS codes in each girl's task indicates the approximate number of steps the girl used to get from the start state (she was given a task and materials to use, but no further instructions or constraints) to the end state (a music box). The youngest girl, and the most inexperienced with the materials, needed approximately 285 steps, while the oldest girl, and the most experienced with the materials, needed approximately 9 steps. In between these two extremes, the fourth grader needed 62 steps and the seventh grader needed 40 (See Table 2.5).

Table 2.5: Frequencies of "Task Strategy" codes. Highlighted rows show the codes with the greatest difference between Amanda and Leah.

Code	**Amanda** *(6 years)*	**Kaylee** *(10 years)*	**Chloe** *(12 years)*	**Leah** *(21 years)*	**Difference Between Amanda and Leah**
Asks a question	15	6	2	0	15
Asks for help	14	1	0	0	14
Assembles	63	13	10	3	**60**
Comes up with an idea	17	4	2	0	17
Comment to me	15	0	0	0	15
Draws	0	1	2	0	0
Gets help from me	13	4	0	0	13
I give her a piece	16	0	0	0	16
Looks at the available pieces	12	6	1	0	12
Off topic	8	0	0	0	8
Pauses to look at project	15	2	1	0	15
Programs	0	1	2	1	-1
Searches for/takes a piece with intent	31	10	8	4	**27**
Searches for/takes a piece without intent	11	4	0	0	11
Takes & looks at a piece	3	1	0	0	3
Takes pieces off	5	3	6	0	5

Code	Amanda	Kaylee	Chloe	Leah	Difference
Talks to herself	19	1	0	0	19
Tests	2	2	0	1	1
Tries a piece unsuccessfully	4	3	7	0	4
Unsuccessful assembly	22	1	1	0	**22**
Total number of building steps to complete task	286	62	40	9	277

Looking more specifically at the differences in actions between these two girls, as shown in Table 2.5, the total number of instances of almost every code decreased as the girl's age increased. In addition, there was a difference of greater than 20 between Amanda and Leah in three of the codes: "Assembles," "Searches for/takes a piece with intent," and "Unsuccessful assembly" (tries to put piece together but cannot). Examining the task event networks, I then looked for the codes "searches for a piece" and "assembles" within 5 steps of each other (Figure 2.1) as a way of pattern analysis.

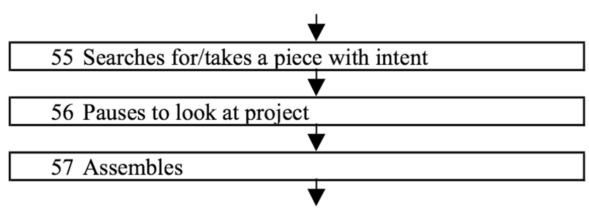


Figure 2.1: Excerpt from task event network from Amanda.

Amanda had 20 instances of this pattern, Kaylee 9 instances, Chloe 2 instances, and Leah 2 instances. The frequency difference in this pattern between the youngest and oldest student is reflected in the videos: Amanda would search for a LEGO piece, find it, place it on her structure, and then repeat the process. Leah, on the other hand, found several pieces at once, assembled, and then searched for several more pieces at once, condensing her searching and assembling into fewer steps.

Patterns in their task completion.

Planning can be an important component to problem solving. Research on planning shows that beginners on a task do not plan because they do not know enough about the task to be able to plan (i.e. how can planning occur for something unknown?) and on the opposite skill level extreme, experts also do not have to plan because they understand the task so well (Thornton, 1995). This pattern was shown in this research—the beginner and the expert did not plan before starting their projects, while the novice and intermediate girls did (Table 2.6).

Table 2.6: Girls planning on a robotics task.

Age of Student	**Drew or Planned Before Starting Task**	**Did Not Draw or Plan Before Starting Task**
Early Elementary (beginner)		✓
Late Elementary (novice)	✓	
Middle School (intermediate)	✓	
College (expert)		✓

This is an important aspect to keep in mind, especially when planning curriculum—girls perhaps need an opportunity to plan before working on their projects. Again, this is something that has been observed in classrooms by other graduate students and staff at the CEEO—during sessions with boys and girls, the organizers often have to "hide" some of the interesting pieces because the boys just like to jump into the project, while girls like to plan, and when the girls are ready to get the pieces they need, there are none left.

Another interesting pattern that I observed was related to how the girls created their projects. As revealed in the interviews with the girls and summarized in Table 2.7, the youngest girl was the only one who did not have an idea of what she wanted to create before she started.

Table 2.7: How the girls in the pilot research came up with their ideas for their music box.

Age of Student	**Had an Idea Of What She Wanted to Create Before She Started**	**Did Not Know What She Wanted to Create Before She Started**
Early Elementary (beginner)		✓
Late Elementary (novice)	✓	
Middle School (intermediate)	✓	
College (expert)	✓	

For example, Amanda said, when asked how she came up with her final design, “I made it up as I went along,” which contrasts what Leah said,

> I had an idea but not completely. . . . I knew that I wanted a person sitting, I knew that one person had to move, and I knew that I wanted to play some kind of music. But the other pieces, I kind of just found by playing around in the box [of extra pieces].

This is further illustrated by how Amanda created her music box—she created one wall, then another, then attached the two, then made another wall, then attached it to the first two, and then made the fourth wall and attached it to the first and fourth. Throughout her building of the walls, she came up with many ideas for what pieces to use and how to make the process faster (for example, by using long beams instead of short brick). The frequency of the code "TS: Come up with an idea" also supports this notion: Amanda had 17 instances, while Leah had none. I would like to note that for this code, I had to observe a concrete example of coming up with an idea. For example, Amanda said to me that she wished there was a faster way to make the walls than the method she was using. She then came up with the idea to use longer beams instead of shorter bricks. Most likely, Leah had the idea before starting, but did not come up with any new ideas while she was working.). Most experienced builders would be able to "see ahead" to the end of the project, and would instead build the walls vertically, adding on level-by-level to all four walls at once (which also gives the project strength). As the research on problem solving suggests, the "means-end" analysis used by Leah, in which she knew what her end state was in relation to her start state, requires a large cognitive load, which developmentally Amanda was probably not capable of.

Conclusions to and Limitations of this Pilot Research

This preliminary research looking how girls solve engineering problems shows, in general, a developmental progression of the girls' actions: the youngest girl used more steps, needed more help, and did not plan in advance when compared to the oldest girl. Referring back to the initial research questions: (1) How do girls of different ages plan and get started on the task of solving engineering problems? (2) What do they actually do when they are engaged in creating the solution to the problem? I believe this pilot research highlighted some of the interesting possibilities of this research, though there are many limitations. First, only four girls were used in this analysis, and the oldest girl was an engineer, which means that her way of completing the task may be specific to females in engineering (i.e. a college-age female with a liberal arts major may have solved the problem completely differently). Second, the patterns found in terms of age cannot be generalized to all children, because no boys were interviewed. In addition, the differences observed between the girls may be a result of developmental change rather than change specific to the type of task.

In this chapter I discussed my pilot research, including the sample population, the methodology for data collection, preliminary findings, and the limitations of these findings. In the next chapter I discuss the changes that were made to both the research questions and methodology because of the pilot research, as well as the methodology that was actually used in the next phase of research.

Chapter Three: Methodology

In the previous chapter, I discussed the methodology of my pilot research as well as the preliminary findings from that pilot research. In this chapter, I will discuss the changes that were made to the research goals because of the experiences in the pilot research and the subsequent methodology for data collection that was used for the next phase of research. In this section, I also include a description of the custom data-collection tool that I designed and developed. I conclude this chapter with a discussion of the techniques used for data analysis for this research.

Changes in Research Goals due to Pilot Research

During the summer of 2005, I reflected upon my experience with the pilot and came to three conclusions that greatly impacted my final choice of research design. First, because research into problem solving in the domain of engineering is still so new, I realized that the initial goals of my research were much too broad in scope; I was attempting to examine both developmental issues (i.e. changes in problem solving that occur because of increase of age and/or experience) and gender issues (i.e. the question of how males and females solve engineering problems differently). Examination of developmental issues implied that there was already a good understanding—through previous research—of problem solving at different ages on engineering tasks that would allow for comparison among the ages, which was impossible in the scope of this research. Examination of gender differences inherently meant that males and females would have to be compared in order to determine how their behaviors were different, and as initially designed, my pilot research did not do so. Thus, attempting to look at both of these issues at once was beyond what I could do for the purpose of a master's thesis, and, perhaps more importantly, would have resulted in a weak research design. Considering these factors, I decided that in this new area of research, it was important to focus on students in one grade. This way, the students would be close to the same developmental level and therefore I would be able to better compare the male and female students for inherent differences in problem-solving techniques.

Second, engineering is an inherently collaborative process—most engineering work is done in teams alongside others. As suggested by the current literature on peer learning and my pilot research, working in groups can be both encouraging and discouraging at the same time, depending on group dynamics. An important component of K–12 education is learning to work in groups, and specifically, work done in school with the robotic LEGO bricks is rarely done individually in an isolated manner (though my pilot research focused on each girl individually in an isolated setting). Instead, classroom activities with the robotic LEGO bricks are often done in pairs or groups (mostly because of the necessity of sharing limited amount of materials). Thus, as I hope that this and future research will inform educational practice, I thought that it was more appropriate to look at children when they work in pairs with the materials, allowing for a more "real" look at how social and collaborative problem solving on engineering tasks manifests itself in young children.

Third, for a similar reason as the above conclusion, I thought the most practical and helpful research for educators is that which is actually done in a classroom. I am aware that most psychological research about problem solving usually occurs in a more traditional setting—in a one-on-one setting similar to my pilot research—but I felt that the goals of my research required an untraditional, at least for problem-solving research, setting. In addition, De Lisi and Golbeck (1999) in their article on peer learning from a Piagetian perspective, write that research in classrooms is “badly needed and should focus not only on outcomes, or change from pretest to posttest, but also on the processes characterizing individual learning within social contexts” (p. 35). Thus, completing this research in a classroom would allow for practical recommendations and a methodology unique to a classroom environment. These three major conclusions, based on my pilot research, guided the selection of a sample population as well as the data collection methodology which will be explained in detail below.

Context of Research

Merredith Portsmore, a Ph.D. candidate in the Department of Education at Tufts University with a concentration in Math, Science, Technology, and Engineering (MSTE) Education, and a graduate research assistant at the CEEO, designed a research program to look at how introducing young children to the engineering design process (Figure 3.1) aids in their development of problem solving.

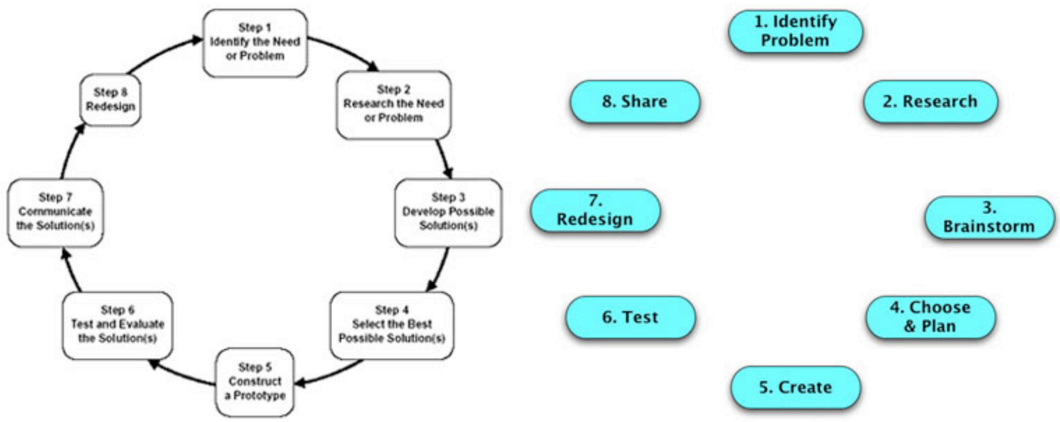


Figure 3.1: The Engineering Design Process. Left: Steps of the engineering design process as set forth by the Massachusetts Department of Education. Adapted from Massachusetts DOE, 2001. Right: Steps of the engineering design process adapted for a first-grade classroom, as developed by Portsmore, 2005.

Her research involved pre- and post-intervention tests, with the intervention being an engineering curriculum designed for use in first grade that emphasizes the engineering design process. Because we were both interested in early childhood and engineering, we decided that if we cooperated and used the same population we would be able to maximize the research potential of the population. Thus, Merredith taught the class and did her interviews outside of the teaching session while I completed in-classroom research. This arrangement worked well for both of us, as we were able to discuss new ideas pertaining to both of our research as it evolved from week-to-week and provide additional observations for each other. I should note that Merredith already had permission from the school and the Institutional Review Board at Tufts to complete this research before we decided to work together; I submitted a request to be added as a researcher and it was granted.

Goals of the Research

Based on the overarching purpose for this research, my experience with my pilot research, the constraints of the sample population, and the existing literature on the topic, I formulated four major research goals: (1) to understand how first graders approach and complete an engineering activity when working in dyads, including both individual and social problem solving abilities; (2) to inform engineering curriculum design for early childhood; (3) to provide a tool to help researchers and teachers assess engineering learning in classroom; and (4) to suggest that the "engineering" mentality is even present in first grade and that there is a need for early introduction to engineering. My research methodology was designed based on these four goals.

Population Sample

The school from which the students were recruited for this research is located in an upper-middle class suburb of Boston. The CEEO has been working with this school system for the past ten years, bringing engineering curriculum and robotic LEGO bricks into the classrooms, especially at the elementary school level. There are five first-grade classrooms in this school, for a total of approximately 100 children. Because of the methodology of Merredith's research, I only worked with two of these five classrooms for an initial total sample population of approximately 45 students. Of these 45 students, 24 parents consented to the research—12 in one classroom and 12 in the other.

Thus in the final sample population for this research, there were 14 female students and 10 male students, ranging from 75 months (6.25 years) to 87 months (7.25

years). In addition, four of the students attend this school as part of the METCO program (a voluntary busing program in which children from Boston can attend participating schools in the suburbs) and six of the students were classified as “English as a second language” learners. Once the population of students who were going to participate in the research was finalized, the two teachers assigned the children into pairs, kindly putting students whose parents had consented to the research together. The teachers requested that the children stay in the same pairs for the duration of the LEGO engineering activities, thus in each classroom there were six dyads (for a total of five female-female, four male-male, and three male-female). Pseudonyms for the children involved in this research will be used in the following sections.

Curriculum and Observation Sequence

Over the course of a two-and-a-half month period, Merredith and I went into the two first-grade classrooms once a week (on Tuesdays). One class met in the early afternoon, right after lunch, and the other in the later afternoon, right before dismissal. During these sessions, Merredith taught the first-grade classes an engineering curriculum designed for first grade entitled “Engineering by Design” (Green et al., 2002) (as discussed in Chapter 1).

The 12 LEGO engineering sessions began on October 25, 2005, skipping one week because the first grade had a pre-planned field trip, one because of their winter vacation, and one because of a snow day. Thus, the students were exposed to the engineering curriculum from the end of October through the end of January. However, due to time constraints imposed by the graduate school, I completed my research during the first eight weeks of the curriculum, finishing the last week in December before the children left for winter vacation.

Each engineering session lasted approximately one hour, and during that time, the students were given a little lesson about the day's topic (e.g. learning the names pieces, sturdy building, etc.), time to work in pairs (when I completed my research), and then time for clean-up. Originally, Merredith had planned the schedule so that each week a new activity from the curriculum would be explored and a new component of the engineering design process would be introduced to the students (i.e. one week they may learn about "beams" and how to "test" their projects), with the final three weeks devoted to an open-ended project of their choosing (Table 3.1).

Table 3.1: Initial proposed sequence of engineering activities for the first grade classrooms involved in this research.

Week	Lesson Title	Concepts	Assessment
1	Introduction to LEGO pieces & engineering	Names of LEGO Pieces	LEGO Matching Sheet
2	Build a Sturdy Wall	Design constraints Sturdy Construction	Can your wall withstand the flick test? The drop test?
3	Building a Chair for Mr. Bear	Design Constraints Sturdy Construction	Can your chair hold Mr. Bear?
4	Introduction to Pulleys	Pulleys Belts Pulley Ratio	Can you explain how your pulley wall works?
5	Introduction to motors	Motors Wires	Can you attach a color wheel to the motor and make it spin?

6	Build a sturdy car	Motor attachment to car	Can you build a car that drives forward using a pulley?
7	Build a sturdy car (continued)	-	-
8	Introduction to Gears	Gears Gear rations Gear spacing & meshing	Can you explain how your gear wall works? Can you tell me which gear combination will go faster or slower?
9	Build a snowplow	Design with pulleys or gears	Can you choose the appropriate combination of pulleys or gears to push heavy snow?
10	Build a snowplow (continued)	-	-
11	Transportation Invention	Define your own problem to solve	Can you identify your own design constraints?
12	Transportation Invention (cont'd)	-	-
13	Transportation Invention (cont'd)	-	-

Note. Adapted from Portsmore, M. (2005). "Exploring the impact of a set of design based engineering activities on first grade students' problem solving strategies, attitudes, and beliefs: PhD Thesis Proposal Draft 2.0," by M. Portsmore, 2005, unpublished manuscript, p. 12.

However, the schedule was altered based on each classroom's pace, and many activities that were supposed to be completed in one session actually needed two, and sometimes three, sessions (Table 3.2).

Table 3.2: Actual sequence of engineering activities for the first grade classrooms involved in this research.

Class #1 Lesson Concept	Introduction to LEGO pieces & engineering	Build a Sturdy Wall	Chair for Mr. Bear		Pulley Walls	Pulleys & Motors	Motorized Pulley Cars	
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Class #2 Lesson Concept	Introduction to LEGO pieces & engineering	Build a Sturdy Wall	Chair for Mr. Bear			Pulley Walls		Pulleys & Motors

Two weeks prior to the start of the observations, I went into the two classrooms twice for an hour each so that the teachers could introduce me to the students, I could explain why I was going to be in their classroom, and they could become familiar with me in their classroom. I played with the students during their free time or helped them with their schoolwork. I did this so that when I started my data collection the children would not be meeting me for the first time in order to reduce reactivity (to be discussed in Chapter 5).

I began my observation with two weeks of “practice” data collection, as the data collection in my pilot research was done in a much more controlled setting in comparison to a first-grade classroom. I brought the equipment I initially thought that I would use (to be described below) and used the two weeks to make any adjustments to the methodology. For the last six weeks, I observed a new pair of students each week so that all pairs were observed once (two pairs in each classroom were observed twice because of the two practice weeks, though only the second observation will be used in the analysis because the methodology did not become standardized until the second observation).

Overview of Data Collection

The methodology for this research was based upon the work of previous researchers who have studied children's thinking and problem solving as well as experts in the field of qualitative research. The overarching methodology was that of "verbal analysis," in which a subject's verbal speech and nonverbal behaviors become the raw data for analysis. Siegler (1986) provides an overview of different methods that can be used to study children's thinking, and Chi (1997) provides a more specific guide for quantifying qualitative analysis of verbal data. Chi suggests eight steps for analyzing and coding verbal data:

> (a) reducing or sampling the protocols, (b) segmenting the reduced or sampled protocols (sometimes optional), (c) developing or choosing a coding scheme or formalism, (d) operationalizing evidence in the coded protocols that constitutes a mapping to some chosen formalism, (e) depicting the mapped formalism (optional), (f) seeking patterns in the mapped formalism, (g) interpreting the pattern(s), and (h) repeating the whole process, perhaps coding at a different grain size (optional). (p. 283)

While acknowledging that this research sequence is an accepted method of research methodology, and in fact the method that I used in my pilot research, I wanted to find a way so that I would not have to transcribe the videotaped sessions. I wanted to create a tool that could be used by future researchers as well as for teachers to use in order to assess children's learning on engineering tasks. In addition, I felt that there needed to be a tool able to capture the details of the interactions that occur between two students working together. Thus, I designed a methodology that had components from several different studies as well as my own insights. I collected my raw data in three ways: participation observation, worksheets completed by the students, and teacher assessments.

Participant Observation

Before beginning this next phase of research, I had to decide on the amount of involvement that I was going to have in the classroom, as I did in my pilot research. As opposed to the pilot research, in which I helped the children when asked, answered their questions, and participated in their activity when appropriate, I decided that the best choice for this research was nonparticipation. I came to this conclusion for one major practical reason—because I was going to be coding their actions and behaviors in real-time, I did not want them to ask me questions that would distract me from my data collection. Therefore, when I was first introduced to the classroom, the children were told that I was there to learn how first graders learned engineering and that I did not know much about the materials, and all questions were to go to Merredith, the classroom teacher, or another adult if they were helping in the classroom that day. Students sometimes forgot this, and I simply said, "I am not sure, you will have to ask one of the other teachers." Admittedly, there were a few times that I did help the students when all of the other teachers were busy (and at their "question-answering" limit) and the students only had a simple question (i.e. "What are these called?").

The Data Collection Tool

Development of the data collection tool.

Before starting the data collection, I had a preliminary idea of what I would like in an ideal software program for this type of data collection. After doing some research on the Internet, I found several companies that offered products close to what I wanted, but nothing exactly fit my needs for this particular research.

In collaboration with Aaron Beals, a software engineer, I developed a browser-based data-collection tool. This tool, while still in its first version, allows users to enter the codes (behaviors, actions, etc.) that they are looking for when observing a student (or students), and the program then creates a button for each code that the user can click. Each click of a button enters that button's identifier into a time-stamped database that also indicates to which student the action "belongs."

To begin, the researcher opens "Phase 1" of the program, in which the time and date are automatically entered (though they can be manually entered or changed), and the teacher name, the student names, and notes about the classroom can be recorded (Figure 3.2).

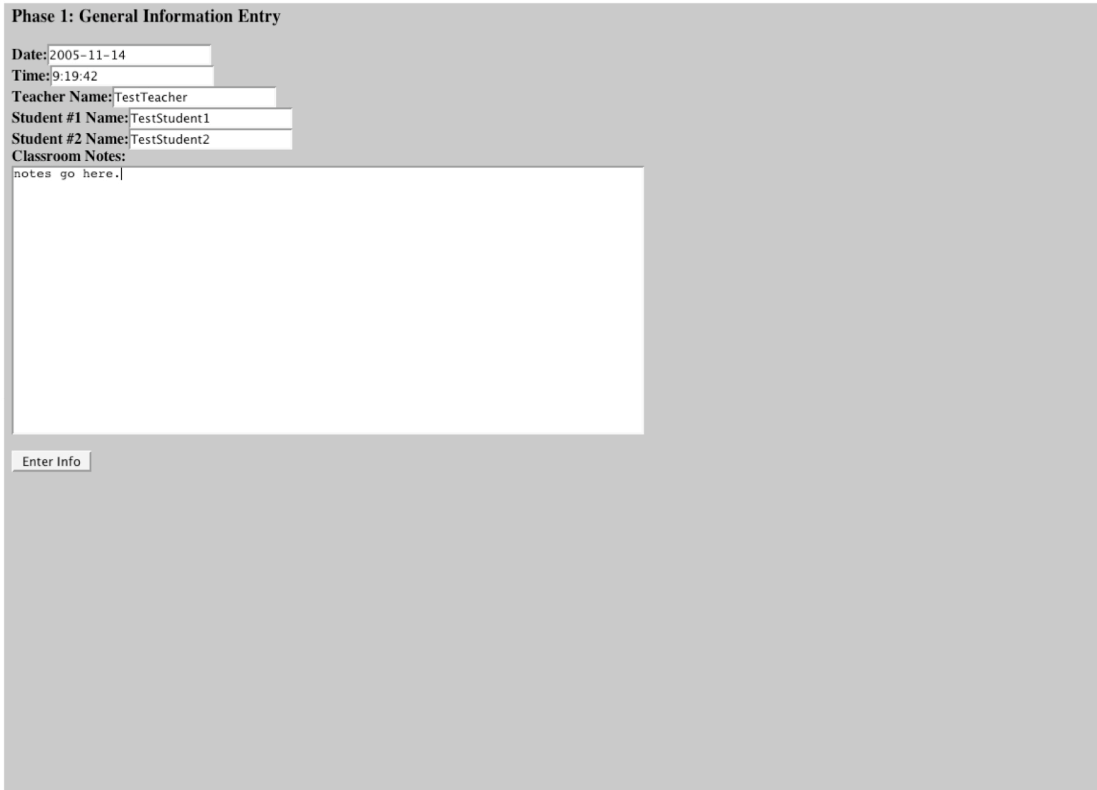


Figure 3.2: Phase 1 of the data collection tool used in this research.

The researcher then moves onto "Phase 2" of the program (Figure 3.3).

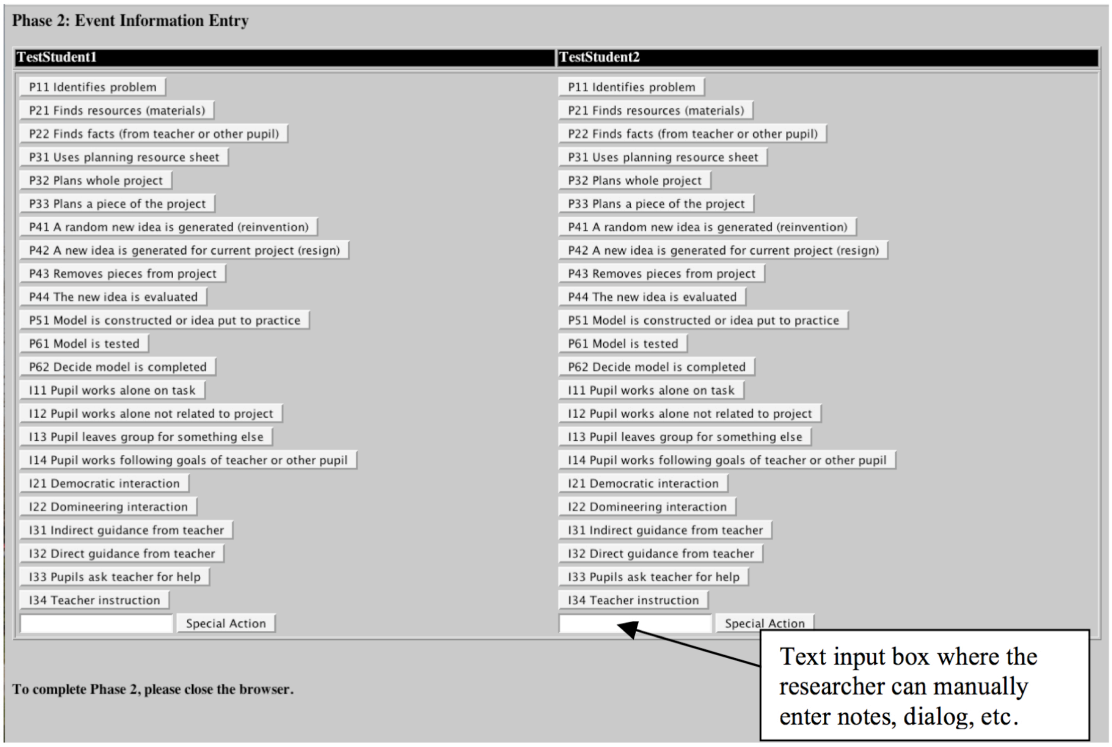


Figure 3.3: Phase 2 of the data collection tool used in this research.

In the second phase, the researcher will see the codes (or whatever criteria the researcher has entered) that were specified as buttons. Also, at the bottom of the screen is a blank text-entry field, so that the user can add additional text if necessary as the data collection is occurring (I often used it to record details of the student's actions and interesting pieces of their verbal speech). In the final step of the program, the researcher can export the collected data in one of two ways: they can either export the database as an Microsoft Excel spreadsheet file or they can generate a web-based report (Figure 3.4; a two-page example of a real report created by the data collection tool in this research can be found in Appendix H).

Date: 2005-11-14
Time: 09:19:42
Teacher: TestTeacher
Student 1: TestStudent1
Student 2: TestStudent2
Notes About Classroom:
notes go here.

Event Time	Student Name	Event
09:24:20	TestStudent1	P21 Finds resources (materials)
09:24:21	TestStudent2	P33 Plans a piece of the project
09:24:21	TestStudent1	P42 A new idea is generated for current project (resign)
09:24:22	TestStudent2	P44 The new idea is evaluated
09:24:23	TestStudent2	P44 The new idea is evaluated
09:24:23	TestStudent2	P44 The new idea is evaluated
09:24:24	TestStudent2	P51 Model is constructed or idea put to practice
09:24:24	TestStudent1	P51 Model is constructed or idea put to practice
09:24:25	TestStudent1	P51 Model is constructed or idea put to practice
09:24:25	TestStudent1	P43 Removes pieces from project
09:24:26	TestStudent1	P62 Decide model is completed
09:24:27	TestStudent1	I11 Pupil works alone on task
09:24:27	TestStudent1	P61 Model is tested
09:24:28	TestStudent1	P51 Model is constructed or idea put to practice
09:24:28	TestStudent1	P51 Model is constructed or idea put to practice
09:24:29	TestStudent1	P44 The new idea is evaluated
09:24:36	TestStudent2	this is me adding words

Figure 3.4: Web-based session report generated by the data collection tool used in this research.

Codes used in the data collection tool.

In order to narrow down and organize the behaviors that I wanted to look for while observing the dyads, I developed a preliminary set of codes based on both my pilot research in the spring, additional information that I gathered while reading existing literature on the topic, my experience doing "practice" data collection in the classrooms for the two weeks of practice data collection, and communication with Sue Ann Kearns, a retired first-grade teacher who had helped author and worked with the "Engineering by Design" curriculum for many years. She provided very helpful information regarding what she looked for when she was teaching and assessing the students. She said that she would look for whether a student exhibited the following behaviors in first grade (adapted from S.A. Kearns, personal communication, October 26, 2005): (1) gets along well with partner; (2) shares (ideas and LEGO blocks); (3) stays focused on the task (or build rockets on his/her own); (4) does most of the thinking for the pair; (5) understands the directions; (6) builds an individual project, not one project jointly with his/her partner; (7) takes constructive criticism willingly; (8) understands the building principles; (9) gets ideas from others at the table; (10) completes the task; and (11) explains what they have done. While a short and simple list, I thought it captured what a "real" teacher would look for in students and her suggestions also reinforced the starting list of codes that I had already developed, as many of the behaviors that Sue Ann mentioned were already manifested in my codes in one way or another.

Once I had made sure to include all of Sue Ann's suggestions into my list of codes, I found that my list of codes were extremely similar to that used by Lavonen, Meisalo, and Lattu (2002), in which they studied the problem-solving strategies and interactions of eighth-grade students using a graphically-based programming language (similar to that of ROBOLAB). Thus, my initial codes were reaffirmed via this study, and I used their categorization strategy, after modifying it for a first-grade classroom and for my data-collection technique. I developed a final list of codes with their definitions for both the problem solving of the students (the codes beginning with "P," Table 3.3), and the interactions between the dyads (codes beginning with "I," Table 3.4).

Table 3.3: Descriptions of the categories of pupils' problem solving during engineering activities used in this research.

Problem…	**P1**	
Identifies constraints of the task	P11	Pupil acknowledges or discusses with partner the goals, constraints, or limitations of the activity are
Recognizing and Finding (Research)…	**P2**	
Finds resources (materials)	P21	Pupil seeks LEGO pieces or other physical materials for project, either from provided kit or "extra pieces" bins
Finds facts (from teacher or other pupil)	P22	Pupil finds facts or ideas related to the problem (look at books, pictures, or ask teacher for help in understanding project), outside of the initial problem statement (i.e. not P11)
Planning (Brainstorm)…	**P3**	
Uses planning resource sheet	P31	Pupil uses provided planning sheet to brainstorm idea for activity (draws idea and write sentence about project)
Plans whole project	P32	Pupils plans the whole project and goals for solving the problem are set
Plans a piece of project	P33	Pupil plans a piece of the project
Is inspired by another group's project	P34	Pupil observes another group's project and is inspired by what he/she sees (i.e. borrows their idea)
Discusses construction plan with partner	P35	Pupil talks with partner about how to build a piece of the project (i.e. "We should do…")

Alternatives…	P4	
A random new idea is generated	P41	Pupil generates a new, random idea unrelated to current project (i.e. decides he/she should be a rocket when working on a car)
A new idea in generated related to current project	P42	Pupil generates a new idea related to current idea is generated (e.g. “Let’s add a piece to our wall”): *redesign*
The new idea is evaluated	P43	Pupil (with or without partner) decides whether to pursue new idea (i.e. is it a “good” idea)
Removes pieces from project	P44	Pupil removes pieces from already built project to incorporate a new idea
Disassembles entire project to start again	P45	Pupil disassembles entire project in order to start again

Constructing (Building)…	P5	
Model constructed	P51	Pupil constructs model
Identifies a problem with structure	P52	Pupil identifies a problem with the structure (e.g. “The chair is too high to add that piece!”

Evaluating…	P6	
Model is tested	P61	Pupil tests to see if the model based on the constraints of the task (i.e. performs drop test, flick test)
Decide model is complete	P62	Pupil decides that model is complete (i.e. brings it to show teacher, tells partner it is complete)
Looks at project to evaluate	P63	Pupil pauses during construction to look at project

Table 3.4: Descriptions of the categories of pupils' social interaction during engineering activities used as codes in this research.

No interaction between the pair members…	**I1**	
Pupil works alone (on task)	I11	Pupil works alone on activity
Pupil work alone (off task, but with materials)	I12	Pupil works alone with materials, but unrelated to activity
Pupil works alone (off task)	I13	Pupil works alone off task (i.e. talks with friends, draws, dances, etc.)
Pupil talks to him/herself	I14	Pupil talks to him/herself while working on activity
Pupil shows partner project	I15	Pupil shows partner project that he/she has been working on
Pupil works alone following goals of teacher or partner	I16	Pupil works on a task after being guided by teacher or partner (e.g. "You should work on making a better base for your chair."

Pupil-Pupil Interaction…	**I2**	
Democratic interaction	I21	Pupils work together to solve activity
Domineering interaction (aggressive)	I22	Pupil dominates project but is mean or harsh to partner (i.e. says "I know what to do!" and grabs the project from the other student who resists)
Domineering interaction (non-aggressive)	I23	Pupil dominates project (i.e. other student does nothing) but is not mean to partner (i.e. says "I know what do to!" and takes project gently)

Pupil-Teacher Interaction…	I3	
Indirect guidance from teacher	I31	Teacher asks pupils what they have done, thinks outloud about the activity, or quietly approves of what the pair has done
Direct guidance from teacher	I32	Teacher says or shows how to find resources, to plan, or to build
Pupil ask teacher for help	I33	Pupil asks teacher questions about facts, resources, or building (not in planning stages though)
Teacher instruction	I34	Teacher gives the problem at the beginning of the lesson

Documentation: Videos, Worksheets, Teacher Surveys, and Photographs

Video documentation.

During each observation, the data collection tool was used but the dyads were also videotaped, for both backup (so that I could re-watch their interactions if deemed necessary during data analysis) and for audio (so that I could transcribe a specific piece of dialog that I was not able to capture in real-time, also for data analysis). During the first practice session, I found that trying to capture first-grade students on video was almost impossible while also trying to collect data in real-time (and vice versa), as I had to follow them around with the video camera as they moved around the classroom. Also, after that first day, I watched the tape and found that it was very difficult to hear the students that I was trying to focus on, due to the other noise in the classroom. Thus, on the suggestion of Iris Ponte, a graduate student in the Child Development Department at Tufts, I setup the video camera on a tripod focused on the table at which the dyad was working. While this video would not capture the students if they went out of frame, I would still have most of their behaviors recorded and I would still be able to code in real-time.

Then, in order to ensure acceptable audio, the students were given Azden wireless lapel microphones (WL/T-PRO) to attach to their clothing (usually their shirts) (Figure 3.5).

Figure 3.5: The Azden wireless lapel microphones (WL/T-PRO) used in this project. The on/off switch at the top was taped down with masking tape to prevent it from accidentally getting switched off while the students were wearing it.

Each microphone system has a wireless transmitter (clipped to their belts) that sends the audio to the receiver (Azden Discrete 2 Channel VHF Wireless Receiver, WR22-PRO), which is mounted onto the camera (Figure 3.6).

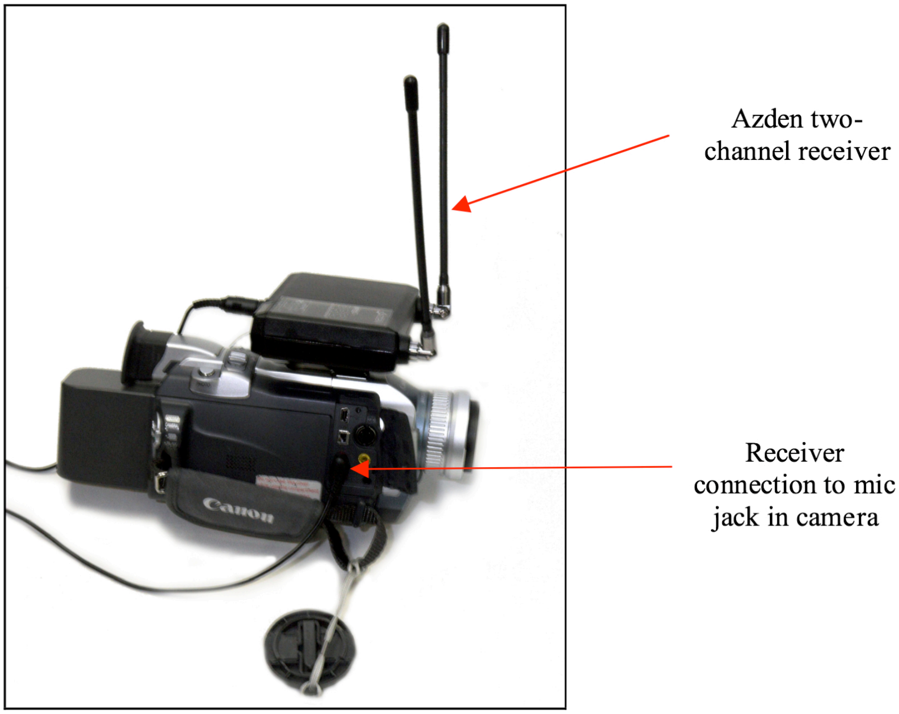


Figure 3.6: The Azden dual-channel receiver, which was mounted on top of the video camera, which was placed on a tripod and focused on the dyad being observed. Two lights (one for each channel) in the back of the receiver indicate whether it is receiving signals.

The range of these transmitters is approximately 250 feet, so even if the children went out of the camera frame or talked towards the floor, I was still able to hear their audio. I have found this system to work well in the first-grade classroom—the microphones still pick up ambient noise, but the students' voices that I want to hear are much louder and clearer than the voices of others.

Worksheet documentation.

In collaboration with Merredith, I created two worksheets for the children, one for before each new activity and one for after. Based on previous teaching experience with the materials, we knew that the students would have a difficult time planning their projects and because of the limited materials and adult help available, and wanted to have a worksheet (entitled "Engineer's Planning Sheet") that they could use to start the process of brainstorming their project. This worksheet consisted of a box to draw a picture of their project and a few lines below the box to write what they were going to create (see Appendix I). Each pair had to show a teacher their completed worksheets before they could receive their LEGO kits.

In a similar vein, students were asked to complete an "Engineer's Final Report" at the conclusion of every activity. Like the planning worksheet, there is a box for a student to draw a picture of their project as well as a few lines to write about what they created. Additionally, there were two questions that the students could "answer" by circling either a happy face, a neutral face, or a sad face: (1) "Did you work well with your partner?", and (2) "Did you enjoy this project?" (Appendix J). Both of these worksheets, once completed for the activity, were scanned and printed at the CEEO for Merredith and I to keep, while the originals were placed into binders that were created for each student (all students in the class had one, including students not participating in the research, though those students' worksheets were not included in the analysis), which the students were able to bring home at the end of the 12 week session as a record of their work.

Teacher survey documentation.

Since I was only focusing on one dyad each week and only able to observe each student once, I wanted to get a sense of what Merredith and the classroom teacher observed in order to enhance and support my observations. To do so, I adapted a teacher survey that Merredith had created for her research and modified it for my research as well (i.e. so that the teachers would only have to fill out one survey as opposed to two) (Appendix K). This survey consisted of questions related to each student's achievement in various school subjects as compared to grade level expectations (e.g. How do you think this student is doing in reading?"), as well as questions related specifically to the LEGO engineering curriculum (e.g. "How did you think this student performed on the LEGO Engineering curriculum?" and "Were you surprised at this student's performance?"). In addition, I asked Merredith, as she is an expert in the technology, to complete a simple survey comparing each student to his or her partner in terms of relative expertise with the materials.

Photographic documentation.

Lastly, throughout the sessions, Merredith and I took pictures of the students' projects so that we would have a record of their work. In addition, using a video software program allows any frame of the videos to be turned into a still picture, which was used to supplemented the descriptions of the results.

Active Interviews

During each of the sessions with the students (usually at the beginning), I asked them questions about their experiences with LEGO bricks both at home and at school, how they prefer to work with the materials (i.e. alone or with a friend), and their interests in the materials. As they worked on the activity, I would also sometimes ask them to explain what they were creating if I felt I needed to clarify their behaviors. However, I preferred to let the students work as much as possible without interruption from me, as I wanted them to be as natural as possible. I found from both my pilot work and my two practice data-collection sessions that if I asked the students a question they were both easily influenced by the question and easily forgetful of where they were in the creation of their project. Additionally, other students in the classroom nearby often stopped what they were doing to listen when I asked the dyad questions and I wanted to keep attention off the students I was observing so that they could act as "real" as possible.

Data Analysis

For data analysis, I had four major forms of raw data, as described above: time-stamped behavior sequences for each dyad, video and audio recordings of each dyad (including the children's responses to my questions), student-completed worksheets, and teacher-completed surveys. Because of the uniqueness of the methodology due to the data-collection tool I created, I needed a way of interpreting the qualitative data and "converting" some of the information into quantitative data. Thus, I relied most heavily upon the behavior sequences for each dyad in order to draw my conclusions, while the other pieces (i.e. audio transcriptions, photographs, etc.) supplemented and strengthened those conclusions. Using these four forms of data, I developed a preliminary classification system for first grade dyads working on engineering tasks and I also examined their behavior sequences for patterns related to problem solving.

Development of a Preliminary Classification System for Dyads Working on Engineering Activities in First Grade

Granott (1993) completed a study in which adults worked in groups to learn about a robot that responded to stimuli; as part of this study, she created a framework for classifying different types of collaborative interactions that defined the various groups. This framework defines social collaboration along two dimensions: relative expertise and degree of collaboration. Each dimension has “three ordinal levels—high, medium, and low” (Granott, 1993, p. 187), as illustrated in Figure 3.7:

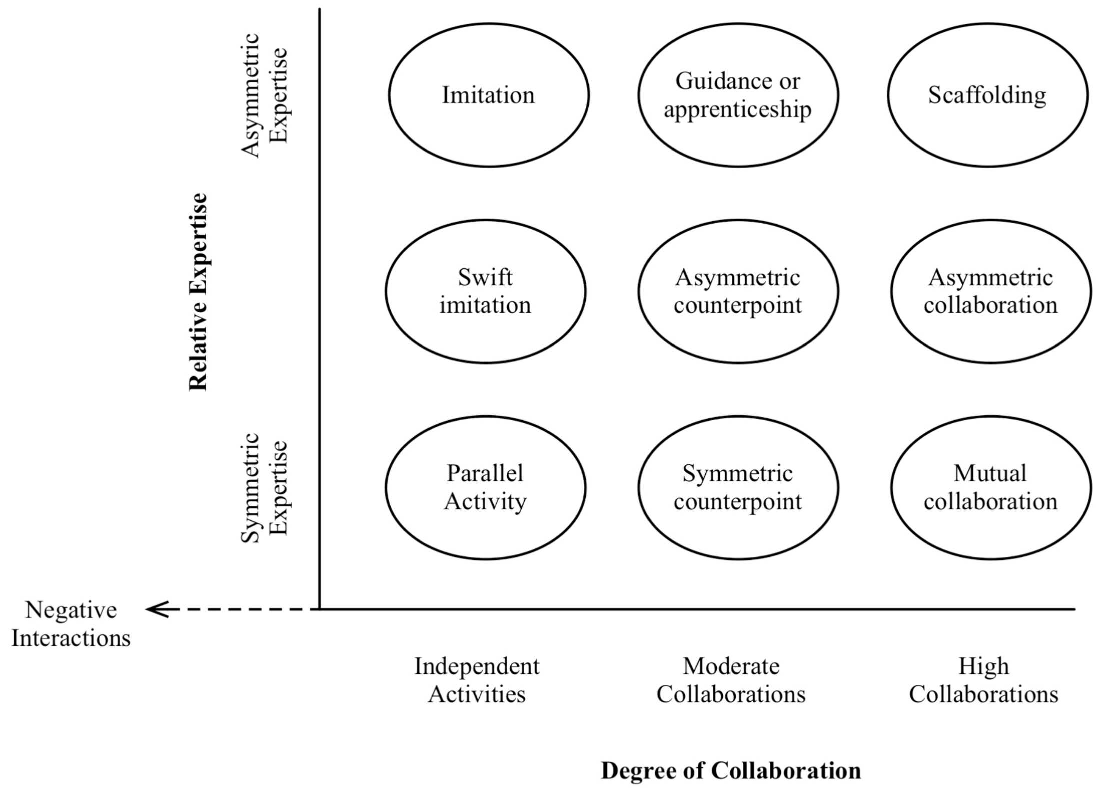


Figure 3.7: Classification of social collaboration along the dimensions of relative expertise versus degree of collaboration, as specified by Granott (1993). Figure adapted from Granott (1993, p. 187).

In addition to providing a visual representation of this classification scheme, she provided a description of each classification as well as keywords to describe each interaction. Using these classifications for adults as a framework, I modified the classifications for first grade and reduced the total number of classifications to four (Figure 3.8).

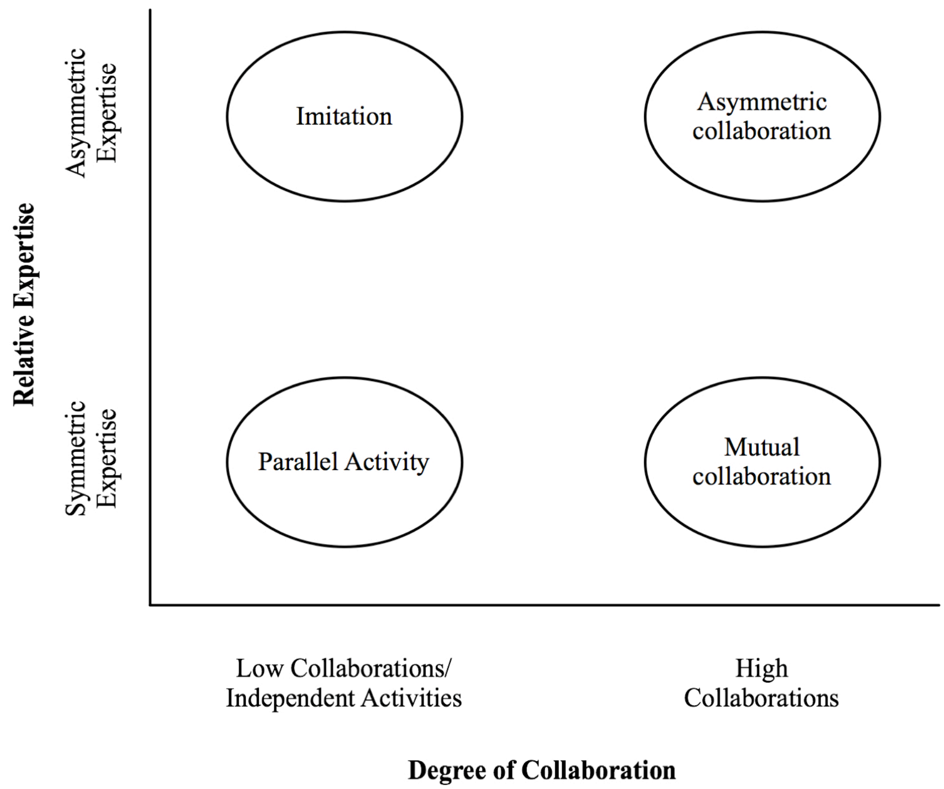


Figure 3.8: Classification of social collaboration in first grade on engineering tasks along the dimensions of degree of collaboration versus relative expertise.

I felt that in first grade, the students were either equal in their skill level (symmetric expertise) or they were not (asymmetric expertise), because at their young age they did not have the same opportunity to become as differentially skilled with the materials as adults would. In addition, I decided that the dyads either in general worked together (high collaborations) or did not (independent activities). Of course, if this same rubric was used in older grades, the additional classifications as specified by Granott could be added as appropriate to the analysis. Once I had devised these four classifications of collaborations for first grade dyads working on engineering tasks, I could delve further into the specifics of the interactions.

Dyad Collaboration Measurements

Explanation of weighting system.

Once I had created the four classifications for dyads working on engineering tasks in first grade, I wanted to get a better sense of what "independent activities" and "high collaborations" looked like when compared to each other. I wanted to be able to get a sense of how each dyad's social interactions, or lack thereof, changed over the course of each session and then be able to compare each individual in the dyad with the other students. To do so, I devised a weighting system for each of the types of interactions. Those interactions in which a student did not work with another student, as specified in the codes as those that fell under the "I1" category, were given a weight of 1. This value was chosen because I considered all interactions positive and at this age, working independently may not be "negative", as it may be in older grades. Those interactions in which a student worked together with another student, as designated at the "I2" coding category, were given a weight of 3. This weight was chosen so that there would be a better visual difference between these interactions and those of no-pupil interactions (i.e. it is much easier to distinguish two lines with slopes of 1 and 3 respectively than two lines with slopes of 1 and 2). Finally, those interactions in which a student worked with a teacher, "I3" codes, were given a weight of 0. This weight was chosen because in this analysis, pupil-teacher interactions were not the focus; though if the focus of the analysis did change, the weights could be changed to reflect the relative importance (Figure 3.9).

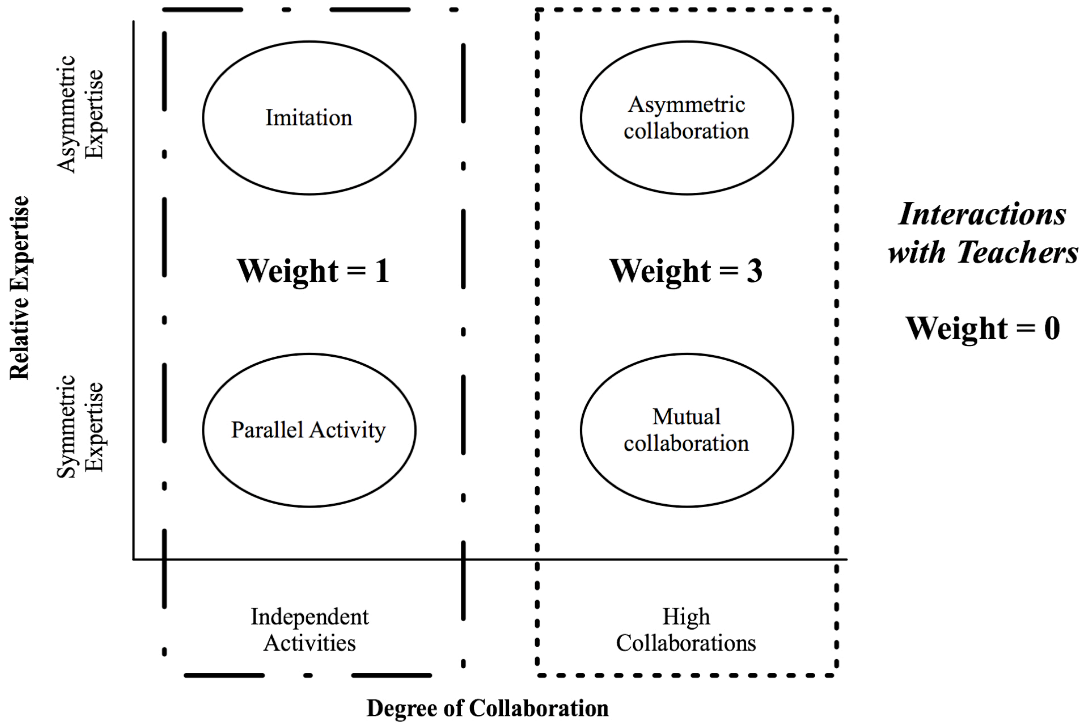


Figure 3.9: Relative weights of each type of interaction.

These weights represent the slopes of the line segments that connect each segment of time. For example, if a student worked alone between the time segment 5 minutes to 10 minutes, that line would have a slope of 1. Using the standard equation for a line:

$$y = mx + b$$

where y equals a value on the y (vertical) axis, m equals the slope of the line, x equals a value on the x (horizontal) axis, and b equals the y-intercept of the line (i.e. where the line crosses the y-axis, in this analysis, b = 0 for the first time segment).

The slope of a line (again, in this case the weight given to each interaction), is equal to the change in y-values divided by the change in x-values (in this case, change in time) for that segment:

$$m = \Delta y/\Delta x \Rightarrow \Delta y = m*\Delta x$$

which in the context of this analysis becomes:

(weight assigned to interaction)(change in time for segment) = change in y for segment

In order to get a cumulative line segment, this value is then added to the y-value of the previous line segment. Finally, one can look at the overall slope of the line that is created by taking the total "cumulative degree of collaboration" value (i.e. the ending y-value) and dividing it by the total time for the session (Figure 3.10). One cannot just look at the resulting "cumulative degree of collaboration" value, as the total time for each session would differ, and thus dividing by the total time standardizes the values and allows for comparison between students.

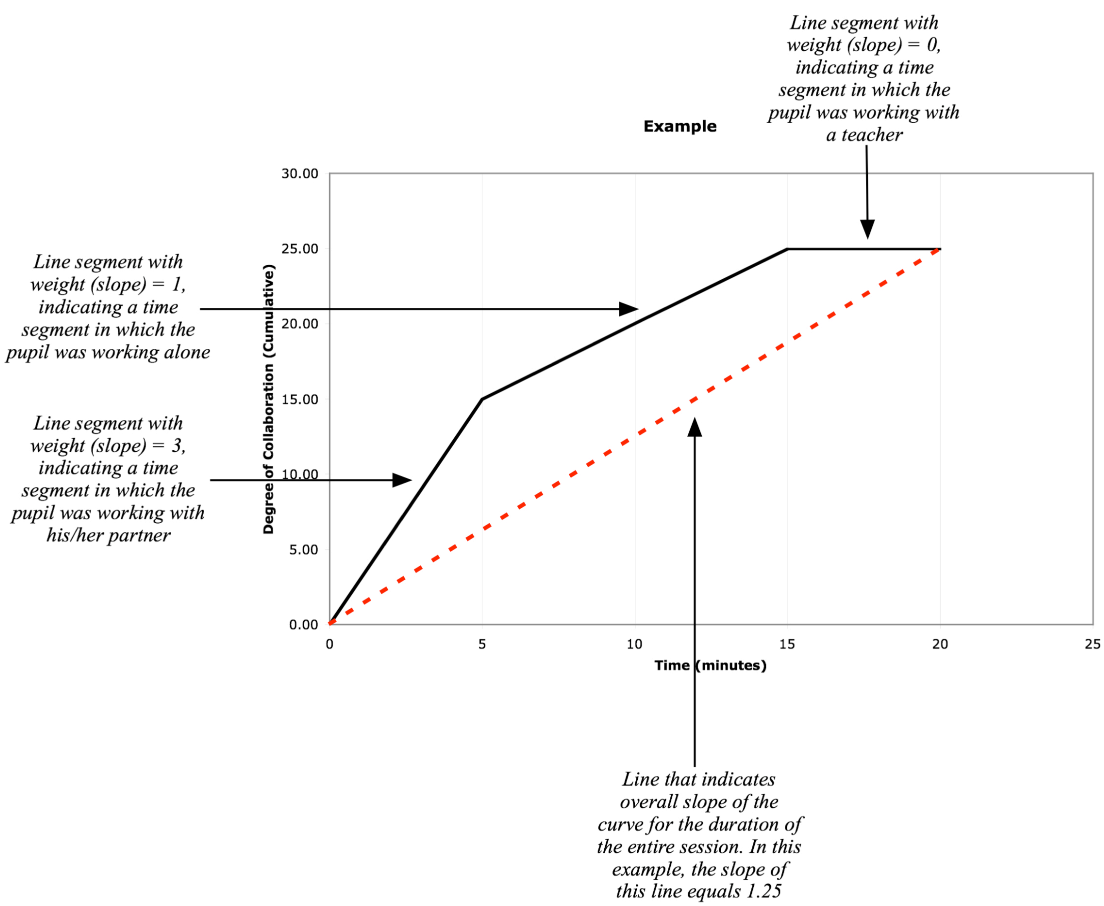


Figure 3.10: Explanation of a sample interaction graph used in this research.

Thus, for each child, it is possible to look at the larger picture of which interactions occurred over the course of a whole session, using the slope of the overall line.

Examples of the use of the weighting system.

In order to better show the value of these types of graphs, I will provide four examples that use data I made up. In the first example, the student worked alone for the entire time of the session, and thus the slope of the resulting line is 1 (perfect non-collaboration) (Table 3.5 and Figure 3.11).

Table 3.5: Example data when the student works alone the entire time.

Example 1			
Time	*Code*	*Weight*	*Plot Value*
0	I1	1	0.00
5	I1	1	5.00
10	I1	1	10.00
15	I1	1	15.00
20	End of session	-	20.00
		Slope	**1.00**

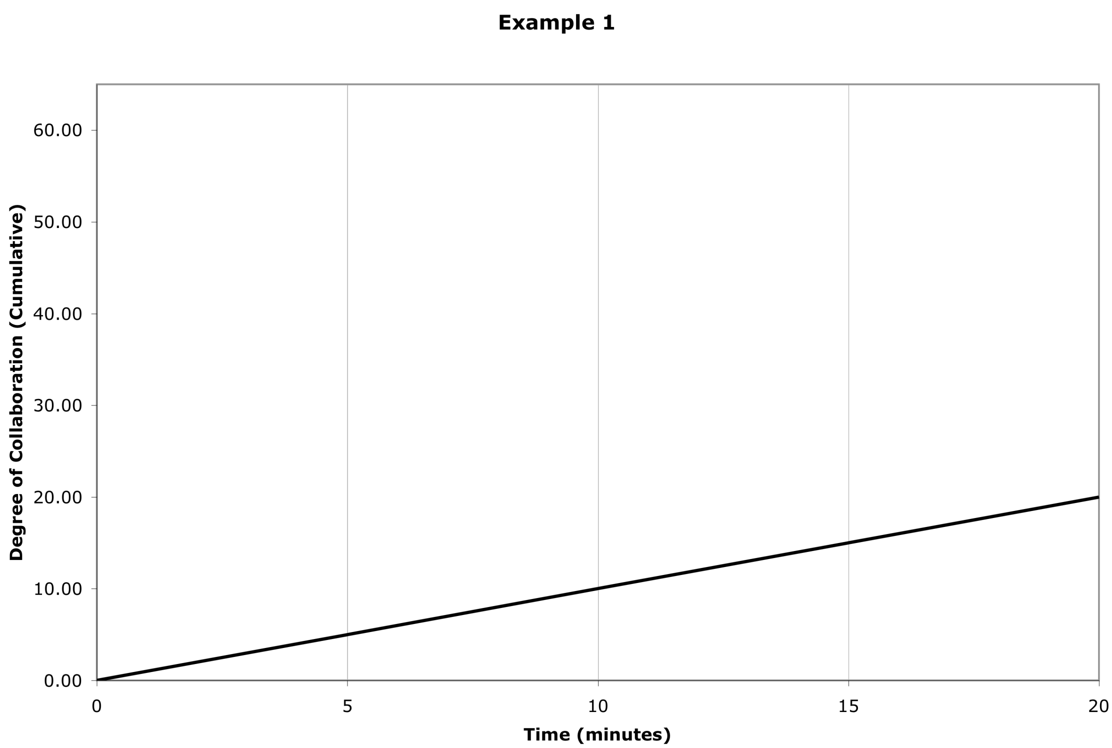


Figure 3.11: Example interaction graph when the student works alone the entire time.

In the second example, the student worked alone for half of the time and with a teacher for half of the time (Table 3.6 and Figure 3.12).

Table 3.6: Example data when the student works alone for half the time and with a teacher for half of the time.

Example 2			
Time	*Code*	*Weight*	*Plot Value*
0	I1	1	0.00
5	I3	0	5.00
10	I1	1	5.00
15	I3	0	10.00
20	End of session	-	10.00
		Slope	**0.50**

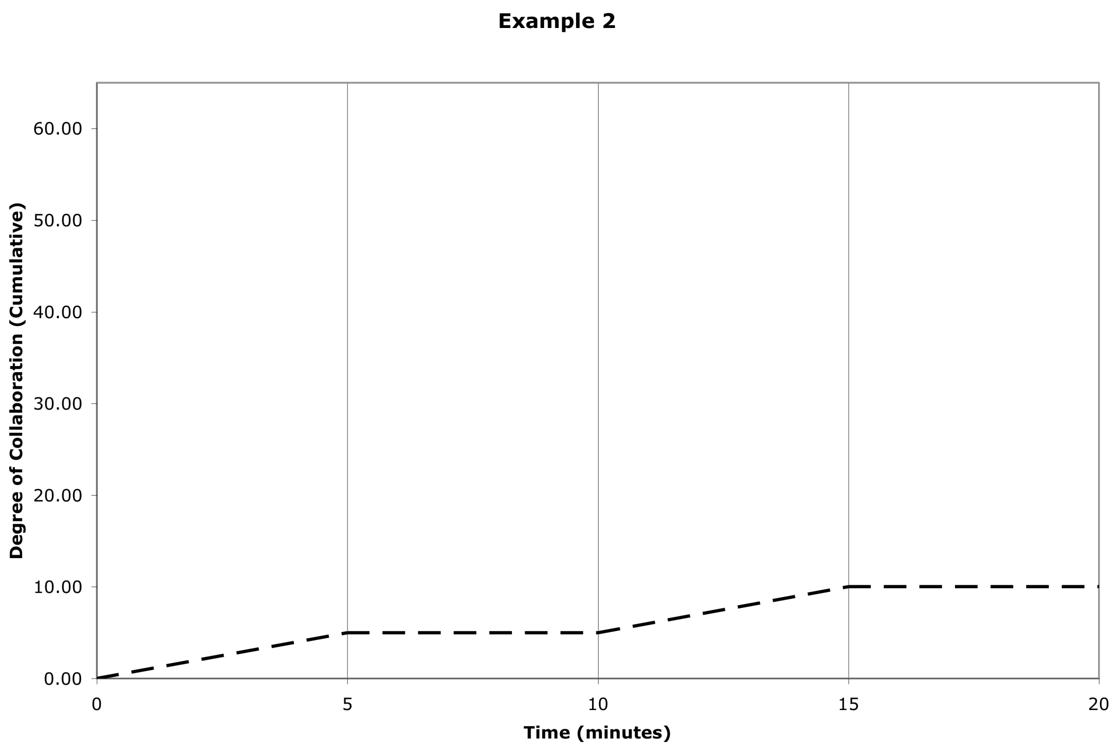


Figure 3.12: Example interaction graph when a student works alone for half the time and with a teacher for half of the time.

Visually, this is seen by the alternating sections of line segments with a slope equal to 0 and line segments with a slope equal to 1. The overall slope of this line, as expected, is equal to 0.5, again since half of the time was spent working with a teacher (slope = 0) and the other half working alone (slope = 1).

In the third example, a student worked in collaboration with his or her partner for the entire session (Table 3.7 and Figure 3.13).

Table 3.7: Example data when a student works with his or her partner for the entire time.

Example 3			
Time	*Code*	*Weight*	*Plot Value*
0	I2	3	0.00
5	I2	3	15.00
10	I2	3	30.00
15	I2	3	45.00
20	End of session	-	60.00
		Slope	**3.00**

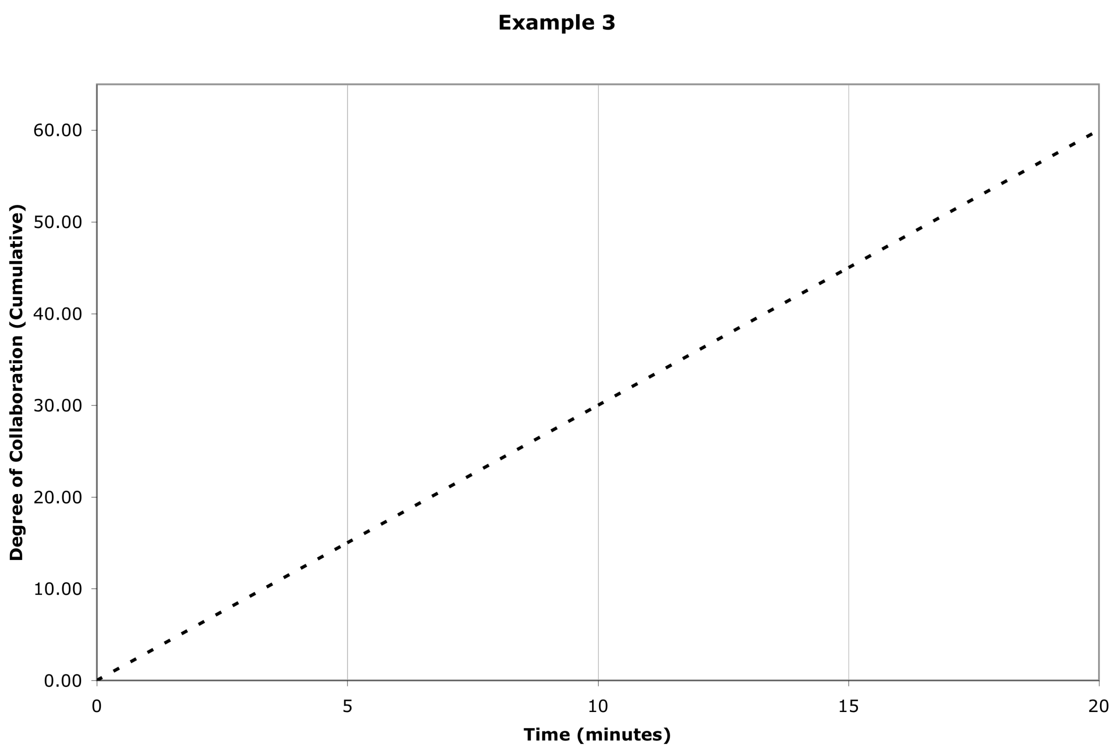


Figure 3.13: Example interaction graph when a student works with his or her partner the entire time.

The resulting slope is equal to 3, which indicates that only collaboration occurred during the course of the session.

In the fourth example, the student worked together with his or her partner for three-fourths of the time, and with a teacher for one-fourth of the time (Table 3.8 and Figure 3.14).

Table 3.8: Data when a student works with his or her partner for three-fourths of the time and alone for one-fourth of the time.

Example 4

Time	*Code*	*Weight*	*Plot Value*
0	I2	3	0.00
5	I2	3	15.00
10	I3	0	30.00
15	I2	3	30.00
20	End of session	-	45.00
		Slope	**2.25**

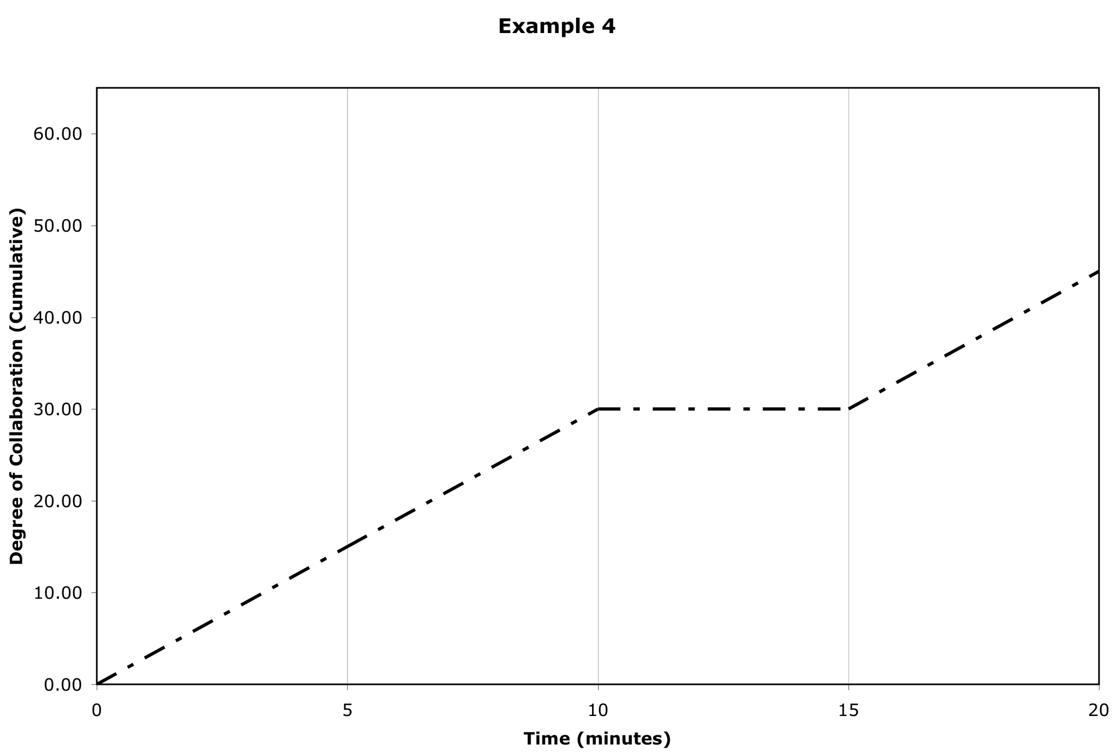


Figure 3.14: Example interaction graph when a student works with his or her partner for three-fourths of the time and alone for one-fourth of the time.

Finally, in order to get a better sense of how the four examples compare to each other, I put all four examples on one axis (Figure 3.15):

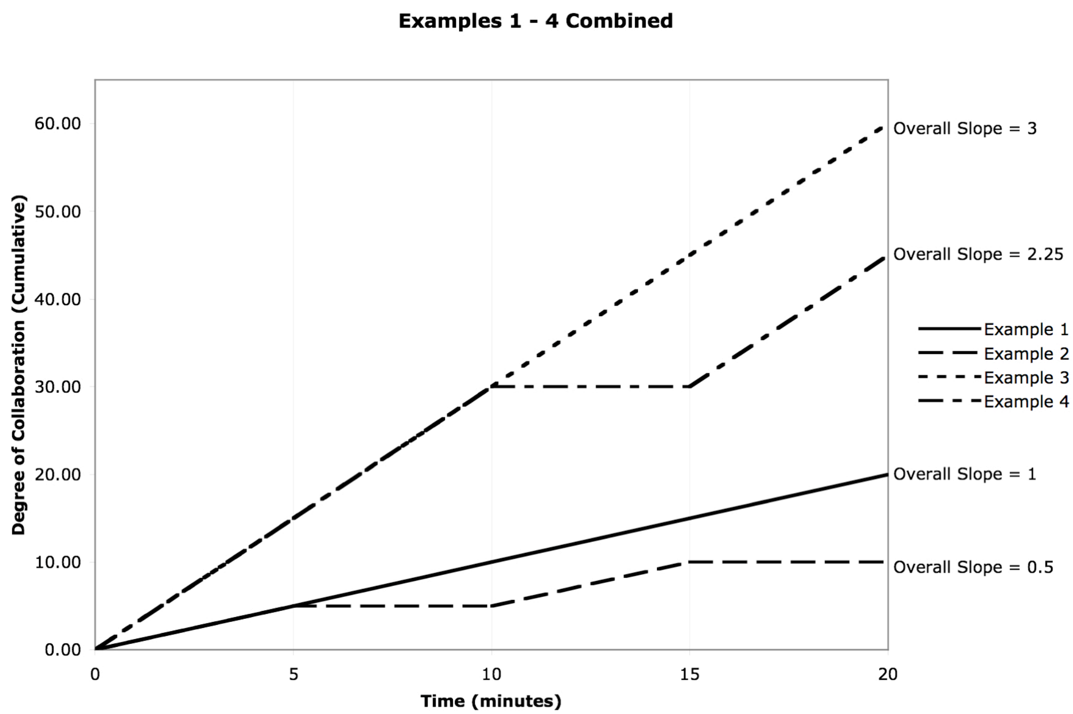
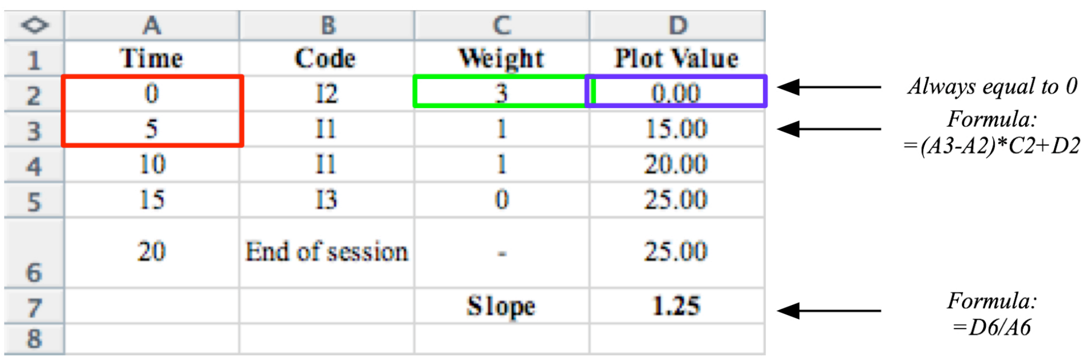


Figure 3.15: Interaction graph with examples 1 through 4 combined.

Using this graph, it is clear that the student represented by Example 2 collaborated the least, while the student represented by Example 3 collaborated the most.

As a technical aside, in order to create these plots from my actual data, I used the reporting feature in the data collection tool in order to create a master spreadsheet in Microsoft Excel for each dyad and made the time relative to the session (i.e. instead of reading "14:53:06," I made the timestamps relative to the initial time, so that when five minutes had past, the value was 00:05:00), and then converted to minutes. I then separated each student's time-stamped data into individual sheets. Next, for each student, I removed all codes except for those in the interaction categories (i.e. I1, I2, and I3). I then assigned the appropriate weights to each time segment (always starting at time zero and plot value zero) and calculated the plot values in Excel (noting that codes are applied every time a behavior changes, and thus you need to multiply the weight of the previous segment in order to find the correct y-value) (Figure 3.16):



	A	B	C	D
1	Time	Code	Weight	Plot Value
2	0	I2	3	0.00
3	5	I1	1	15.00
4	10	I1	1	20.00
5	15	I3	0	25.00
6	20	End of session	-	25.00
7			Slope	1.25
8				

Figure 3.16: Screenshot of Microsoft Excel spreadsheet used to calculate the plot values for the interaction graphs.

I then created a scatterplot of the data, using time in minutes as the x-axis and degree of collaboration as the y-axis.

As a final step, I created a virtual instrument in the software program LabView so that I could more easily determine the percent of time each student spent on each type of collaboration. Rather than manually having to do it in Excel by finding the length of the time segment each time the type of interaction changed, this module allowed me to simply select a comma-separated (CSV) file for each student that had the time of the interaction in one column and the weight of the interaction in the adjacent column. The module then returned the time spent on each type of interaction during the session as well as the percent of time (as no sessions were exactly the same time and it would be difficult to compare across individuals if not done as percentages) (Figure 3.17).

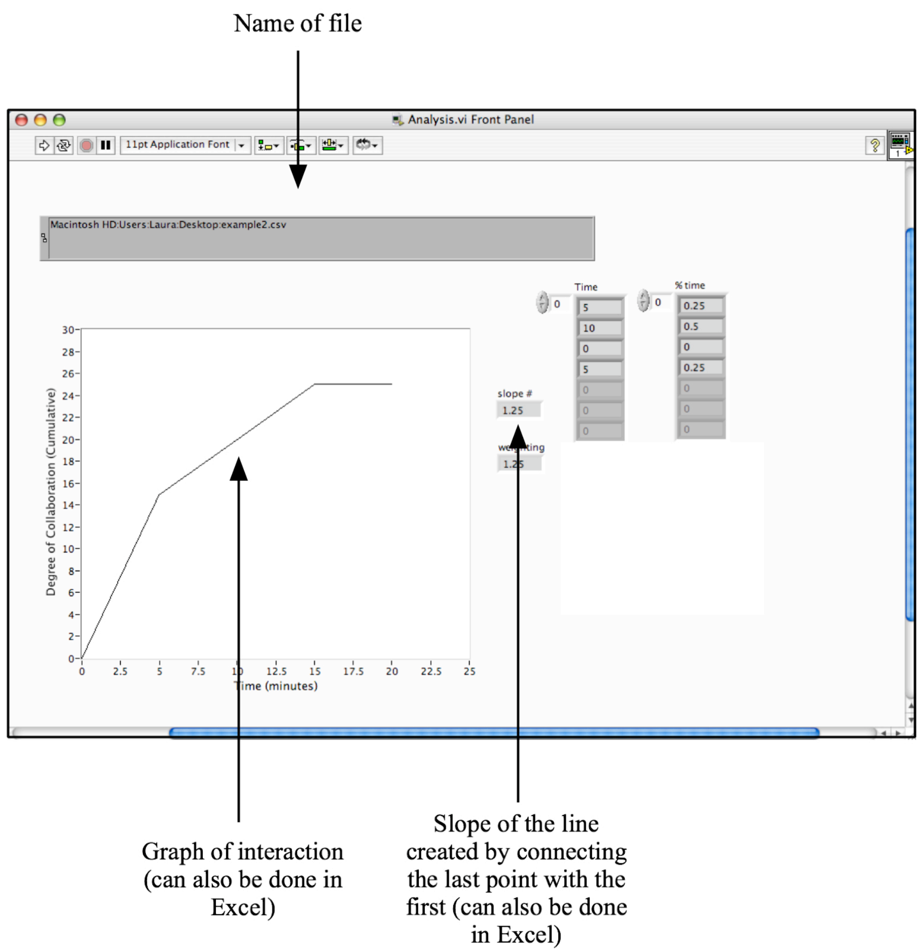


Figure 3.17: Explanation of the LabView virtual instrument used to aid in the analysis in this research.

Task Event Networks

As in the pilot study, I created task event networks for four of the dyads. The dyads chosen were those that represented the “ideal types” based on the classification system that I developed after having observed and reflected upon all of my observations. These task event networks were created in a slightly different way than what was done in the pilot study. First, a different software program, OmniGraffle, was used to actually draw the event networks. Second, when I used my data collection tool, I would often add comments to myself (e.g. “Student said something interesting—re-watch on tape”) or ones that further explained the code entered previously (e.g. if the code “P21 Finds resources (materials)” was used, I may add after it, a comment such as “(more markers)”). In order to produce the task event networks, I used a “clean” version of the data in which only the actual pre-determined codes were used. Sometimes, however, I kept snippets of dialogue that I was able to record in real-time and placed them next to the appropriate code to help illustrate why I chose that code (Figure 3.18).

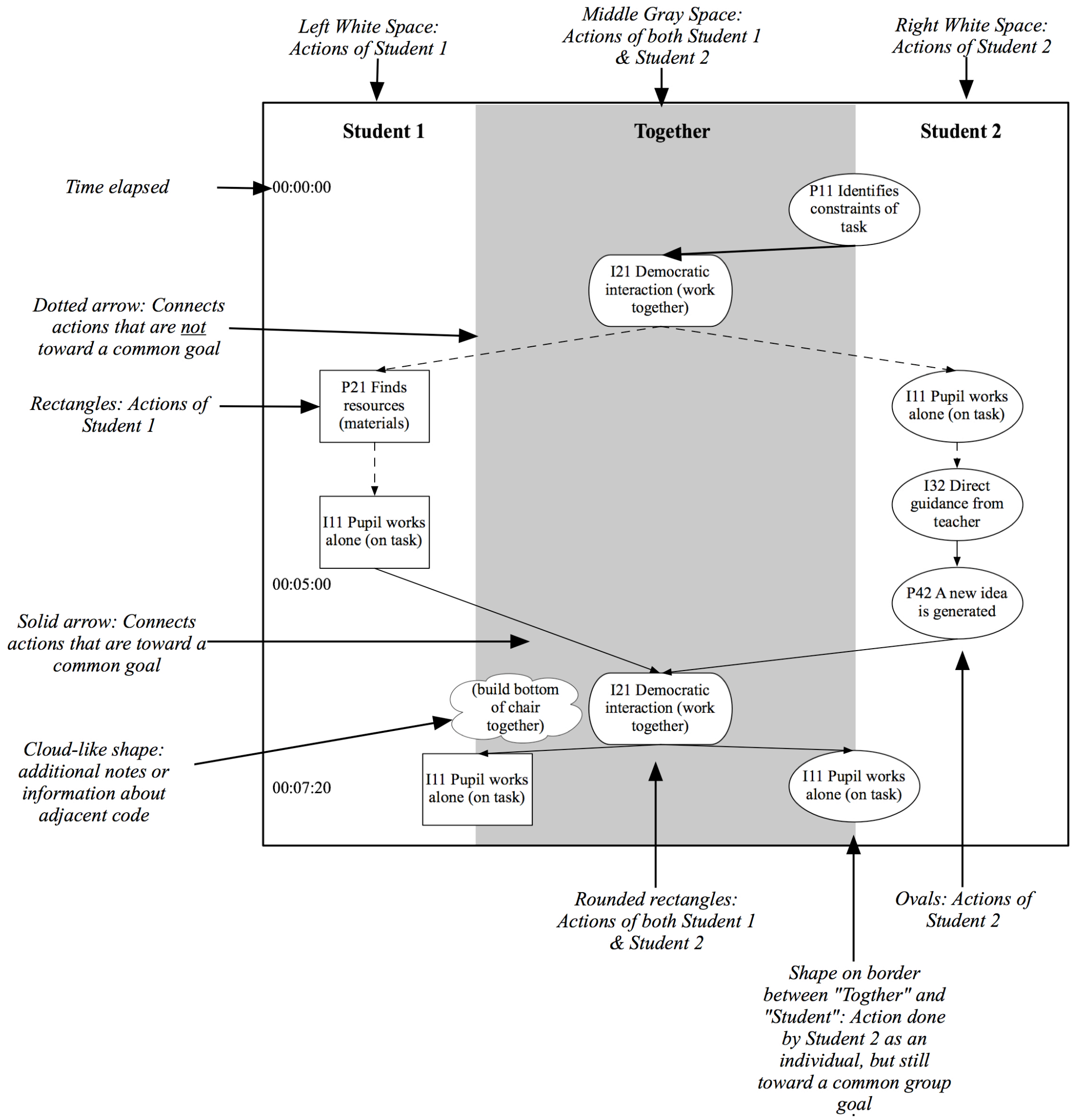


Figure 3.18: Example piece of a task-event network, with explanations for the symbols, used for data analysis in this research.

In this example flowchart, we see that the dyad started at time 00:00:00 working together, with Student 2 (his codes are indicated by the ovals, and those of Student 1 by rectangles) beginning the session by “P11 Identifies the constraints of the task.” His oval lies on the border between the gray and the white in order to indicate that that action was done as an individual, but toward a common goal. Next, the dyad worked together (this code and the previous code are connected by a solid arrow, indicating that the two codes were done toward a common goal). Next, the two students worked on their own, but not toward a common goal (i.e. each were working on their own projects), as indicated both by the fact their shapes are entirely in the appropriate white space and that they are connected to the previous code with a dashed line. Next, Student 2 came up with an idea related to his project that led to a change in the dyad's construction plan, though each student worked on their own toward this new common goal (e.g. if each had decided to create one piece of the project that would later be combined into one project). The location of the shapes and the style of the arrows are slightly redundant in their symbolism, but I wanted to make clear the difference between when students were working alone but toward a common goal and alone but not towards a common goal. The four task event networks and their implications will be discussed in the next chapter.

Classifications of the Twelve Dyads Observed in this Research

After determining a methodology for finding the amount of collaboration, as indicated by the slope of the resulting line on the interaction graphs, I applied this technique to all 24 students involved in this research. After this, for each student, I had a number that quantified the amount of his or her collaboration during the session I observed. I then looked at the values for each student in comparison to his or her partner and took the average so that I could get a single value for each dyad; this value then became the "degree of collaboration" dimension for placing each student in one of the four classifications. I decided that values over 2 would indicate "high collaboration," while those less than 2 would indicate "low collaborations." I chose this cutoff-point based on two simple examples that I believe represent high collaboration: (1) if a dyad had worked together for half the time and alone half the time, then the slope of the resulting line would be 2, and (2) if a dyad had worked for three-fourths of the time together, and one-fourth of the time alone, then the resulting slope would be 2.25. Then using Merredith's evaluation of the relative expertise of the pair (the relative expertise dimension), I was able to place each dyad in one of the four classifications.

In this chapter I have discussed the changes that were made to the methodology because of the pilot study, the goals for this research, the context of the research, the observation sequence, the data collection techniques used in this research (including the data-collection tool that I developed), and the data analysis techniques that were used in this research. In the next two chapters I will discuss findings of this research based on the methodologies used.

Chapter Four: The Role of Collaborative Problem Solving on Engineering Tasks in First Grade Classrooms

In this chapter I will discuss the four types of dyadic interactions that I observed and classified while working with young children in first grade learning engineering tasks. To supplement and help illustrate the characterization of each classification, I will provide an example case from my observations. Each example case will include an interactions graph, dialog between the students in the dyad, and the dyad's task-event network. I will then discuss the breakdown of the twelve dyads involved in this research in these four categories then conclude with possible implications for the classroom.

Introduction

As discussed in the previous chapter, Granott (1993) developed a technique to classify interactive collaborations based on the dimensions of "degree of collaboration" and "relative expertise." Using this technique as a model, I developed four classifications of interactions that I observed in first grade while dyads of students worked on an engineering task (Figure 4.1).

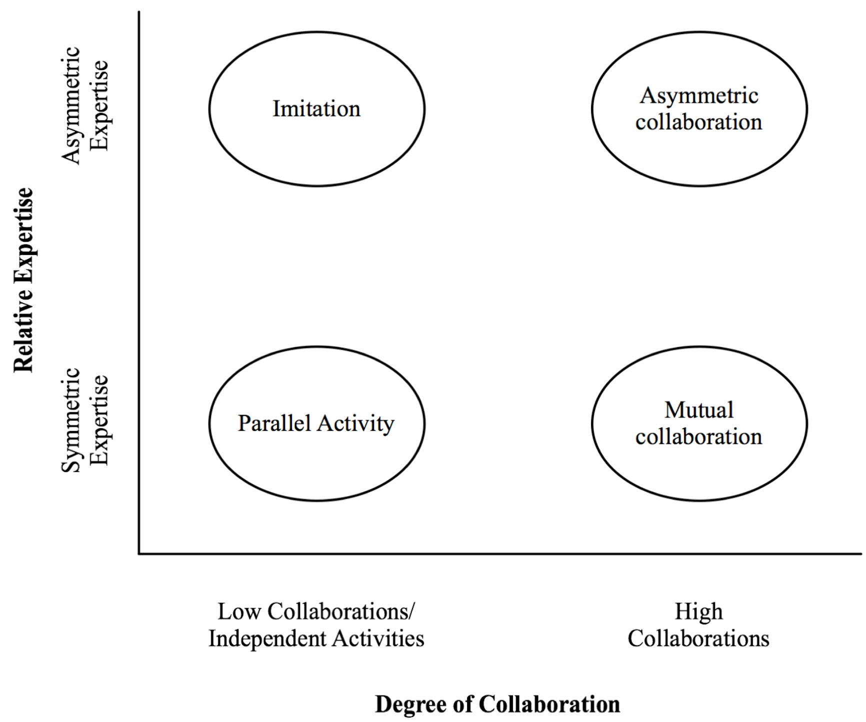


Figure 4.1: Classification of collaborative problem solving in first grade on engineering tasks along the dimensions of degree of collaboration and relative expertise.

I would like to note, however, that Granott's classifications were only based on positive interactions between group members; she acknowledges that there are also disruptive interactions (i.e. the negative interactions), but does not go into these negative interactions with the same level of detail. While perhaps some of the interactions seen in first grade could be considered "negative" in an adult sense, I decided that since young children in first grade are just learning about being "good" partners and working with others, all of their interactions are "positive" because they are learning from them.

Furthermore, Granott described nine different positive interactions that occurred amongst adults working with robotics. However, for first grade nine classifications were too many and too difficult to differentiate as the two dimensions—degree of collaboration and relative expertise—were not as broad or applicable for young children. For example, while some of the students may have previously been exposed to LEGO bricks at home or at school, they were still only six and seven years old and did not have such great degrees of differing experiences with the materials as compared to adults.

I would also like to note that the classifications that I developed were for dyadic interactions; several scholars have reminded me to be mindful of the distinction between pairs and groups (which implies three or more). Interactions and collaborations between two students can be quite different than those among three or four students. While beyond the scope of this research, the methodology used here could be applied to groups of more students (with some slight changes to the data collection tool).

In addition, before going too deep into the description of the classifications, I would like to acknowledge that the classifications suggested represent a general categorization that describes the dyad best over the course of the eight weeks of my observations. A dyad may move among the classifications within in a given session or from week-to-week. Future research could follow more closely one dyad to see how their interactions change over the course of the engineering curriculum, though this was beyond the scope of this research (to be discussed further in the final chapter).

Classification of Dyads in First Grade Working on Engineering Tasks

In this section, I will discuss the four classifications that I have developed in order to describe young children's collaboration on engineering tasks, starting with mutual collaboration, then asymmetric collaboration, then imitation/intimidation, and finally parallel activity. For each classification, I will include a set of descriptive keywords (again, based upon those set forth by Granott, 1993), and an example of a dyad that I observed that met that criteria. Included in each example will be an interactions graph, a flow-chart showing a piece of the details of the session, dialog from the session, and chart of the percentage of time each student spent in the three types of interactions (pupil-pupil, pupil-teacher, no interaction).

Mutual Collaboration

General description.

A pair engaged in mutual collaboration is one in which an observer would see many of the following behaviors:

- Highly collaborative interaction between peers of equal skill that is reciprocal and symmetric.
- Equal dominance during activities.
- Engaging in a common goal (i.e. either work together or work individually on different components of the project after discussing a construction plan).
- Sharing of materials.
- Talking together frequently about ideas and goals.

If one thinks about dyadic collaboration as a “dance” of sorts, this would be one in which the partners moved easily together, sharing dominance, adjusting the rhythm of the dance based on each partner’s ideas and contributions. There could be moments in which the partners dance on their own, but seen from distance, it is clear that their movements are in synchrony with a common theme that ties them together.

Example dyad: Isabelle and Emily.

Isabelle and Emily serve as the best example of a dyad that engaged in mutual collaboration. This was a pair for which this type of collaboration was present from the beginning of the session and continued both during each session and throughout the eight weeks of observation. These two girls had equal expertise with the materials and were also friends. If we look at their individual interaction graphs, we can see how clear this becomes (Figure 4.2, Table 4.1 and Figure 4.3, Table 4.2):

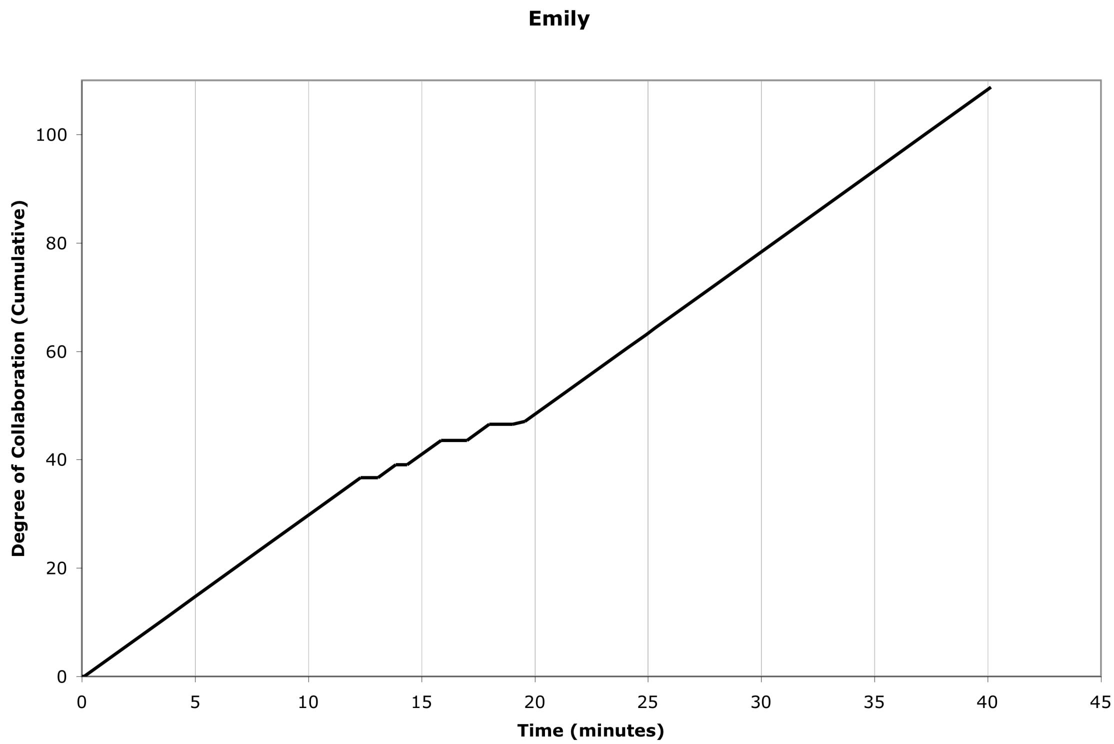


Figure 4.2: Interaction graph for Emily (mutual collaboration).

Table 4.1: Slope and percentage of session time Emily spent in each type of interaction (mutual collaboration).

Slope	2.7
Percent I3* (pupil-teacher interaction)	17.9
Percent I1* (no pupil interaction)	0
Percent I2* (pupil-pupil interaction)	79.2

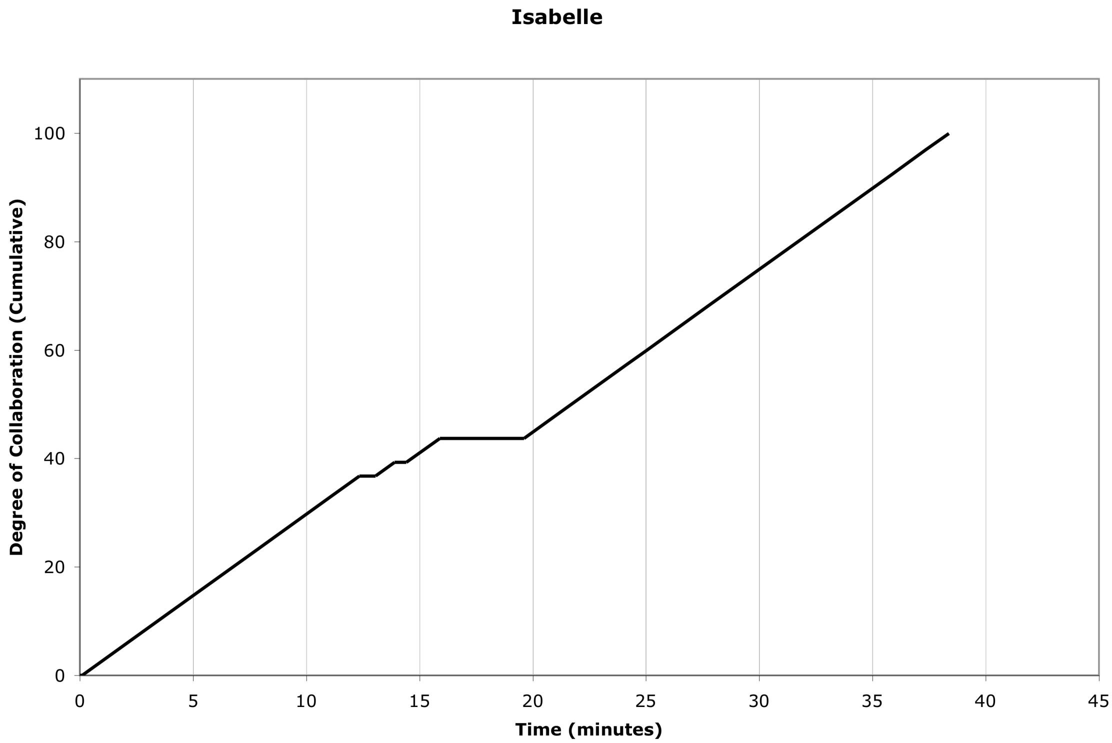


Figure 4.3: Interaction graph for Isabelle (mutual collaboration).

Table 4.2: Slope and percentage of session time Isabelle spent in each type of interaction (mutual collaboration).

Slope	2.6
Percent I3* (pupil-teacher interaction)	16.7
Percent I1* (no pupil interaction)	0
Percent I2* (pupil-pupil interaction)	83.3

For both students, approximately 80 percent of the time during the session was spent working together, while the remainder of the time was spent in interactions with a teacher (with no time spent working alone). Furthermore, the resulting slopes of their interaction graphs were large—greater than 2.5, indicating highly collaborative interactions within the framework of this research.

This is a dyad that worked with each other really well—bouncing ideas off of each other and coming up with new ideas based on their collaborative work. During the session that I observed them, their task for the day was to create a motorized “pulley wall,” a wall made of LEGO beams and pulleys. The students could attach paper circles that they colored to the pulleys in order to make spinning discs. The two girls worked on the same paper, each coloring a piece of the wheel (Figure 4.4).

Figure 4.4: Picture of Emily and Isabelle working together to color the paper circles.

Once the two circles were colored to their satisfaction, they said (Figure 4.5):

Isabelle: “I'll cut this one.”

Emily: “And I'll cut this one.”

Figure 4.5: Emily and Isabelle working together to cut out their paper circles.

This is a simple snippet of dialog, but it shows how the two students worked with each other (as also reflected in the proximity to each other in the picture). Next, we can look at a small segment of time in more detail to get a different look at the collaboration of the two students working in mutual collaboration (Figure 4.6).

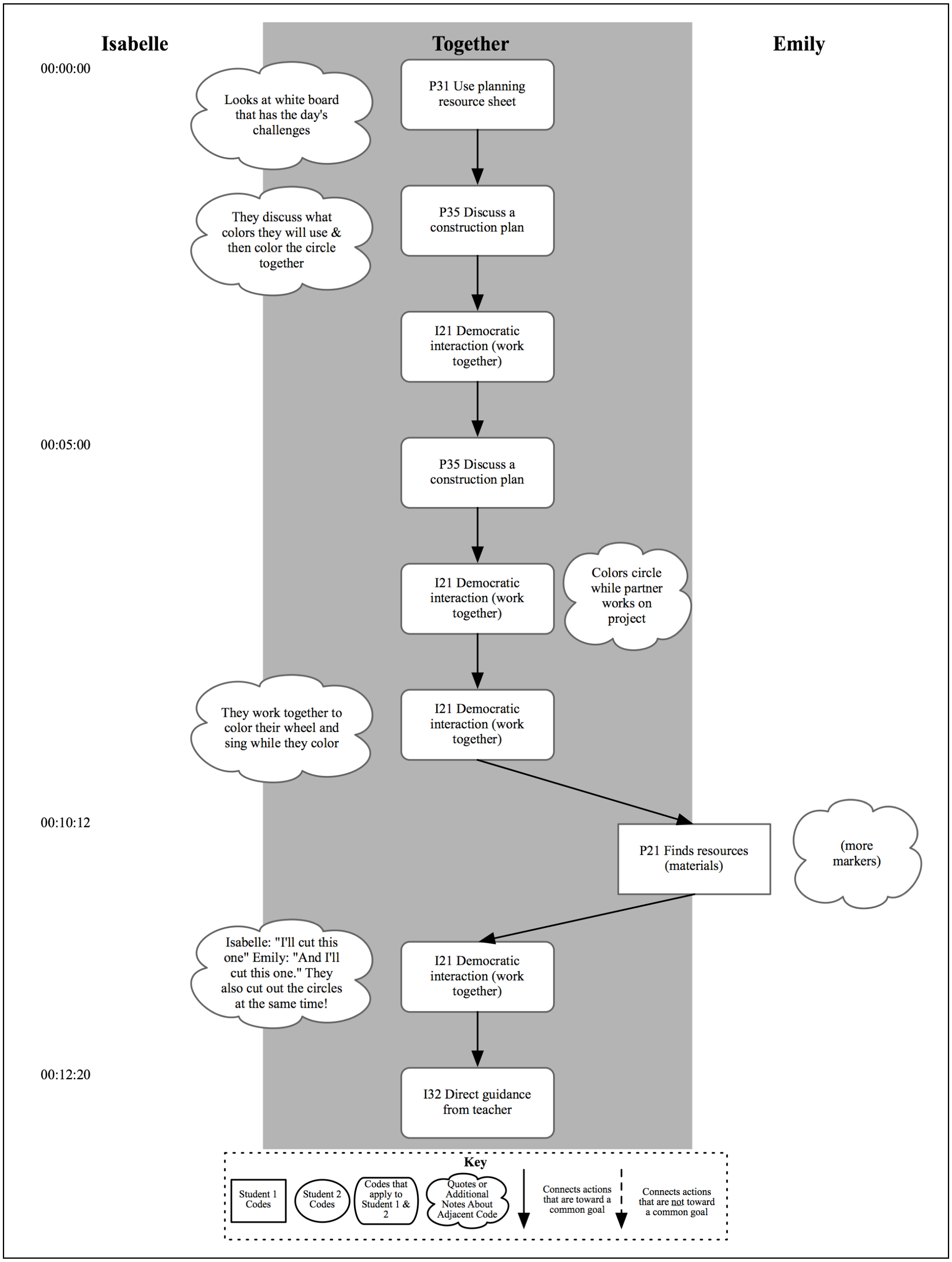


Figure 4.6: Flow chart showing excerpt of Emily and Isabelle's session.

This twelve-minute excerpt visually shows how this dyad progressed together, with an occasional brief individual interaction, but one that was still toward a common goal. They would discuss a construction plan, and then move to working together on those plans.

Asymmetric Collaboration

General description.

Asymmetric collaboration is similar to that of mutual collaboration, except that one peer is more capable than the other (i.e. more skilled with the materials). Some key phrases that describe this type of dyadic interaction include:

- Worked on a common activity with a sharing of the goals and materials.
- The more capable peer guided and helped the less capable peer in a positive and encouraging manner (i.e. the less capable peer was still given opportunity to work with the materials with guidance from the more capable peer).
- Times of unequal dominance but still toward a common goal (i.e. the more capable peer might show the less capable peer how to do a particular piece of the project, but the teaching is done in a kind manner).
- Sharing of materials throughout the activity.
- Frequent dialog between partners about the project (i.e. discussed construction plans, new ideas, problems, difficulties, etc.).

In this “dance,” one student is more capable than the other, but is able to guide the less capable peer in manner that, much like in mutual collaboration, easily reflects the common goal that they are working toward.

Example dyad: Keira and Hannah.

Keira and Hannah are the best example of this type of interaction—Hannah was slightly more skilled than Keira. If viewed from a distance, their behaviors would look very similar to that of the first example, Emily and Isabelle, but a closer inspection of their behaviors and dialog reveals several times at which Hannah helped Keira. In this snippet of dialog, we see that Hannah subtly guides Keira along:

Hannah: (They test a stuffed animal, Mr. Bear, in their LEGO chair and realize that it does not support him well.) “Hey, let’s . . no, I want to make it [the chair back] so it like, goes taller so it goes a little bigger.”

Keira: “Yeah. That would be cool.” (Together they add beams to the back of their chair.)

Hannah: “Now let’s make it go smaller once” (referring to using a smaller beam to the top of the chair). (Looks at the top of the chair) “That looks good.” (Takes Mr. Bear and with Keira tests him in the chair.)

Keira: (After they put him in the chair and see that the taller back holds his head up) “Perfect!”

Turning to the interaction-graphs, we see that these two students followed a similar pattern to that of Isabelle and Emily; most of the time (again, over 80 percent) was spent working in collaboration with the other student and the remainder of the time was spent working with a teacher (Figure 4.7, Table 4.3 and Figure 4.8, Table 4.4).

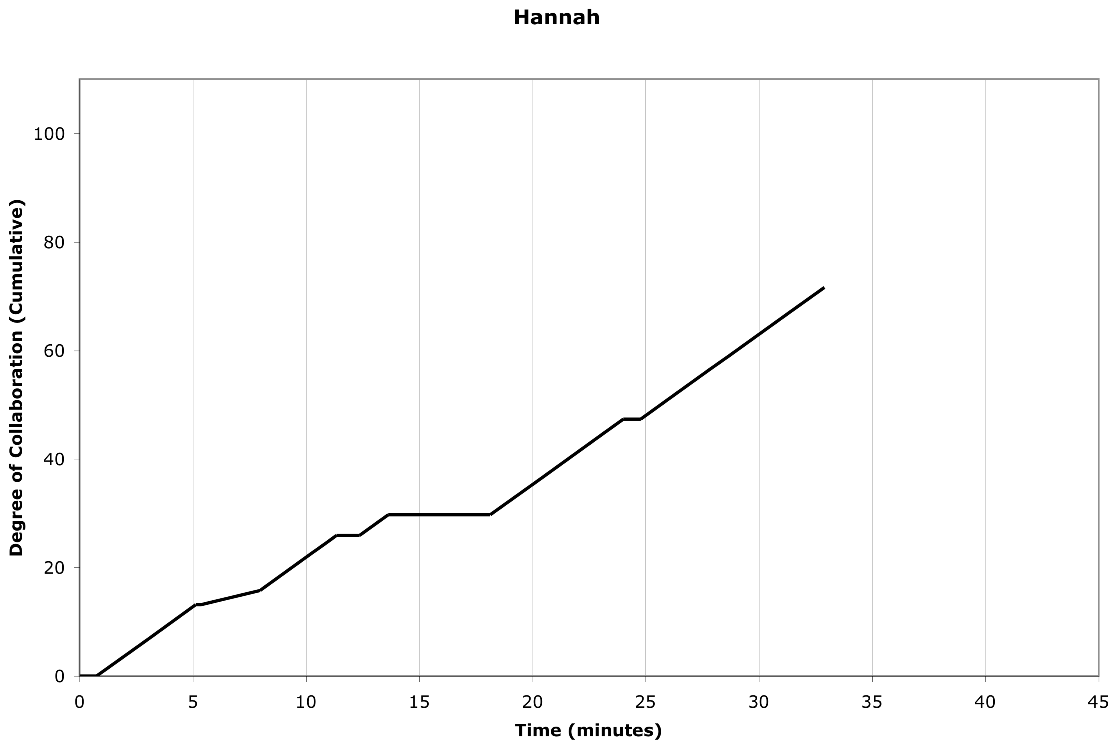


Figure 4.7: Interaction graph for Hannah (asymmetric collaboration).

Table 4.3: Slope and percentage of session time Hannah spent in each type of interaction (asymmetric collaboration).

Slope	2.2
Percent I3* (pupil-teacher interaction)	14.5
Percent I1* (no pupil interaction)	0.0
Percent I2* (pupil-pupil interaction)	85.8

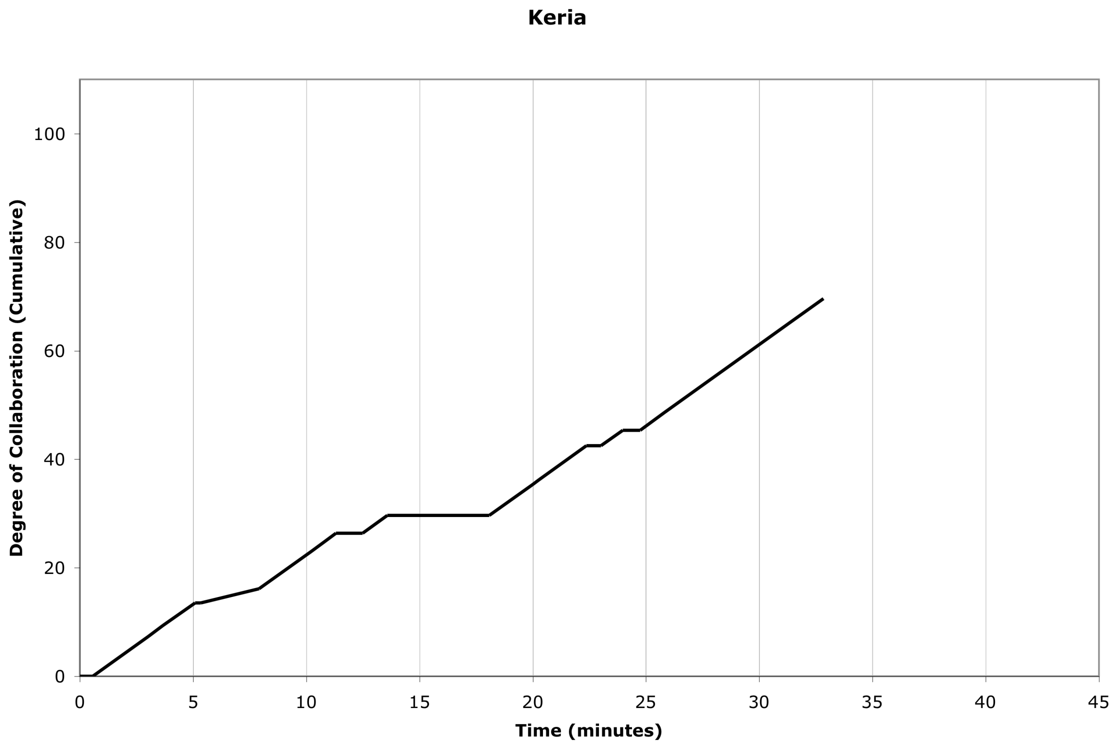


Figure 4.8: Interaction graph for Keira (asymmetric collaboration).

Table 4.4: Slope and percentage of session time Keira spent in each type of interaction (asymmetric collaboration).

Slope	2.1
Percent I3* (pupil-teacher interaction)	18.4
Percent I1* (no pupil interaction)	0.0
Percent I2* (pupil-pupil interaction)	80.8

The overall slopes of these graphs are both greater than 2, suggesting high collaborations. These slopes are, however, lower in value than the previous two. This is because for these two students, the teacher interactions occurred for several short "bursts" throughout the session, as opposed to Emily and Isabelle, in which the main teacher interaction occurred at one time, allowing for a greater growth in the slope of the line. Much like for Emily and Isabelle, a picture of these two students working together helps give a sense of how this interaction occurred (Figure 4.9).

Figure 4.9: Image of Keira and Hannah working together.

Like in the previous pair, these two students worked together on almost every aspect of the project—in this picture, one student is holding the project stead while the other is adding a piece.

If next we look at their detailed flowchart (Figure 4.10), we see a similar pattern to the mutual collaboration example pair, as is expected since both are classified as "high collaborations."

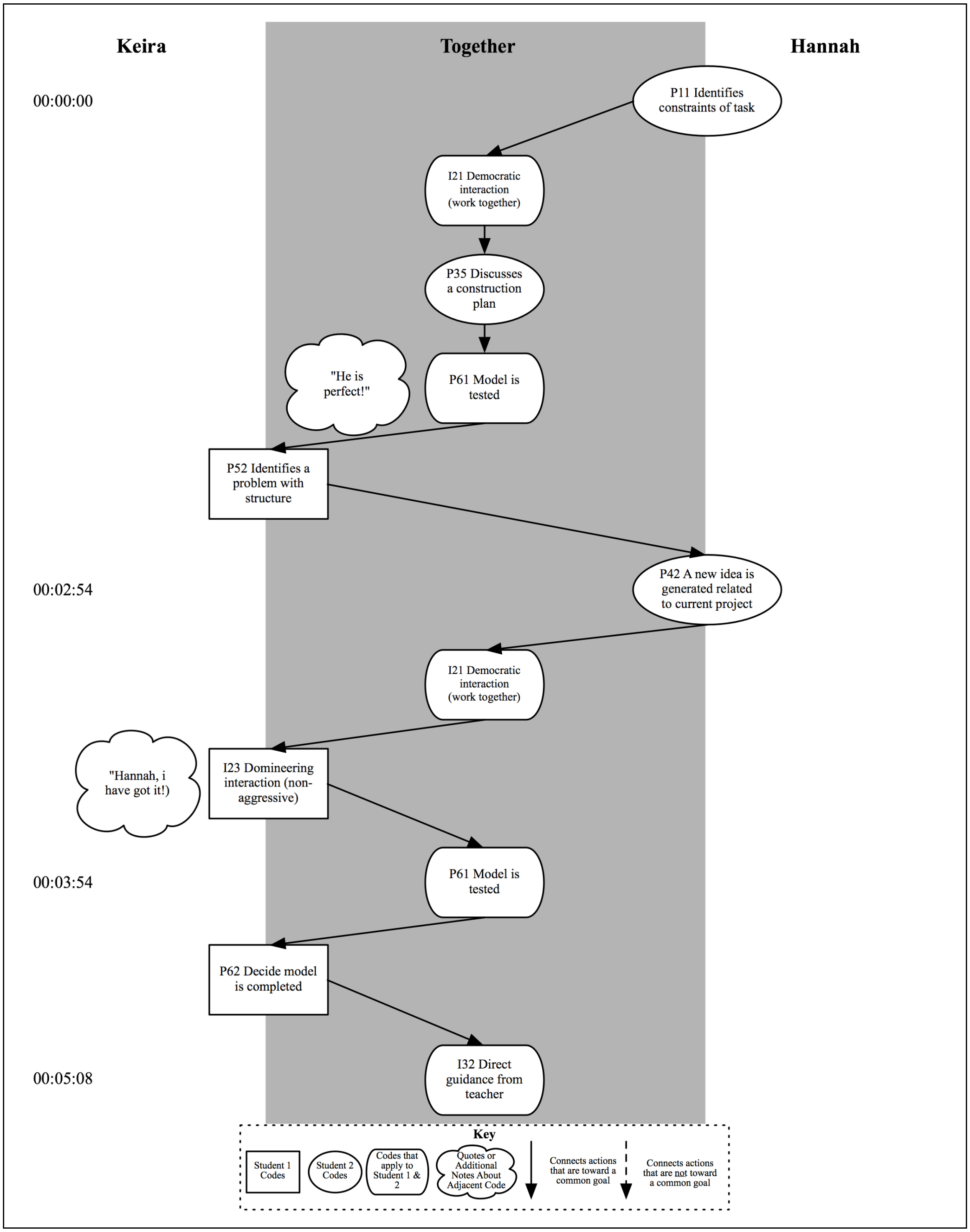


Figure 4.10: Flowchart showing an excerpt from Keira and Hannah session.

In this five-minute excerpt, the students do contribute individually and together toward a common goal. In an excellent example of collaboration with a more skilled peer, Keira identifies a problem with the structure and Hannah quickly finds a solution to the problem. I will now discuss the two types of interactions that occur when there is low collaboration between the two students: imitation/intimidation and parallel activity.

Imitation/Intimidation Collaboration

General description.

This type of interaction is the first of the two in the "independent activities" section of the initial classification (imitation/intimidation and parallel activity). In both of these classifications, there is little collaboration between students. In this particular situation of imitation/intimidation, however, the following phrases best describe the dyad:

- Worked on separate individual tasks for the activity (i.e. little sharing of goals/ideas)
- The less capable peer imitated the other (i.e. mimicked the behaviors).
- Asymmetric flow of information (i.e. one student seemed to have all the information)
- More capable peer may have dominated the activities, intimidating the other peer into passiveness (i.e. more capable peer might "take away" the project from the less capable peer when a new idea is generated).

In this "dance," the less capable student copies the behaviors of the other student, not exhibiting any new ideas or really adding any personal touches. In some situations, the more capable student may force the other student to follow his or her steps, not giving them any room for their own ideas nor teaching them along the way so that the other student could eventually dance on their own.

Example dyad: Matthew and Tracy.

Matthew and Tracy serve as the example dyad that would be classified as "imitation/intimidation," though there was more imitation in this particular case than intimidation. Tracy was less skilled with the materials than Matthew and for the most part, they worked on independent projects. We can see how their interactions played out during the course of the session by looking at the interactions graphs for each student (Figure 4.11 Table 4.5 and Figure 4.12, Table 4.6).

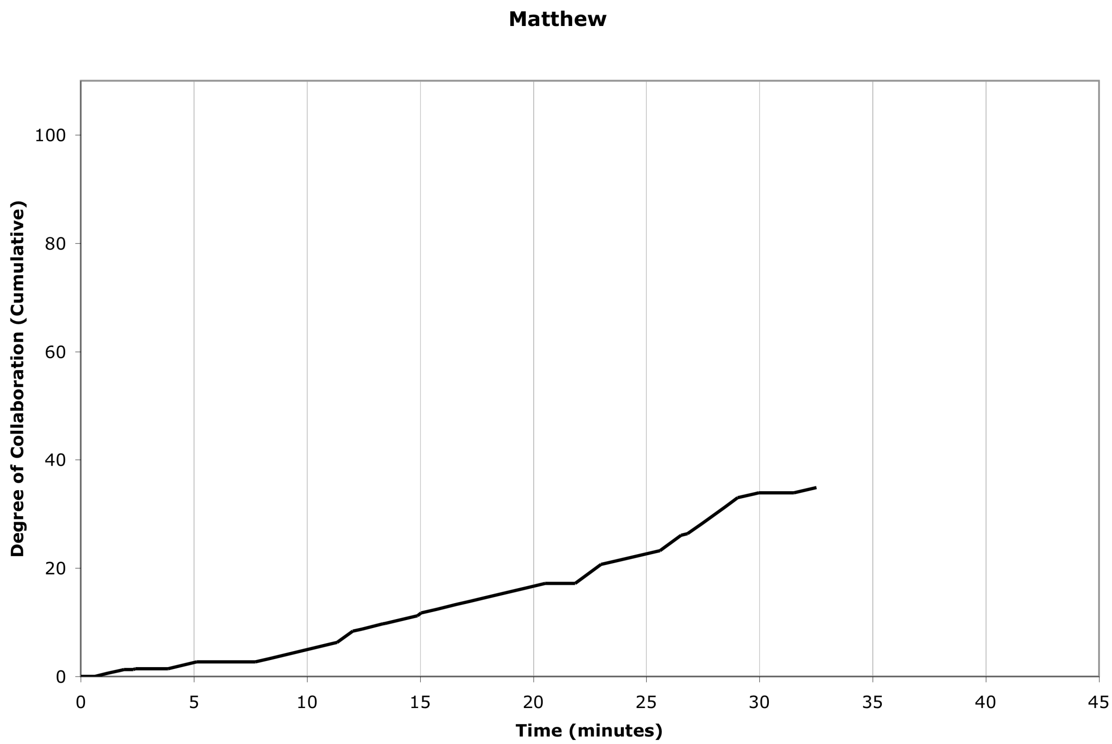


Figure 4.11: Interaction graph for Matthew (imitation/intimidation).

Table 4.5: Slope and percentage of session time Matthew spent in each type of interaction (imitation/intimidation).

Slope	1.1
Percent I3* (pupil-teacher interaction)	10.8
Percent I1* (no pupil interaction)	67.8
Percent I2* (pupil-pupil interaction)	21.4

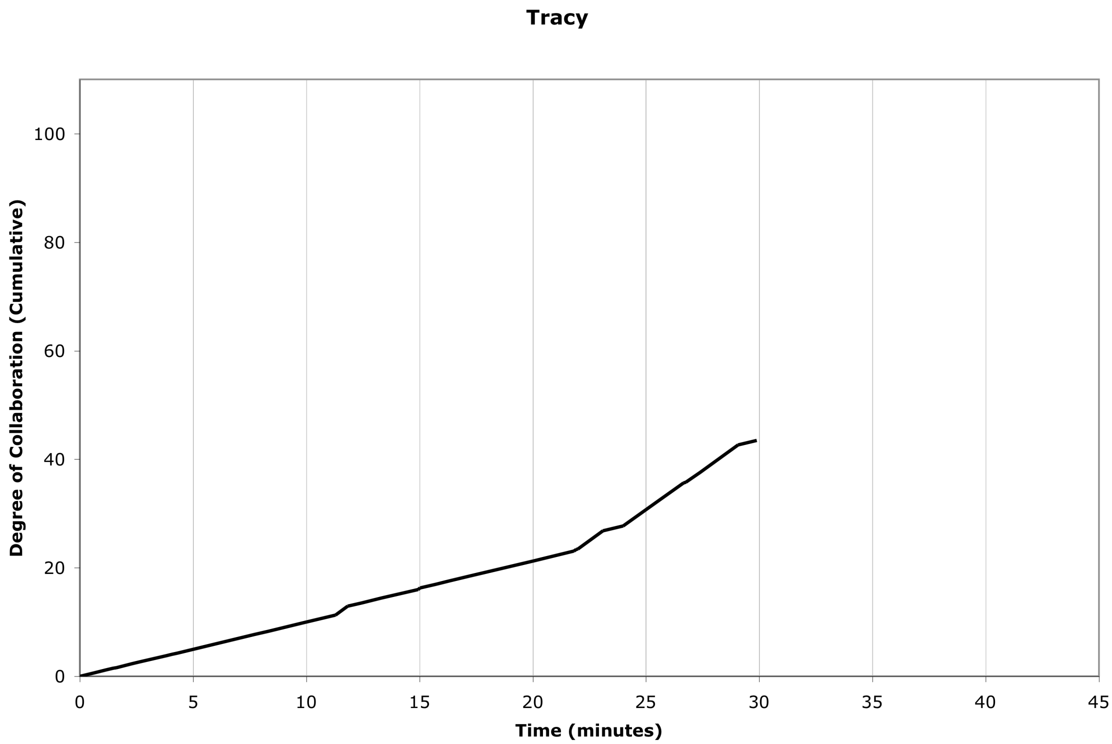


Figure 4.12: Interaction graph for Tracy (imitation/intimidation).

Table 4.6: Slope and percentage of session time Tracy spent in each type of interaction (imitation/intimidation).

Slope	1.5
Percent I3* (pupil-teacher interaction)	2.7
Percent I1* (no pupil interaction)	66.7
Percent I2* (pupil-pupil interaction)	30.6

For both students, over 65 percent of the time was spent working alone, with Matthew having more teacher interaction than Tracy. They both had moments when they worked together, but overall, they worked independently, as suggested by the resulting slopes of the line which were 1.1 (Matthew) and 1.5 (Tracy), indicating low collaboration. During the course of the session, Matthew would continually work forward to achieving the goal of the activity, making a “Chair for Mr. Bear,” by getting materials, testing the project, coming up with new ideas, etc. Tracy, on the other hand, was for the most part stuck on one “train of thought”; she kept playing with a three-beam structure that she had attached with connector pegs, and when Matthew showed his project, she would look at his and decide hers was to act as legs for the structure. A piece of this dialog is presented below:

> Matthew: “Ok, here’s part of it.” (Made the base of the chair for Mr. Bear with lots of pieces.)
>
> Tracy: (Looks at what she made in comparison to what he made—a simple three-beam structure that is held together with connector pegs so that it moves around.) “Ok, I just made the legs.”
>
> . . .
>
> Matthew: (He has been working on building up the base of the chair, including adding little legs) “Oh, look at part of this chair.”
>
> Tracy: “Good—I just made some legs.” (She has not progressed in her design since her last statement.)

Like in the two previous examples, a picture of these two students working together allows another visual—notice how they are seated far apart, with the materials in between them (Figure 4.13):

Figure 4.13: Image of Matthew and Tracy working apart.

We can also look more closely at an excerpt of their session as a flowchart (Figure 4.14):

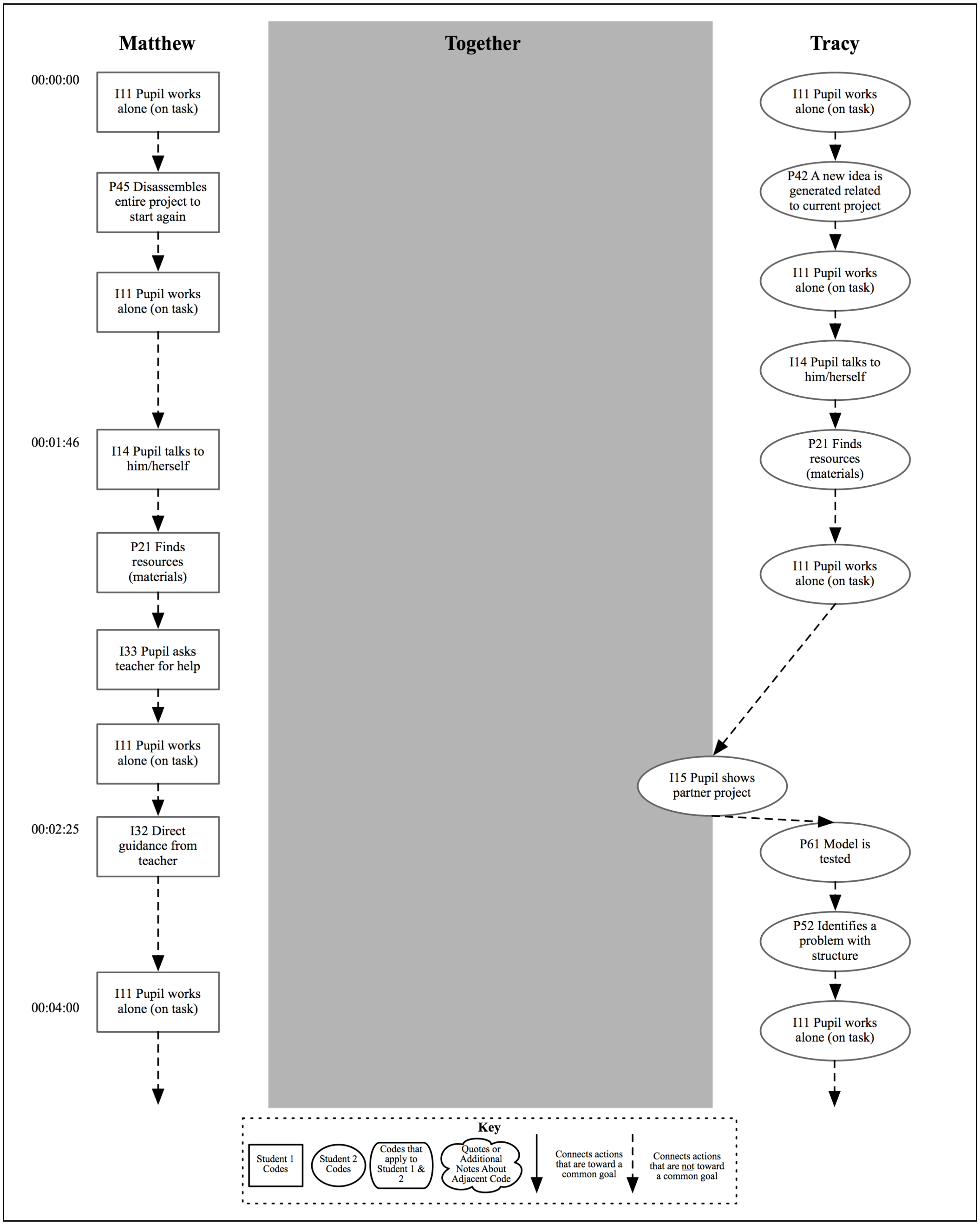


Figure 4.14: Flowchart from an except from Matthew and Tracy's session.

Notice the contrast of this flowchart to that of Keira and Hannah or Isabelle and Emily. In this four-minute piece, we see how the position of the two students in the picture above is reflected in their flowchart—the students are sitting next to each other, but not really working together. Though at times they may think that they are working together, their actions are toward individual goals. The final classification, parallel collaboration, is similar to the imitation/intimidation classification, except that the students are of equal ability.

Parallel Collaboration

General description.

Like the previous classification, parallel collaboration is one in which there is little or no collaboration between the students in the dyad, but in this case the students are equally skilled. Some key behaviors seen in this type of pair include:

- Interaction among peers of equal expertise and when engaged in activities worked mostly independently on separate simultaneous processes (may be brief periods of collaboration).
- When working on their own, students were absorbed in their own activity (may have talked to him/herself, asked the teacher only about his/her project, etc.).

In this dance, the two students may be next to each other on the dance floor, but they are dancing to two different beats. One student may occasionally stop dancing to show the other a new move; not in the sense of wanting the partner to change his/her moves, but rather in the sense of just wanting to show what he/she has done (though the partner may not care or even acknowledge that this interaction is occurring).

Example dyad: Francis and Dominic.

The example pair for parallel activity is Francis and Dominic. These two students shared floor space in the classroom, but this was really all that connected them—they even argued over the materials. We can look at their interaction graphs to get a better sense of their interactions over the course of the session (Figure 4.15, Table 4.7 and Figure 4.16, Table 4.8):

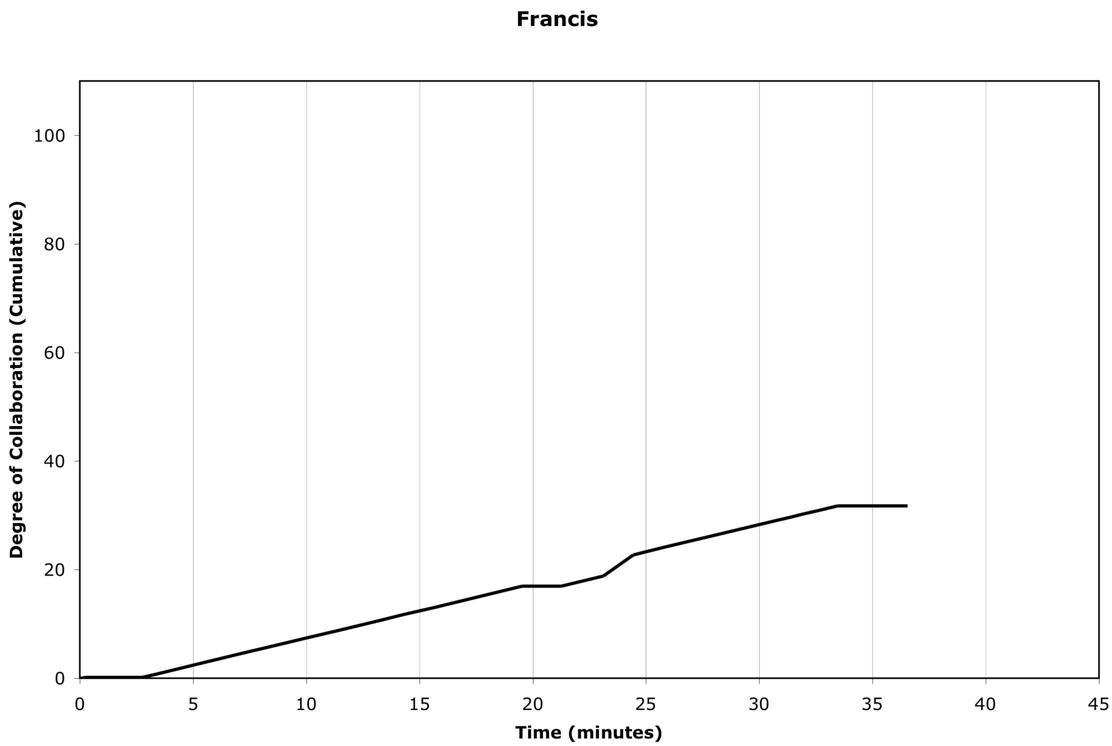


Figure 4.15: Interaction graph from Francis (parallel activity).

Table 4.7: Slope and percentage of session time Francis spent in each type of interaction (parallel activity).

Slope	0.9
Percent I3* (pupil-teacher interaction)	15.2
Percent I1* (no pupil interaction)	79.7
Percent I2* (pupil-pupil interaction)	0.1

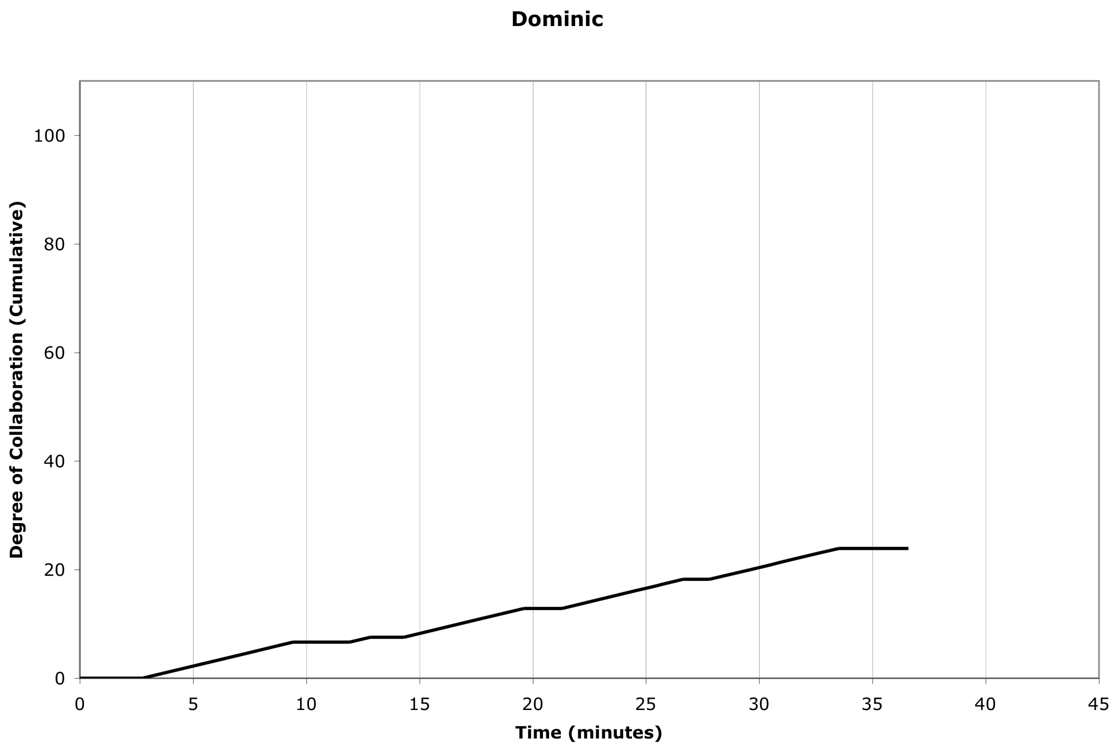


Figure 4.16: Interaction graph from Dominic (parallel activity).

Table 4.8: Slope and percentage of session time Dominic spent in each type of interaction (parallel activity).

Slope	0.7
Percent I3* (pupil-teacher interaction)	19.1
Percent I1* (no pupil interaction)	80.9
Percent I2* (pupil-pupil interaction)	0

Both of these students spent approximately 80 percent of their time working alone, and the remainder of the time working with a teacher. The resulting slopes, both under 1, indicate that this was a low-collaboration dyad (recalling that a resulting slope of 1 would indicate that the student worked alone for the entire session). Dominic's resulting slope is less than Francis's because the teacher had to interact with him on a more frequent basis, and in the case of Francis, the teacher only intervened once for a short time. As included in the last three examples, an image of the two students working together helps to visually show how their physical separation reflected their lack of cooperation (Figure 4.17).

Figure 4.17: Image of Francis and Dominic working apart.

Furthermore, we can look at this dyad's detailed flowchart to get a better sense of the students' collaboration (Figure 4.18).

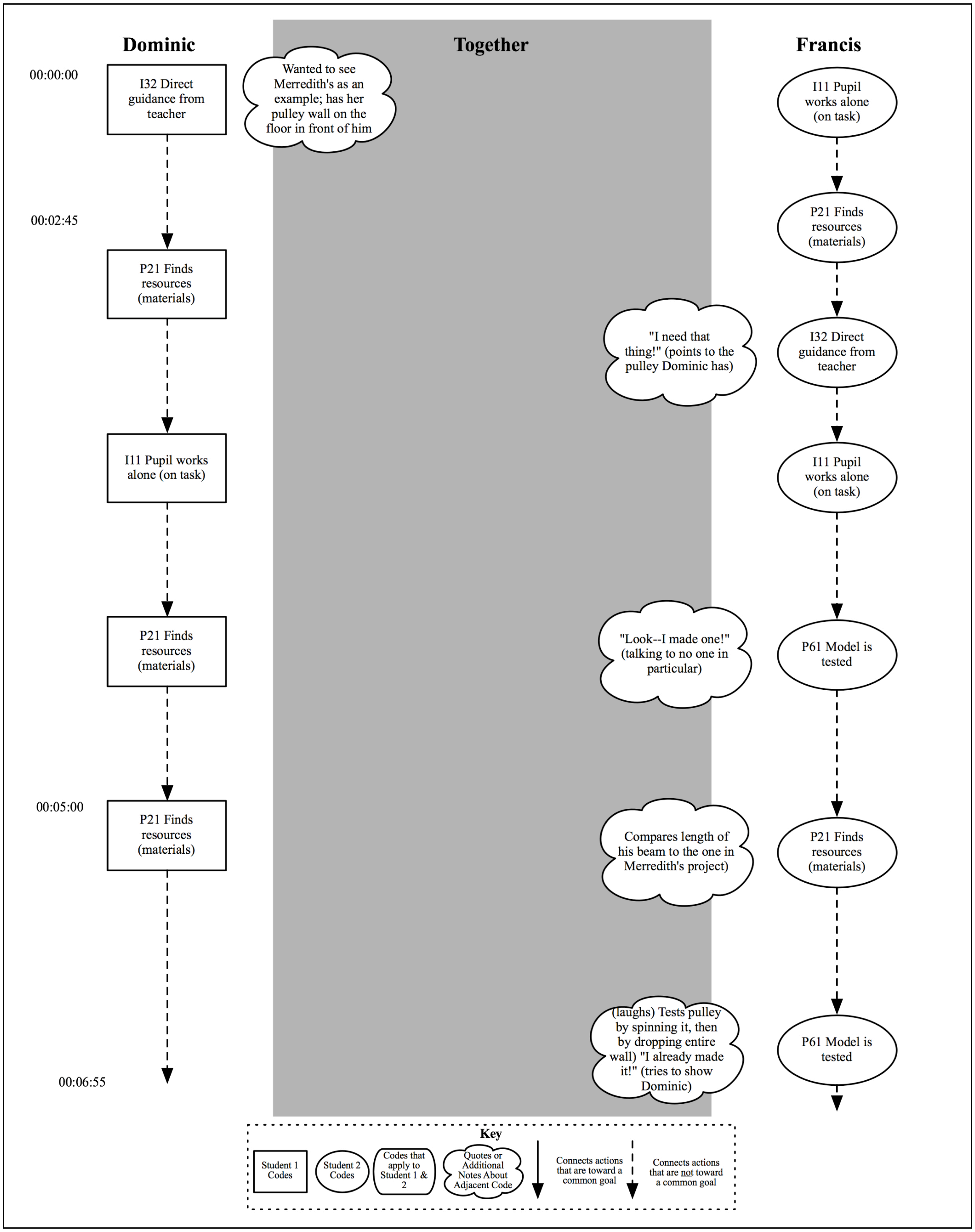


Figure 4.18: Flowchart of an excerpt from Dominic and Francis's session.

This flowchart created from a seven-minute excerpt of their session looks very similar to Tracy and Matthew's—the actions of the two students run in parallel to each other. Dominic received help from a teacher early in the session while Francis worked by himself (he also talked to himself quite a bit). An excerpt of dialog from this session:

Merredith: "Here you guys go. Here's a few more and here's a big one." (Hands him beams of various sizes.)

Dominic: "No, I want to see how it work [*sic*] so I can figure out how to make mine."

Merredith: "Oh, you wanted to see the one I made?"

Dominic: "Yeah."

Merredith: "Why don't we just make you one of your own so you can keep it? So, what did mine have on it?"

Dominic: "That's why I wanna . . . I can't remember!"

Merredith: "You remember part of it, right?"

Dominic: "No. Not really."

. . .

Francis: "I already make [*sic*] it!" (laughs). "Look at it!" (Says to no one; uses his project as a spaceship.)

Dominic: (looks up) "It isn't supposed to be a spaceship." (Immediately looks down again and continues with his work.)

Francis: "I know but I make a . . ." (does not finish his thought.)

. . .

Francis: “Dominic, why you make [*sic*] two of them?” (Does not really talk to Dominic.) “I want to make a car” (Makes engine noises and “drives” his project through the air).

Now that I have discussed each of the four classifications, I will conclude this section with a comparison of the two extremes—Emily and Dominic.

Comparison of Extremes: Emily and Dominic

While the scales of the x- and y-axes of the interaction graphs have been constant throughout this discussion, I thought it was important to end with a comparison of the two extremes—the student with the least interaction (i.e. the smallest resulting slope), Dominic, and the most interaction (i.e. the largest resulting slope), Emily (Figure 4.19).

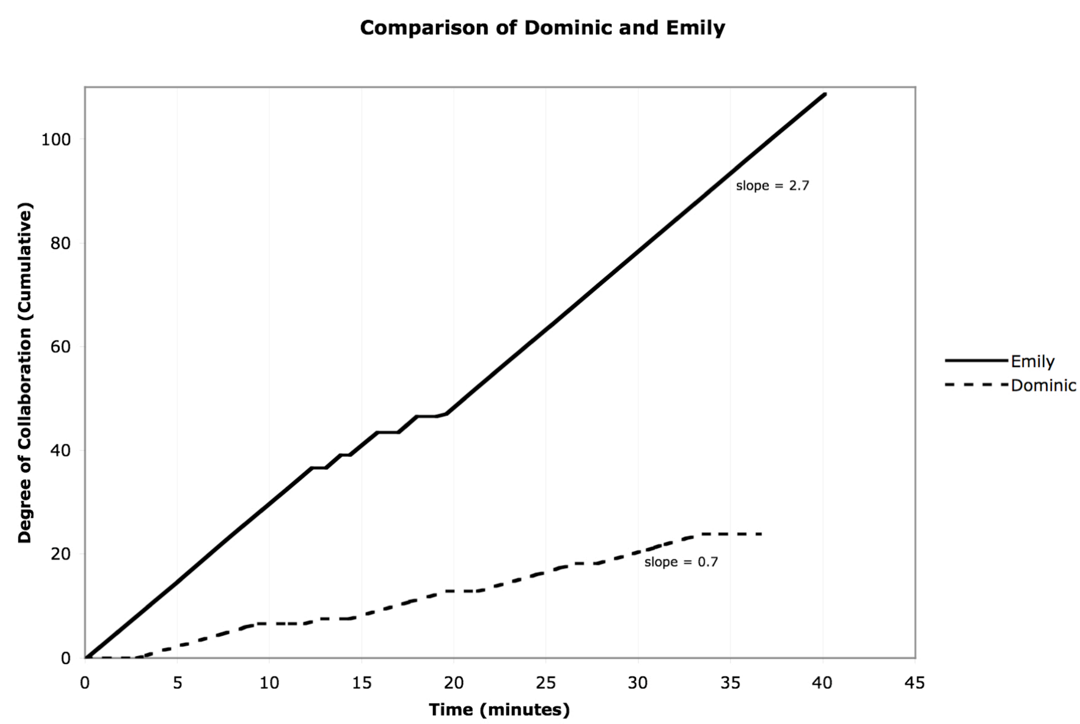


Figure 4.19: Interaction graph showing Dominic and Emily.

This graph clearly shows the difference in the two extremes—Emily worked for majority of the time with her partner, while Dominic spent most of the session time working alone. Both had interactions with a teacher, but had very different amounts of interactions.

Applying the Classifications to the Classroom

I have described each of the four types of dyadic collaboration classifications applicable to first graders working on engineering tasks. I will now discuss how the twelve student dyads that I observed fit into this framework.

As discussed in the previous chapter, I used Merredith's evaluation of the relative expertise of the dyad for the "relative expertise dimension" and the slope of the resulting line from the interaction-graphs as the "degree of collaboration" dimension. The breakdown of the dyads is shown below in Figure 4.20. Note that the small numbers under each stick figure shows the age of the child in months, a slash, followed by the classroom teacher's assessment of that child's social problem solving relative to grade-level expectations using this scale (Table 4.9):

Table 4.9: Levels of social collaboration relative to grade-level expectations.

1	*2*	*3*	*4*	*5*
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

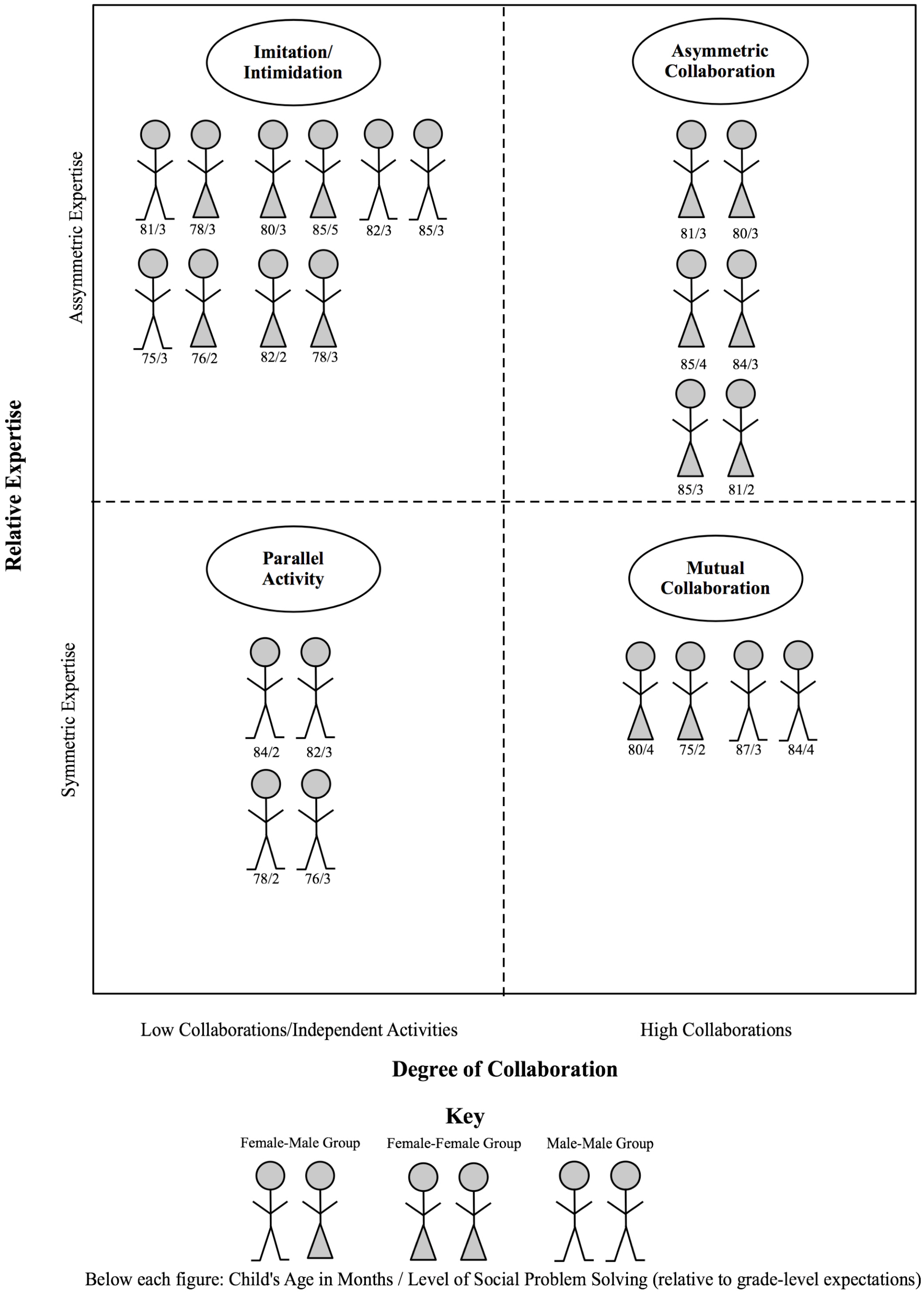


Figure 4.20: Categorization of the dyads in this research, along the dimensions of Relative Expertise and Degree of Collaboration, based on gender make-up of dyad.

From this figure, we see that four of the six female-female dyads and one of the four male-male dyads fell under the “high collaborations” dimension, while both of the male-female dyads, the other two female-female dyads, and the other two male-male dyads were classified as “low collaboration/independent activities.” Furthermore, all but one of the students in the “high collaborations” dimension were more than 80 months old (6.6 years); the one student that was not 80 months was paired with a student that was rated as “above grade level expectations” for social problem solving. However, there are three dyads in the “low collaborations” dimension in which both students were older than 80 months, and further examination reveals that two of these groups are male-male dyads. Thus, there is a possibility that both age and composition of the dyad is important for collaborations. However, it is difficult to make any specific statements about the gender of the dyad in relation to collaboration because of the small sample size of the population (to be discussed further in Chapter 5).

Other researchers looking at collaborative problem solving in young children have suggested that there are gender differences in their problem solving by way of the types of speech they use (Ausch, 1994; Holmes, 1997; Holmes-Lonergan, 2003), and Holmes-Lonergan in her studies of preschool children (2003), suggests “children in mixed-dyads may experience more problems than same-sex dyads in completing tasks, particularly when they use controlling rather than mitigating types of behavior. Children in same-sex dyads are more likely to succeed when they use gender-consistent patterns of interaction” (p. 516). However, Charlesworth and Dzur (1987) suggest that the types of cooperation behaviors seen in young male-male dyads are more physical in nature and are typically seen as uncooperative and negative, in contrast to the more traditional verbal interactions seen in cooperative female-female dyads; thus "the traditional classification of cooperative and competitive behaviors does not meaningfully differentiate boys and girls" (p. 199). Cannella (1992), in contrast, suggests that female pairs had the most conflict in comparison to male-male and male-female groups, but that the materials used during the interaction may play a role in the types of cooperation that occurred. In summary, the research on cooperative problem solving in young children when comparing boys and girls is contradictory, which leaves much room for further research.

Implications for the Classroom

This is only a beginning examination of the collaboration of dyads in first grade when working on an engineering task; using the methodology presented in Chapter 3, however, it would be possible to observe a greater number of dyads both in different types of schools and at different ages. However, there is clearly a need for care when forming dyads when engineering tasks, quite contrary to times when teachers randomly assign students to pairs. De Lisi & Golbeck (1999) wrote:

> Attainment of educational objectives using peer learning is a joining function of students' cognitive systems and the particular content area being worked. From a Piagetian perspective, the important question is not, 'will children learn from peer team experiences?' Instead, the issue is the *quality of learning* or level of understanding vis-à-vis the educational objective (p. 36).

If we want students to have a high quality of learning, there are a few issues that I would suggest a teacher consider when forming pairs working on engineering activities based on this research; namely the role of friendship, the social collaboration abilities of the students in the pair, and the gender composition of the group.

The Role of Friendship in Dyadic Cooperation

I asked all of the children that I observed a series of questions about their experiences with LEGO bricks and the conditions under which they like to work with the materials (i.e. alone or with a friend, at home or at school, with a girl or boy partner, etc.). Their responses, while humorous in the candor that only young children have, suggest a need for teachers to consider the "friendship" status of the partners that they assign. During my first interview, one girl told me that she liked playing with the materials at school, but not at home. When I asked her to explain why, she responded, "Because I don't have to do it alone." The idea of working with a friend is shown in another dialog, this one with Keira and Hannah:

> Laura: "Do you like to play with LEGOs in school?" (Both girls shake their heads "yes.") "Why?"
>
> Keira: "Because it is fun and we are friends. . . It, um, makes much work [*sic*] easier."
>
> Hannah: "We are best friends."
>
> Keira: "Yeah."
>
> Laura: "So, if you guys had a choice, would you rather work on LEGOs on your own or with a friend?"
>
> Hannah: "With a friend."

Of the 14 girls involved in this research, 13 told me that they would prefer to work with a friend when using the LEGO materials. In contrast, of the 10 boys, 9 said that they preferred to work alone with the LEGO materials (the one boy who said that he would prefer to work with a friend also told me that it would have to be with a boy). In the two example dyads exhibiting “high collaboration” (Kiera and Hannah and Emily and Isabelle), the students were friends with each other, while in the two “low collaborations” pairs, they were not friends with each other. Again, while only I have only collected a preliminary sampling of children’s responses, I believe that in order to help students become interested in these types of materials, which are traditionally masculine in nature[2] that teachers need to seriously consider the “friendship status” of the partners. From my observations, I found that pairs, in particular two females, in which the students were friends were better able to cooperate and work through disagreements without teacher intervention. DeVries (1997) , in her article about Piaget’s social theory, also provided principles for classroom teachers to consider for peer learning; one of her principles was along a similar vein as mine. She wrote,

> In conflicts, children are especially motivated by the disequilibrium in an interaction to reflect on ways to reestablish reciprocity. Motivation to co-operate in conflict resolution depends on whether children care about the relationship that is in jeopardy. . . . Peer friendship is therefore important to children’s operational and co-operational development. (p. 14)

For example, the most un-cooperative group that I saw (both students had resulting slopes less than 0.7) consisted of two students who, quite frankly, did not like each other and were not friends. They had many conflicts that required teacher intervention, but this could have been because they were not invested in the relationship. Thus, if teachers want to involve students and make them want to work with the materials, they should try to put friends together.

[2] As illustrated by this example: I had asked one girl if she had LEGO bricks at home, and she replied, “I only have sisters,” implying that because she only had sisters that she would not have LEGO bricks at home.

Social Problem-Solving Abilities Relative to Grade-Level Expectations

In many, but not all, of the dyads exhibiting "low collaborations," one or both of the students were below grade-level expectations in terms of social problem solving, according to the classroom teacher. However, this is not necessarily negative; even though the students did not collaborate with each other, they were still able to be involved in the activity. While it all depends on the classroom teacher's overall goals for the students, it may be best to not force students who are below grade level in social problem solving to work together on these types of activities, for fear of making them uninterested in early introductions to engineering. While use of LEGO bricks and other engineering materials can often be a catalyst for group work, there are times when it is more appropriate for students to be just given the opportunity to work with the materials on their own. Only a classroom teacher would have the knowledge of the students to make this evaluation, but again, the most un-cooperative group I observed was one in which the two students, one of which was below grade-level expectation in social problem solving, should been allowed to work individually instead of being forced to work together.

Gender Composition of the Group

While I have only completed a preliminary look into the impact that the gender composition of a dyad has on collaboration during an engineering task, it seems that in first grade, single-sex dyads tend to be more cooperative. I do not currently, however, see any differences between male-male dyads and female-female dyads in terms of cooperation when both the friendship between the two students and the social problem-solving abilities of the pair are considered. Researchers looking at children's play styles have found that young children prefer to work with same-sex peers (Fabes, Martin, &

Hanish, 2003; Macoby & Jacklin, 1987; Martin & Fabes, 2001), but that boys often prefer to work in same-sex groups while girls prefer to work in same sex dyads (Benenson, Apostoleris, & Parnass, 1997; Fabes, Martin, & Hanish, 2003). It is interesting to note, as mentioned previously, that most of the boys said that they would prefer to work alone with the materials, suggesting the importance of the nature of the task in determining the boys' preferred working situation (Holmes-Lonergan, 2003), and that perhaps the task itself is what determines cooperation (Ausch, 1994). This is especially interesting for my work, as engineering education is a new area of research and it may be the task that influences the gender differences in cooperation. In addition, because of the young age of the children and their experience with the materials, I would speculate that in older grades, the male-male dyads would be more likely to divide the work between each other (i.e. each doing one piece that leads to a common goal) while the female-female dyads would work together at each step, as suggested in Strough and Cheng (2000).

In this chapter I have discussed the four types of collaboration classifications I observed when working in first grade, including key phrases that describe the behaviors of the dyad. For each of the four classifications, I provided a description of a sample dyad that showed those characteristics, the interaction graphs for the two students in the example dyad, and a flow chart that detailed a piece of their session. I concluded the chapter with some suggestions for classroom teachers when partnering students to work on engineering tasks. In the next chapter, I discuss the limitations of this research, provide suggestions for future research, and offer a personal reflection on the experience of completing this research.

Chapter Five: Conclusions, Implications, Limitations, and Future Research

Limitations

Research Bias in Interpretation of Data

There could have been bias in the collection of the data for this research, as the tool had never been used before. However, I did videotape all of the sessions, and if I had thought that this was an important part of the research at this stage, I could have re-watched the tapes while using the tool to see if my original observations held true. I felt, however, that for this thesis work, testing of the data collection tool for reliability was outside the possible scope. In addition, I used the same procedure for collecting the data for each observation, including the same interview questions, in a hope for reliability across sessions. Thus, in the future to reduce the possibility of bias, I would suggest that inter-rater reliability, as suggested by Stangor (2004), be done with the tool (i.e. have two people collect the data at the same time and compare their observations). I did not do that for this research because of its exploratory and preliminary nature. Furthermore, in an attempt to reduce bias, the methodology of creating the interactions graphs, determining the overall slope of the graphs, and generating the task event networks was applied across observations to ensure that each observation (and hence each dyad) was interpreted the same as the others.

Reactivity

Reactivity in research has to do with the participants altering their behavior because they, consciously or unconsciously, know that they are being watched and/or recorded (Maxwell, 1996; Stangor, 2004). In an attempt to minimize this problem, I went into the classroom two weeks before starting data collection and just played with the children during their free time so that they would become used to my presence. I also explained to them why I was in their classroom and showed them what equipment I would be bringing with me (i.e. laptop, video camera, microphones, etc.). Since I was going to be using a laptop as my main form of data collection, I was initially concerned about the students' perceptions what I was doing while observing them. However, their classroom teachers had laptop computers and told me that they often used them during the class to take notes on the students, and thus that was not a problem for the children. In addition, they often had visitors to the classroom for various reasons, and while acknowledging my presence, we very quickly able to accommodate me into their routines. Also, because I made sure not to introduce myself as a teacher (I told them I was just there to "learn how first graders learned engineering"), they knew that I was not evaluating them as a traditional teacher would. This is reflected in the off-task behaviors that I occasionally observed, such as singing, dancing, coloring, making spaceships, etc., that would normally be stopped by a teacher. I believe each of these steps helped to reduce the possibility of reactivity.

Generalization of Findings

Only 24 students were involved in this research, for a total of 12 dyads, and all students came from one school system in an upper-middle class town. Thus, these results are not generalizable to any other population, due to small sample size and specificity of the location. However, I presented a new data collection tool and methodology for analysis that would allow for future research in this area to be completed on a larger scale so that conclusions could be more generalizable.

Future Research

This was only a first attempt to understand how first grade students problem solve on an engineering task. For this document, I chose to focus only on the social collaboration (i.e. the collaboration classifications) that occurred between students in a dyad, as that seemed to be one of the most important aspects of the overall problem solving process and one of the most salient features in the classroom. In addition, I wanted to create a new data collection tool that would make research on this topic easily replicable; to me, a unique area of study required a unique methodology. My suggestions for future research follow two veins: research that continues to look at social collaboration on engineering tasks and research that looks more closely into specific problem-solving processes on engineering tasks in a more traditional sense.

Collaborative Problem Solving

To start, I would suggest that the same procedure be used but with a larger sample size so that conclusions could be drawn about gender differences in dyads in first grade (i.e. the presence or lack thereof of gender differences). Then, perhaps the methodology could be expanded to other grades so that a larger picture could be painted of the role of gender composition, friendship, and level of expertise in dyad's collaboration on engineering tasks. Once this was established, I would move toward understanding how a dyad changes collaboration classifications both within a session and among sessions (i.e. how does the collaboration between two students change over time, as their age, knowledge of the materials, and comfort with their partner increases).

Once a firm understanding of the role of dyad composition on engineering tasks was established, I would consider expanding the research to triads, as many students using the LEGO robotic technology and other engineering education toolsets have to be in groups because of lack of materials. I would also suggest using a similar methodology but on a different task, to see if it is the engineering aspect of the activity that does or does not facilitate cooperation between partners (i.e. I would compare a dyad's cooperation on both an engineering and a non-engineering task).

Future research could also further examine the collaborations that occur on engineering tasks between students with mixed social problem-solving ability or levels of expertise (i.e. novice/expert), in a more traditional Piagetian manner (e.g. "What differences in collaboration occur when one student is above/below the other in social problem solving?" "What collaborations occur when one student is above/below the other in terms of skill level with the materials?"). This would, however, require a better assessment of each child's skill level with the materials beyond the teacher assessment as I used; Azmitia (1988) completed a study with five year-old children in which she characterized them as either novice or expert on a LEGO block activity though she did not include the details of the test used to determine this characterization. In my research, Merredith was an expert in the technology and thus was able to assess each student's skills relative to his or her partner based on her experiences and observations, but not all researchers or teachers will have this same level of expertise.

Building on this idea of observing mixed-ability peer dyads, future research could also look at novice/expert interactions when the expert is the teacher or another adult. While the research could still examine the cooperation between two students, the amount, type, and quality of teacher interactions with the student could be important (I had decided not to consider this for this research as it was beyond my scope). This could be examined in more detail by using my data-collection tool, but varying the weights of the collaborations (i.e. not weighting teacher-interactions at 0).

An important piece, however, of these ideas for future research is to also understand how the different collaborations influence a dyad's engineering "product," their learning of the engineering concepts, and their engagement in the activities (perhaps considered their overall engineering "success"). Methods of assessment of the products of engineering activities are being explored at the Center for Engineering Educational Outreach (CEEO) at Tufts University, but it is difficult topic, especially with young children (i.e. how do you assess whether one dyad's "Chair for Mr. Bear" is "better" than that of another dyad?). Thus using the evaluation technique presented in this research for classifying collaborations in combination with assessment methods would lead to an enhanced understanding of engineering learning.

Traditional Problem-Solving Processes

Using the data collection tool, I was able to capture a great deal of information about students' problem solving on engineering tasks. However, I chose to analyze only one small component—their social problem solving as reflected in their collaborations—because at the conclusion of my observations it seemed the most prominent feature of the engineering curriculum in first grade. Additional research could look at how students plan (or do not plan) for engineering tasks, including looking at their drawings and discussions with their partner. Another area of interest my be the amount that students re-designed during the process of one activity; for example, looking at when and how many times students took apart their projects to begin again. In addition, one could look at how students complete engineering tasks using the engineering design process as a framework for problem solving. Future researchers could also interview children in more depth regarding their beliefs and interests in the engineering fields—their honest answers may help educators understand better when and how to implement engineering into the curriculum. There are a number of possibilities that future researchers could examine. in the interest of making engineering a means by which to teach other subjects (i.e. math and science) and in order to interest females and minorities in engineering as a field.

Conclusion

Over the last chapters, I have discussed various aspects of problem solving in young children on engineering tasks—beginning with an introduction to general problem solving, moving next to an explanation of the pilot research that I completed, transitioning to a discussion of the tool and methodology used in the second research phase, and finally providing a description of how the tool and analysis methodology were applied to a first grade classroom.

As stated in the first chapter, when I began the work for this thesis I wanted to focus on gender-differences in problem solving on engineering tasks. This soon proved to be too broad a goal—as research on engineering education and problem solving is a new area of research—and instead I decided to focus on one grade level in order to begin the groundwork for future research. After beginning my observations in the classroom, I realized that it was not necessarily the gender of the students that mattered, but how the students collaborated with each other on the engineering activities. I had four initial goals for the main phase of this research: (1) to understand how first graders approach and complete an engineering activity when working in dyads, including both individual and social problem solving abilities; (2) to inform engineering curriculum design for early childhood; (3) to provide a tool to help researchers and teachers assess engineering learning in classroom; and (4) to suggest that the "engineering" mentality is even present in first grade and that there is a need for early introduction to engineering. While each of these starting goals was met with varying amounts of success, I feel that I have provided five contributions to the field of engineering education with young children:

(1) I have developed a new data-collection tool that allows a researcher to collect data in "real time" in a digital medium. This tool could be used by other researchers or, with modifications, by teachers who wish to assess their students' problem solving on engineering tasks. The data collected with this tool allowed for a unique method of looking at social collaboration in dyads, with both interactions graphs and task event networks.

(2) I have provided a classification system, based on the previous work of Granott (1993), using the dimensions of relative expertise and degree of collaboration for describing collaborative problem solving on engineering tasks in a first-grade classroom. This classification system describes four types of dyadic collaborations: mutual collaboration (equal expertise, high collaboration), asymmetric collaboration (unequal expertise, high collaboration), imitation/intimidation (unequal expertise, low collaboration), and parallel activity (equal expertise, low collaboration).

(3) I have analyzed the distribution of dyads in a first-grade classroom using the data collected and the classification system. Preliminary analysis suggests that gender alone does not affect a dyad's collaboration, but rather gender in combination with other factors, such as the "friendship status" of the pair and their general social problem solving abilities that influence the success of the dyad.

(4) I have provided suggestions for teachers when pairing students to work on engineering tasks, including considering the “friendship status” of the dyad, the gender composition of the dyad, and the relative social problem-solving abilities of the students relative to grade-level expectations.

(5) I have highlighted the need for additional research in the area of engineering education with young children, in particular females. This research was a just a first step toward a better understanding and as described in the previous section, there are many possibilities for continuation.

Personal Reflection

I wanted to end this thesis with a personal reflection on the journey that began two years ago. When I started as a masters student in the fall of 2004, I was given the challenge to understand how problem solving occurred in girls on engineering tasks using robotic LEGO materials. Because it was a new area of research, the vagueness of this task was both overwhelming—in the sense that there were so many possibilities that I could pursue that sometimes I felt that I did not know where to begin—and empowering, as I could chose a particular topic within this broader scope that was interesting to me. I began with my pilot study and after those four months of preliminary data collection, I felt even further from my goal than I had when I began. After talking with Marina and Chris, I decided to focus on only one age group, as the enormous developmental changes that occur between early elementary school and college made research difficult.

When I finally decided on a population and had a better sense of my goals at the end of the summer of 2005, I began my search for a methodology. I, to be quite honest, was dreading the idea of transcription from videotape, as much of the traditional research on problem solving has done. I had done it for my pilot research, and while I understand and respect the place for that type of methodology in research, I felt that it was going to be a large burden on me in the months following data collection. I had an idea to do "real-time" data collection in a digital medium in order to make the process of both collecting and analyzing the data much easier. A search on the Internet revealed tools that were close to what I wanted, but did not have all of the features I desired. Perhaps because of my engineering background and knowledge of programming, I knew that there had to "be a better way," and I enlisted the help of my husband, a database and software engineer. I explained to him exactly what I wanted my ideal data-collection software to do, and he was able to figure out the technical details behind it.

Armed with this new tool for data collection, I was able to collect my data in real-time and process it when I returned from the classroom. When it came time for analysis, all of the data were available to me in an easily accessible digital format. However, the analysis was not always easy—I often felt that I could keep looking at the data forever, continuing to find new angles to look at how the students I observed solved an engineering task and I knew from my research methods classes that "fishing" for results is never a good method. In my "darkest" hour, a few weeks behind my self-imposed schedule, I felt that I had dug myself into an "analysis" hole. Through discussions with my husband, Marina, and fellow graduate students, I finally found a "way out," and I am quite proud of my accomplishment.

There are a few lessons that I have learned about research along the way; some seemingly trivial and/or humorous but important to me, and some more general observations, but nonetheless I would like to share (in no particular order):

(1) Use a reference manager, such as Endnote or RefWorks. Creating a bibliography by hand is time consuming and it is easy to forget a reference or make a mistake. In addition, while most journals that I would publish to use APA style, there are some journals that require other output styles and a reference manager allows for easy switching between output styles.

(1a) Always immediately import citations from online databases during the literature review phase into reference managing software. Waiting until later and manually entering the information usually takes much more time and the resulting citations are not as rich with the information that comes with imported citations, such as abstracts and keywords.

(2) Young children like to move around a lot—using lapel microphones made understanding the students later on much easier (so when I had to transcribe, I did not have to rewind many times to try to figure out what they were saying). The microphone system that I used can actually be used on other digital audio recording devices (such as an Apple iPod), so that it could also be useful for older children and adults in situations when the environment is noisy and you need to focus in on one or two voices.

(3) Be grateful to those who have to listen to your research, both the during the highs and lows. Many, many times in this research I did not know what my next step would be and I just needed to bounce ideas off someone else. All of the grad students at the CEEO, my husband, Marina, Chris, and David Henry (and any one else who I made listen) were vital in helping me with this research. I would never have progressed so far without the input of those both more experienced than I and outside of my research.

(4) At the beginning, be specific about the research goals and questions to be answered. Otherwise, it is too easy to get lost in a wealth of information and never actually finish. Choose a topic that is manageable so that a solid methodology can be developed, a large sample can be recruited, and the results can be meaningful.

(5) Learn to use Microsoft Word or another document managing software to your benefit—using style sheets, numbered outlines, captioning, cross-references, and indexes can make completing the document easier in the end; it may seem like more work to setup the initial document, but worth the effort in the end.

As I near the end of this phase of the journey, I know that I have much more to learn about research methodology and research procedures. However, I am grateful for this experience and again, appreciate all those who contributed to my success.

Appendix A: Sample Field Notes Used in Pilot Study (Excepts from Amanda)

Three asterisks indicate a break in the field notes.

Participant: Amanda
Grade: First
Date: 04-27-2005

***

Amanda: Look at what I found! (She holds up a long yellow brick. She counts the number of studs on the brick—by twos—and finds it has twelve studs). Twelve. (She puts the 2 by 6 yellow brick perpendicular to her structure, in order to make one of the side walls. 00:14:27 She looks at it, and then looks into the bin of extra pieces, where she finds another long black brick. She places this brick on top of the yellow one she has already placed on the table next to her structure. She asks me to help her find some of the pieces.)

LB: How about this length one—is that what you are looking for? (I give her a gray 2 by 6 brick).

Amanda: Uh-huh.

LB: Ok. (She tries to add the new brick, but is struggling because the stack is getting higher, which makes it more "tipsy").

Amanda: Are there more?

LB: I don't know—I don't know how many I put in here. (We search through the bin of extra pieces together. 00:15:00 She finds a 2 by 4 black brick and tries to add it to her structure. In the bin I find much longer brick, which she likes better, and she adds that to her wall. She places her free-standing wall perpendicular to her other wall, and then takes the 2 by 4 black brick from before and uses it to connect her two walls.)

Appendix B: List of Codes Used in Pilot Study

CODE	CODE COMMENT/CORRESPONDING INTERVIEW QUESTION
PARTICIPANT BACKGROUND	**PB**
PB: Age	Age (birthday and year)
PB: Favorite Subject	Favorite subject in school
PB: Future Job	Thoughts of future occupation; what they want to be "when they grow up"
PB: Grade	Grade in school
PB: Least Favorite Subject	Least favorite subject
PB: Siblings	Number of siblings
KNOWLEDGE OF MATERIALS	**KW**
KW: General LEGOs	Knowledge of general LEGOs
KW: ROBOLAB	Knowledge of ROBOLAB software
KW: Robotic LEGOs	Knowledge of robotic LEGOs
GROUP WORK	**GW**
GW: Gender of People	Preferred gender of people to work with in a group and why
GW: Number of People	Preferred number of people to work with in a group and why
PROBLEM SOLVING CONCEPTIONS	**PSC**
PSC: Classes	Which classes do you think problem solving is taught in?
PSC: Definition	What do you think "problem solving" means?
PSC: Miscellaneous	Miscellaneous discussion about problem solving
PSC: Other Person	Do you think that two people will answer a problem in the same way?

PSC: Taught in School	Do you think problem solving is taught in school?

TASK STRATEGIES	**TS**
TS: Asks a question	She asks me a question
TS: Asks for help	She asks me for help
TS: Assembles	She assembles the pieces
TS: Comes up with an idea	She comes up with an idea (i.e. “I can use two small bricks instead of one large one.”)
TS: Comment to me	She says something to me about the project (i.e. “Look what I did!”)
TS: Draws	She draws a sketch of her project
TS: Gets help from me	I help her with her project
TS: I give her a piece	I give her a piece that she requests
TS: Looks at the available pieces	She looks at the pieces that are available, but does not take one right away
TS: Off Topic	She talks about something not related to the immediate task
TS: Pauses to look at project	She takes a moment to look at her project before continuing
TS: Program	She programs her project in ROBOLAB
TS: Searches for/takes a piece with intent	She searches for a piece knowing what she wants
TS: Searches for/takes a piece without intent	She searches for a piece but does not know what she wants
TS: Successful action	She tries a successful action (i.e. was able to put two pieces together after struggling)
TS: Takes & looks at a piece	She takes a piece out of the bin or kit, looks at it (almost studying it)
TS: Takes pieces off	She takes pieces she already added to her project off
TS: Talks to herself	She talks to herself (i.e. “Stack!” to the pieces)
TS: Tests	She tests a piece of her project
TS: Tries a piece unsuccessfully	Tries a piece on her project but it doesn't work (i.e. tries a piece, but it is the wrong one)
TS: Unsuccessful assembly	She tries an unsuccessful assembly (i.e. she tries to put on a piece but can't get it to attach)

POST-TASK QUESTIONS	PT
PT: Color	Was the color of the pieces important in what you built?
PT: Coming up with an Idea	Did you know when you started you wanted to make it look like this?
PT: Easiest Part	What was the easiest part of the task?
PT: Hardest Part	What was the hardest part of the project?
PT: Important Part	Which is more important--how it looks or how it works?
PT: Least Fun	What was the least fun part about the project?
PT: More time	What would you change about your project if you had more time?
PT: Most Fun	What was the most fun part about the project?
PT: Pieces	When searching for pieces, did you know what you were looking for or were you inspired by what you saw?
PT: Planning	Do you usually plan before projects?
PT: Project Change	Did your idea change as you built your project?
PT: Steps to Start Project	How did you start your project?

Appendix C: Sample Coding of Field Notes Used in Pilot Study

LB: And what was your favorite part about doing "Pucky's Dependable Pet Feeder"?

AM: Um, well I liked the part I got in cause and I have a dog, so that was nice for me cause I like dogs.

LB: Oh, that's good. Do remember, when you were making that project did you do anything on the computer? KW: ROBOLAB~

AM: UhhÉ

LB: Do you remember?

AM: Yes, but I didn't really. Jackie did because this is my first year at the school.

LB: Oh, ok, but you used the computer for your project? (she nods yes) So my next question is, what is your favorite thing to do in school? PB: Favorite Subject~

AM: Um, read.

LB: How come?

AM.: Well, at first I thought I couldn't read, and then after I tried it to, I realized that I love to read, so now I like reading now a lot.

LB: So, what is your least favorite thing to do in school?

AM: Umm, (pauses to think)É

LB: Anything? Or nothing?

PB: Least Favorite Subject~

AM: Not really. At the beginning of the year, songs, but now I love songs .

Appendix D: Sample of Across-Case Charts for Analysis Used in Pilot Study

	Preferred Number	Preferred Gender
Amanda 6 years	"Ummm, it depends on what it is." [why?] "Like, umm, when...the cars that we made, I kinda wanted to do it with like Jackie cause she knew a little more about it, so then I wanted to do it with someone who was instead in second grade not in first grade cause she is in second grade here." [ever by yourself?] "Um, sometimes." [why?] "Like... when...it is something like a...maybe a card....Yeah, like if it was a teamwork card, then I wouldn't be happy....Like making a poster with another person, then I would like to do that by myself."	"It doesn't matter." [why?] "Um, because...I don't know why...."I'd work with anybody."
Kaylee 10 years	"I don't like to work in a threesome or anything more than four."	"A girl....Most of the time" [why?] "Because I don't hang out with boys usually." [always a girl?] "No, 'cause I have some boy friends." [why?] "They do it all themselves and they don't really ask you anything.... and they are loud."
Dalia 12 years	"It depends. If it has multiple parts I like to work in groups so that different people can do different parts and combine it, but if it's one part than I like to work on by myself. I like my own ideas."	"Girls." [why?] "Because I am more comfortable with them....I don't know -- I'm just more used to them."
Chloe 12 years	"I usually prefer doing it individually." [why?] "'Cause then you can usually work a lot faster, like um, usually when you have a group you have to talk and sometimes there are disagreements and that slows you down."	"A girl." [why?] "It is easier to work with a girl rather than a boy because you probably know them better than a boy. And it is easier for you to communicate 'cause you are going through...it is just easier."

Lily 21 years	"And I guess now I would prefer to work by myself. Basically because I know at work needs to be done and when you work with a group you don't always know who is going to put in as much effort as you will."	"I would say mixed. It wouldn't matter in college—I think it's kind of whoever in the class you get along with best."

Appendix E: Sample Generalized Chart

(Based on the girls' responses to interview questions, as indicated in the chart in Appendix D)

Age of Girl	Prefer to Work with Girls when in a Group	Will Work with Boys or Girls when in a Group
Early Elementary		✓
Late Elementary	✓	
Middle School	✓	
College		✓

Appendix F: Sample Coding of Task to Create Event Flow Chart for Pilot Study

(only one page of many)

AM: How do you get these things out? (trying to grab the red 2x4 bricks from the top tray of the kit. I hold the tray in place for her so it doesn't move around, and she is able to grab a brick).

TS: Asks for help~

LB (00:08:12): I know, sometimes they are hard to grab. (Abigail grabs a "2 by 4" red brick from the top tray of the kit. She then sits back on a couch and looks into the extra pieces bin, but does not grab anything out of it. She then returns to the top tray the kit and grabs another red "2 by 4" brick. She places the two next to each other on the table, but does not connect them. She then grabs the top tray of the kit a yellow "2 by 2" brick. She connects it to one of the red bricks, but struggles trying to figure out how to attach the two, as it is difficult for her to manipulate the small pieces. Once she is successful in attacking a yellow "2 by 2" brick to the end of the "2 by 4" red brick. She then attaches that to the other red brick, and now she has the start of her structure. Because of the height of the table in relation to the height of the couch, Abigail has decided to kneel on the floor in front of the table in order to work. She holds up her structure to her mom, who's sitting outside the view of the camera. From the top tray of the kit she searches for another piece.) So what piece are you looking for now?

TS: Searches for/takes a piece with intent~
TS: Looks at the available pieces~
TS: Searches for/takes a piece with intent~
TS: Searches for/takes a piece with intent~
TS: Assembles~

AM: Well, I'm working on one side of the box so it will probably be that big maybe. (Gesturing on the table).

LB: Ok. (She grabs another "2 by 4" red brick from the top tray of the kit and lines it up with the other red bricks in her structure. She then grabs two "2 by 2" yellow bricks.

TS: Searches for/takes a piece with intent~

AM: I hope I have enough left.

TS: Comment to me~

LB: Well, we also have pieces in there, so we can always find something that would work for you. (She now tries to attach one of the yellow "2 by 2" bricks to the end of one red "2 by 4" bricks to the other end of a red "2 by 4" red brick. Like before, she struggles to get the pieces actually connected. She first tries to connect the pieces while holding them in the air in front of her, but she cannot seem to get them to connect. So she kneels on the floor in front of the table and places the red brick on the table, and tries to add the yellow brick on top of that. She has to look at the structure from the side, while holding the red bricks in one hand and the yellow brick and another. The red and yellow bricks connect it, so now she has structure that has three red "2 by 4" bricks on the bottom and two yellow "2 by 2" bricks connecting it. She adds another red brick connected to the structure with another yellow "2 by 2" brick. She is much more successful in connecting these pieces then she was previously.)

TS: Unsuccessul assembly~
TS: Assembles~
TS: Successful action~

AM (00:10:09): Ok, I've got it attached. (She ruffles through the bin of extra pieces, picking up the piece, looking at it, and throwing it back in the bin. She continues to ruffle through the bin, and asks me a question.) Are there any regular blocks in here, like not crazy shaped like this? (As she holds up a piece with rounded corners.)

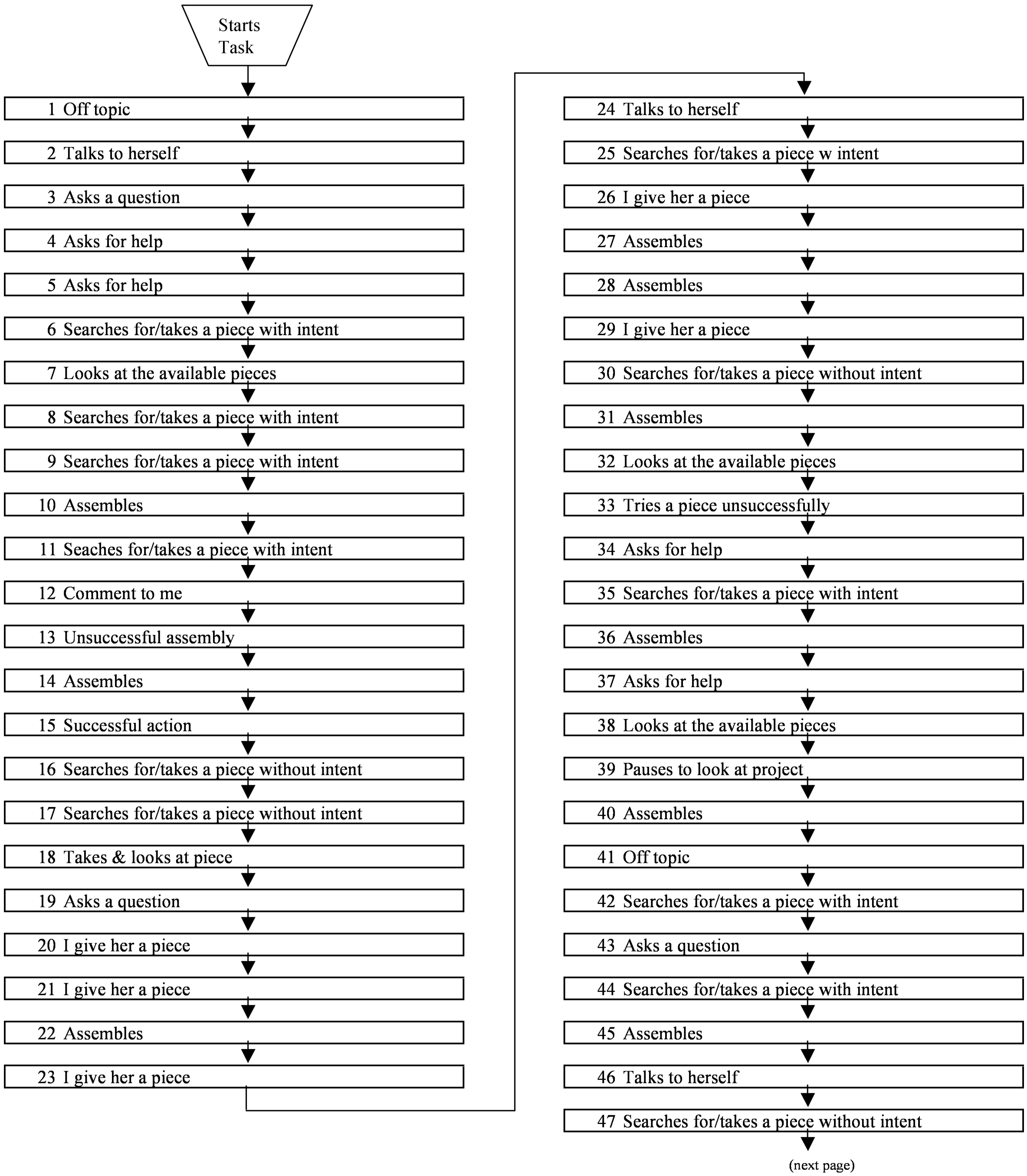
TS: Searches for/takes a piece without intent~
TS: Searches for/takes a piece without intent~ TS: Takes & looks at a piece~
TS: Asks a question~

LB: Can you explain a little more?

AM: Like any blocks like this. (She points to one of the red "2 by 4" bricks in her structure.)

Appendix G: Sample Event Flow Chart Used in Pilot Study

(This Task Event Network is a total of 6 pages long; only the first page is being shown)



Appendix H: Two-Page Sample of Report of Observation from the Data Collection Tool

Date: 2005-11-15

Time: 12:32:15

Teacher: Spear

Student 1: Lorin (94 months/7.83 years)

Student 2: Alice (78 months/6.5 years)

Notes About Classroom:

This is the third week of LEGO engineering, but the first week of my real coding. The last two weeks I spent "testing" my codes and observation techniques, and I hope that this week will work. I have modified my codes based on my past two weeks, and I think that this week will work well! Also, a little thing, but I am going to tape down the buttons on the kids' mics so that they don't turn off turning the session without me knowing.

Today they are going to be working on a "Chair for Mr. Bear." This is an activity that might not be finished today, and so it might go until next week.

Constraints:

(1) Keeps him from falling over and forward

(2) Keeps him from leaning to the side

(3) Can only use beams and bricks

Introduced them to:

(a) connector pegs in order to connect the beams as well as the differences between black and gray pegs.

(b) plates; 3 plates = 1 brick/beam

(c) bushings, axels, green 1x2 cross bricks (brainstorm their uses for legs, seat)

(4) Decorative pieces (sliders)

Discussed what they learned last week about sturdy walls: drop it for test, "covering the seams/cracks"; Mr. Bear's chair has to pass the same test (dropped from the knee)

Pieces of design process discussed:

Create: Chair for Mr. Bear

Test: Drop test (ankle, knee)

Redesign: (it will break!) look at where it broke, and fix it (new idea for how it is put together)

New steps (before other steps):

Brainstorm: "think really hard" "think till you get a lot [of ideas]"

Chose and plan: "choose an idea and plan how you are going to make it"

5 steps total today!

Talks about the planning sheet; partners have to touch the LEGOS and share ideas. Students have to show Merre or Ms. Spear before they get there box of LEGOS.

1	12:53:51	Alice	P31 Uses planning resource sheet
2	12:53:52	Lorin	P31 Uses planning resource sheet
3	12:54:27	Alice	I14 Pupil talks to him/herself
4	12:54:39	Lorin	I32 Direct guidance from teacher
5	12:55:08	Lorin	I14 Pupil talks to him/herself
6	12:55:31	Lorin	look at what each other are drawing
7	12:55:51	Alice	looks at what Lorin is drawing
8	12:57:08	Lorin	I21 Democratic interaction (work together)
9	12:59:15	Lorin	P42 A new idea is generated related to current project
10	12:59:18	Lorin	P33 Plans a piece of the project
11	12:59:53	Alice	obseves another group
12	13:01:03	Lorin	decide planning sheet is done
13	13:01:09	Alice	decide planning sheet is done
14	13:01:29	Lorin	I31 Indirect guidance from teacher
15	13:01:33	Alice	I31 Indirect guidance from teacher
16	13:01:36	Lorin	I32 Direct guidance from teacher
17	13:01:39	Alice	I32 Direct guidance from teacher
18	13:02:51	Lorin	P21 Finds resources (materials)
19	13:03:04	Lorin	I21 Democratic interaction (work together)
20	13:03:07	Alice	I21 Democratic interaction (work together)
21	13:03:34	Lorin	P35 Discusses a construction plan with partner
22	13:03:35	Alice	P35 Discusses a construction plan with partner
23	13:03:45	Lorin	P51 Model is constructed or idea put to practice
24	13:03:46	Alice	P51 Model is constructed or idea put to practice
25	13:04:09	Alice	P42 A new idea is generated related to current project
26	13:04:17	Lorin	P35 Discusses a construction plan with partner
27	13:04:22	Lorin	P33 Plans a piece of the project
28	13:04:27	Lorin	P21 Finds resources (materials)
29	13:04:28	Alice	P21 Finds resources (materials)
30	13:04:40	Lorin	I23 Domineering interaction (non-aggressive)
31	13:05:02	Lorin	tries to take pieces from Alice, Alice resists
32	13:05:31	Alice	P21 Finds resources (materials)
33	13:05:32	Lorin	P21 Finds resources (materials)
34	13:06:10	Lorin	P42 A new idea is generated related to current project
35	13:06:19	Lorin	P33 Plans a piece of the project

Appendix I: Engineer's Planning Sheet for First Graders

Engineer: ________

Engineer's Planning Sheet

Draw what you think you are going to make below:

What did you draw?

____

____

Appendix J: Engineer's Final Report for First Grade Students

Engineer: ________

Engineer's Final Report

What did you make?

____

____

Did you work well with your partner?

☺ 😐 ☹

Did you like this project?

☺ 😐 ☹

Appendix K: Teacher Survey

Student: ______________________

ID: ______________________

Please rate each child with respect to how they are performing at this particular point in the school year relative to grade level expectations.

1. How do you think this student is doing in reading?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

2. How do you think this student is doing in general in mathematics?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

3. How do you think this student is doing in terms of problem solving in mathematics?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

4. How do you think this student is doing in terms of social problem solving (i.e. working with others to solve problems)?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

5. How do you think this student is doing in terms of listening and following directions?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

6. How do you think this student is doing in terms of attention span?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

7. How would you rate this student‘s interest in school and learning?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

8. How did you think this student performed on the LEGO Engineering curriculum?

1	2	3	4	5
Significantly Below Grade-Level Expectations	Slightly Below Grade-Level Expectations	On Target with Grade-Level Expectations	Slightly Above Grade-Level Expectations	Significantly Above Grade-Level Expectations

9. Were you surprised at this student’s performance?

- ☐ No, the student performed as I would have expected.
- ☐ Yes, the student performed better than I expected.
- ☐ Yes, the student performed worse than I expected.

10. Compared to this student’s LEGO partner, ____________________, do you think that this student was:

- ☐ Significantly more skilled with the materials?
- ☐ Slightly more skilled with the materials?
- ☐ Equally skilled with the materials?
- ☐ Slightly less skilled with the materials?
- ☐ Significantly less skilled with the materials?

10. Which of the following sets of keywords do you think best describes the interaction between this student and his or her partner?

- ☐ *Imitation/Intimidation*: Worked on separate individual tasks for the activity (i.e. little sharing of goals/ideas); the less capable peer imitated the other; asymmetric flow of information (i.e. one student seemed to have all the information); more capable peer may have dominated the activities, intimidating the other peer into passiveness.
- ☐ *Mutual Collaboration:* highly collaborative interaction between peers that is reciprocal and symmetric; equal dominance during activities; engaged in a common goal; shared materials; talked together frequently about ideas and goals.
- ☐ *Asymmetric Collaboration:* Worked on a common activity with a sharing of the goals and materials; the more capable peer guided and helped the less capable peer; times of unequal dominance but still toward a common goal.

☐ *Parallel Activity:* interaction among peers of equal expertise but when engaged in activities worked mostly independently on separate simultaneous processes (may be brief periods of collaboration); when working on their own were absorbed in their own activity.

Comments (if you feel so obliged!):

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