Inservice Teachers’ Approaches to Open-Ended Engineering Design Problems and
the Engineering Design Process

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Engineering education is becoming increasingly popular in K-12 education. Massachusetts has recently adopted curriculum frameworks in technology and engineering, with a focus on the engineering design process. However, these new standards have created a need for professional development in this area, particularly among lower grade level teachers. The research presented in this thesis looks at twelve participants in a professional development workshop for teachers to learn about design projects using LEGO™ and ROBOLAB™ technology. The study aimed to answer the following questions for the Massachusetts inservice teachers, grades K-8, attending the workshop:

1. What kinds of concerns do these teachers have about engaging their students in open-ended engineering design projects?

2. What approaches do they take to solving open-ended engineering design problems presented during the professional development setting and how do they change with varied exposure to the model of the engineering design process provided by the Massachusetts Frameworks?

3. How do their self-reported confidence levels in their building, programming, and design skills change over the course of the workshop?

Participants were surveyed and videotaped during the workshop sessions. A video concept mapping technique was used to illustrate the design processes used by the participants. Three assertions were reached from the data gathered:
1. Administrative support, particularly in the form of professional development and classroom volunteers, is important for bringing engineering design problems to the classroom.

2. a) Teachers came from multiple perspectives entering the workshop, with some displaying a distinct preference for building or programming.

b) For some of the teachers, it was difficult to accept the open-ended nature of the design problems because they do not have unique solutions and there is no correct answer.

c) The teachers had a variety of natural design processes that were minimally affected with exposure to a model of the engineering design process. However, the teachers showed a greater comfort with generating multiple possible solutions after exposure to the design process model.

3. For these teachers, the workshop was a valuable experience that led to increased confidence in their use of the LEGO pieces and ROBOLAB tool set.
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Driven by its prestigious academic institutions, high-tech companies, and commitment to superior education, Massachusetts became the first state in the country to include engineering in its state K-12 curriculum frameworks in 2001. The engineering and technology standards put these subjects on par with physical or life science (Massachusetts Department of Education, 2001). While the inclusion of these subjects broadens the opportunities for students to gain technological literacy and may provide them with exposure to new and engaging learning experiences, it comes with many challenges. A shift needs to occur in the traditional classroom structure, and teachers need to be trained in the content and teaching methods required by engineering and technology.

These significant changes to the landscape of science education in Massachusetts have resulted in an increased need for professional development. The nature of engineering lends itself well to a classroom environment with open-ended design challenges serving as the primary activity for exploring the concepts and processes of engineering. In my work with educators from a variety of backgrounds, I have encountered a similar apprehension from many teachers when incorporating engineering design activities into their classrooms. Most teachers have had little exposure to the field of engineering. In addition to a lack of content knowledge, some teachers feel uneasy
with the multiple solution paths that their students will take during an open-ended design problem. For the teachers I worked with, their source of anxiety seems to lie in not knowing the right answer, or rather that there is no right answer. However, I found little research of teacher knowledge and comfort with engineering design to back up my notions. If these assumptions are correct, professional development may be able to address the concerns of these teachers by allowing them to engage in learning experiences similar to those their students will, as well as providing them with the content and technological knowledge necessary to be comfortable as a resource for their students. In order to develop teacher education experiences that will prove valuable to the teachers in their classrooms, we must know about how teachers engage when they themselves are the learners of engineering design and how to best affect change in their classrooms.

Motivation and Goals

In my work at Tufts University’s Center for Engineering Educational Outreach I was able to have conversations with many Massachusetts teachers and students about engineering and engineering design. I had been in classrooms during engineering lessons and worked with hundreds of teachers during professional development workshops. Despite teacher and student enthusiasm for having engineering design in the classroom, it was not often easy to implement. I noticed the difficulties some had in taking what they had learned during a workshop to the classroom, and many teachers had aired these concerns and frustrations about implementation during those workshops. I began to wonder what could be done to address the concerns and difficulties these teachers were having implementing engineering design activities in their classrooms. I aim in this study
to gain a better understanding of some of these teachers and their experience during a professional development workshop focused on engineering design.

Before I outline my research, it’s important to review the related literature. First I look at some of the national efforts advocating K-12 engineering education. Then I define engineering and the engineering design process for the purposes of this study. Next I discuss the study’s theoretical framework. Then I look at the challenges for changing the classroom to include engineering design including teacher’s preconceptions and content knowledge. Finally I discuss what is known about teachers and design before outlining my research questions.

Engineering Education

The Push for Engineering Education

Technologies from personal computers and cellular phones to oil refinement and water treatment processes now play an intricate role in our daily lives, yet how many of us understand how they work? In 1985, the American Association for the Advancement of Science (AAAS) began an effort to increase the mathematical, scientific, and technological literacy of all Americans with Project 2061 (AAAS, 2003). Technological literacy is an area of much discussion, but can be simply stated as a familiarity with the workings of technologies around us. With two noteworthy publications, Science for All Americans in 1989 and Benchmarks for Science Literacy in 1993, the AAAS has laid the groundwork for the American education system to move forward in this direction (AAAS, 1993). The International Technology Education Association (ITEA) has been working since 1994 on a similar project, Technology for All Americans. As a major part of this project, ITEA developed curriculum content standards for studying technology in
the K-12 classroom, which were published in 2000. Additionally, the ITEA developed standards for student assessment, professional development, and programs as a guide to help implement the content standards (ITEA, 2004a). Both the AAAS and the ITEA are focused on students gaining a deep understanding of the scientific content while also increasing the scientific and technological literacy of all students. Meaningful learning experiences, such as open-ended engineering design problems, are a vital component of the efforts of each organization. In fact, engineering design is one of the major threads listed among the ITEA K-12 technology standards (ITEA, 2004b).

Following the spirit of Project 2061 and Technology for All Americans, the Massachusetts adoption of technology/engineering standards in its state curriculum frameworks extends engineering education from pre-kindergarten through high school (Massachusetts, 2001). Massachusetts is not alone in exploring new curricular directions. Other states, including Texas and New York, have begun investigating similar frameworks, and other countries, including Great Britain, Australia, and New Zealand, have adopted engineering, design, and technology standards (Crismond, 2001; McRobbie, Stein, & Ginns, 2001). Across the country, and indeed around the world, many are looking towards engineering education in K-12 as a way to provide students with an engaging avenue towards technological literacy. Since the movement supporting engineering education is clear, it is important that engineering and engineering education are clearly defined.

What is Engineering Education?

What exactly is engineering education? Skeptics, including some teachers, question if engineering is in fact a unique subject area (Stein, McRobbie, & Ginns, 1999).
They posit that it is simply an extension of math and science curricula that are already included in traditional schooling. One could make the argument that engineering is simply a new means of presenting old information but in a more engaging way. Certainly, even in this case engineering would be a valuable tool for reaching students who are not motivated within the traditional classroom. However, engineering does contain unique elements that make it a subject worthy of study on its own. The important ideas of material selection, manufacturing, and trade-offs, central to engineering, are rarely addressed in traditional curricula. Additionally, engineering design as a process is a rich topic worthy of in-depth exploration.

Engineering is not just science, nor is the same as technology. Technology refers to products and processes that are often the result of engineering. Engineering is a field of study and practice that produces technology. In Science for All Americans, the American Association for the Advancement of Science (1989) describes technology as “extend[ing] our abilities to change the world” while engineering is “the systematic application of scientific knowledge in developing and applying technology” (p. 35). One engages in engineering, but uses technology.

Engineering differs from science in a number of ways. Science searches for answers to questions about our world including life, motion, and materials. Scientists engage in experiments and “search for relations among variables” (Schauble, Klopfer, & Raghavan, 1991, p.860). For scientists, there is one right answer existent in nature, though theories can only approximate the truth. Engineering problems, however, are defined by constraints that usually offer more than one solution, and a variety of ways to arrive at them. Engineers attempt to “optimize a desired outcome” through systematic
testing and design refinement (Schauble et al., 1991, p.860). Science explores all theories
and solutions until one can be concluded, for the time, to be the closest to the truth;
engineering explores multiple solutions until one is reached that provides an acceptable
result, only approximating truth (Schauble et al., 1991).

Content Areas for K-12 Engineering

Now that I have presented my definition of engineering, I will describe what this
includes for the K-12 classroom. For the purposes of this study, content areas for
technology and engineering for K-12 students have been defined by the Massachusetts
Curriculum Frameworks (Massachusetts Department of Education, 2001). It was
important to look at these content areas to understand what K-12 education could look
like in the classroom as well as gain insight into the teachers’ perspective of engineering
at their grade level. Today, technology is an important aspect of children’s lives even
before they enter school. Children’s toys, homes, and learning environments incorporate
many technologies that can be fascinating. It is important in the younger grades that
children learn to identify and safely use some everyday technological objects. This
familiarity with technology can lead them to identify the properties and uses of materials,
understand simple and complex machines, learn about the tools used to create, and begin
to identify needs that engineering can address. Design is emphasized in the frameworks
beginning at grade 3. As students grow older they learn about engineering systems, and
they can incorporate their science and mathematics knowledge to look at engineering in
the areas of manufacturing, transportation, energy, communication, and biotechnology.
Importance of K-12 Engineering Education

Why is engineering design important for an elementary classroom? For one, engineering and design can prove highly motivating particularly for students who struggle in a traditional setting (Resnick, 1991). It is important to develop these students’ interest in math and science early, before they lose confidence in themselves as learners of mathematics and science. This is especially crucial for girls who begin to show a particular drop in interest in middle school (Gallagher, 1994; James, 2002; Jones, Howe, & Rua, 2000). Design also helps develop students’ metacognitive abilities. When they are faced with making and explaining design decisions, they are compelled to think about why things work, why they made certain decisions, and how they think about problems (Papert, 1980). Moreover, the emphasis placed on design in the technology/engineering standards in the Massachusetts frameworks reflects the importance of the underlying elements of design – creativity and invention. Often lost behind facts and figures, creativity and invention fuel the development of knowledge, which is certainly something that should be fostered in our schools (Piaget, 1952).

The Engineering Design Process

The key element of the content and importance of engineering education is design. The engineering design process is a central component of the ITEA standards (ITEA, 2004b) as well as the technology/engineering standards in Massachusetts (Massachusetts Department of Education, 2001). It includes phases of idea generation, solution development, testing, evaluation, redesign, and communication. It involves “a kind of procedural knowledge” including both “‘knowing-how’ understanding of procedures… [and] ‘knowing-that’ understanding of the circumstances under which such
procedures should be applied” (Rowe, 1987, p. 112). The engineering design process has been modeled in a number of ways, each containing the key phases above. However, there is some argument about what the most accurate model of the design process would look like, and some argue that no model can describe the reality of design accurately (Stein, McRobbie, & Ginns, 2002; Welch, 1999).

So why do we use a model at all? In working with preservice teachers in Australia, Sarah Stein, Campbell McRobbie, and Ian Ginns (2002) found that these models may not be followed step-by-step in the design of an artifact, but they may “be viewed as sources of information that can provide general overviews of the types of activities that tend to occur during most design and problem solving activities” (p. 1). The preservice teachers found models useful for identifying opportunities to scaffold their students learning and for insight into ways the students’ work may be assessed (Stein et al., 2002). Perhaps, these models may also be useful in supporting teachers’ learning about engineering, but this area has not been explored in the research. For my purposes, however, the model developed in the Massachusetts Frameworks can serve as a useful referent for discussion.
Figure 1.1: The Engineering Design Process. From the Massachusetts Department of Education Curriculum Frameworks (2001), this is the model of the engineering design process used throughout the study.

The eight steps laid out here cover the process involved in creating a solution to an ‘open-ended engineering design problem’. There is a great variety among problems falling into the category of ‘open-end engineering design’, but they are all of a similar nature. ‘Open-ended’ problems have constraints that are “ill-defined” (Rowe, 1987, p. 40), meaning that they are designed to have multiple interpretations and thus multiple solutions. In fact, a significant part of problem solving in engineering “consists of problem definition and redefinition” (Rowe, 1987, p. 41). Struggling with an open-ended problem can lead to deep understanding. Now I turn to the educational theories that are the basis for my use of open-ended problems.

Theoretical Framework

Constructionism

When engaging in a design problem, students are learning by doing, an educational approach with its roots in the theory of Jean Piaget. Piaget claimed that knowledge is not transmitted to children, but is constructed in the children’s minds, a
theory that is known as constructivism (Siegler, 1986). Piaget acknowledged that knowledge is not only constructed in isolation in the mind, however. Students are constantly interacting with their teachers, families, peers, materials and surrounding environment. The importance of these social learning experiences was also the basis of work from an important educational theorist, Lev Vygotsky (Vygotsky, 1978). Vygotsky theorized that students could learn more through peer or teacher-learner interactions than they could on their own. His Zone of Proximal Development describes the potential for learning a student has, and it is expanded through social interactions. This is especially applicable in engineering design, which is inherently social. The interactions between students, teachers, materials, and the environment that hold such importance for both Piaget and Vygotsky are vital to success in an open-ended engineering design problem.

The use of design problems in the classroom also has its roots in constructionism. Developed by Seymour Papert of the Massachusetts Institute of Technology’s Media Lab, constructionism is based in the Piagetian constructivist tradition while incorporating social aspects of learning considered important by Vygotsky (Kafai & Resnick, 1996; Papert, 1980). It asserts that knowledge is not just constructed through interaction, but it is constructed best when one is engaged in building some sort of external artifact, be it a robot, a theory, or a story. Constructionism, following from Piaget’s views of motivation, places an emphasis on affect (Papert, 1980), arguing that “learners are most likely to become intellectually engaged when they are working on personally meaningful activities and projects” (Kafai & Resnick, 1996, p. 2). Constructionism also places importance on diversity, connections with multiple points of view, and encouraging “multiple learning styles and representations on knowledge” (Kafai & Resnick, 1996, p. 3). Students are
encouraged to continually reflect on their learning experiences and find ways to share their projects. This builds a deep, fundamental understanding within the learner. Incorporating this framework into professional development is one aim of the workshop explored in this research.

Changing the Classroom to Include Engineering Design

Though the benefits of engineering design in the classroom have been theorized and championed, actually including design in the everyday classroom provides many challenges that teachers, administrators, and those involved with professional development must address. For professional development to be effective, it must address the teachers’ concerns and help them to become comfortable implementing engineering design activities in the classroom. Professional development in engineering needs to enhance teachers’ content knowledge, discuss conceptions of engineering (held by students and adults alike), delve into constructivist theory and the constructionist framework and consider their impacts on pedagogy. Ultimately, the goal of any teacher education program is to create a classroom change to improve the learning environment for the students.

Challenges for Classroom Change

Teachers often hold practical concerns about implementing engineering design activities. They wonder where they will fit it in an already overburdened curriculum (Stein et al., 1999), though in Massachusetts this content has become required by the state standards. Teachers are concerned with how to plan these activities and how to best structure their classroom when engaging students in this type of problem (Stein et al., 1999). They require support from the administration to both implement these activities
and receive training (Ogle & Byers, 2000). Additionally, if teachers feel that they are the “sole disseminator of knowledge” in the classroom, tied to their theory of learning, they may not feel comfortable using open-ended projects (Ogle & Byers, 2000, p. 5). Ball addresses this problem, calling it “the natural internal instinct of teachers everywhere to believe that we are making a difference, and to think that we are ‘right’” (Ball, 2002, p. 4). Finally, teachers wonder what the students are learning from such projects, especially if they do not hold constructivist theories of learning (Stein et al., 1999). Though this same question about what students are learning has been posed about traditional teaching methods that are often focused on fact and procedure memorization (Shaw & Etchberger, 1993). However, teacher education and professional development programs can influence both these concerns about the content of engineering (McRobbie, Ginns, & Stein, 2000; Stein et al., 1999) and theories of learning and teaching (Peterman, 1993).

Educational Background and Preconceptions

Engineering. Like their students, teachers enter the classroom with preconceptions about teaching, learning, engineering, design, and technology that affect the way in which they can or will engage in an engineering design project (McRobbie et al., 2000). Few teachers, especially in the lower grades, have had advanced training in math or science, and even fewer have had a great exposure to engineering. According to the National Center for Education Statistics (NCES), over half (58 percent) of elementary level teachers hold a degree in general education, which generally demand fewer content courses (Lewis et al., 1999). For example, pre-kindergarten through 6th grade pre-service teachers have minimal math and science requirements and no required coursework in design, engineering and technology (Bers, Ponte, Juelich, Viera, & Schenker, 2002).
Elementary teachers generally have only a superficial knowledge of the related subject matter of technology (McRobbie et al., 2000) and do not possess much knowledge of engineering (Robinson & Maddux, 1999). It is of little surprise then that they do not value engineering education and wonder what their students learn from engaging in design activities (Stein et al., 1999). In fact, teachers in Britain who follow a design and technology curriculum, which covers concepts similar to engineering design, see these activities as more vocational and less about developing problem solving skills (Mittell & Penny, 1997). However, it has been shown that by engaging teachers in these activities in a professional development environment, as they would engage their students, and providing them with opportunities for reflection, all these concerns can be lessened (McRobbie et al., 2001; Robinson & Maddux, 1999).

A lack of experience with and educational background in engineering seems to impact the preconceptions teachers hold about engineering, design, and technology. McRobbie, Stein, and Ginns (2000) found that though some preservice teachers realized there is a process involved in creating technology, they had naïve perceptions about the engineering design process. They held vague notions of experimental procedures and research, but they made only very narrow connections between the process and the production of technology. However, by engaging the preservice teachers in an authentic design project, it was found that these preconceptions evolved into more complex understandings of design. Many of the preservice teachers believed that after their experience in this training exercise they had the confidence to engage their own students in meaningful design projects (McRobbie et al., 2000).
Teaching and Learning. A teacher’s conception of learning directly impacts the learning environment within that teacher’s classroom. Kenneth Tobin (1993) cautions that before we can understand how professional development can change teaching practices, we must first understand this culture of teaching and learning. To do this we must reflect upon teachers’ own images of teaching and learning. Shifting to a constructivist learning style can be difficult because teachers are often “guided by an image of past experience” that is not constructivist in nature (Tobin, 1993, p. 218).

Paradigm shifts, like that required to be successful with implementing engineering design activities, can often make teachers uncomfortable because what they are to teach is not reflected within their own educational experience (Anderson & Roth, 1989; Ball, 1996). When teachers have to venture into new and unfamiliar territory, extra work, additional commitment, and flexibility within the new environment are required from them (Anderson & Roth, 1989; Montes & Rockley, 2002; Wilson & Chalmers-Neubauer, 1990). For these reasons, and often a lack of administrative support, teachers often prefer traditional methods (Montes & Rockley, 2002). The teachers who do venture into this new realm must have both strong pedagogical and content knowledge to remain comfortable in their classrooms (Tobin & Fraser, 1990). These challenges, however, can be overcome with support and professional development so that the rewards, evident in the students’ learning, can be achieved.

In her work studying teachers and mathematics reform, Deborah Ball (1996) provides many useful insights into the nature of what teachers bring with them to the classroom that can be applied to engineering as well. Teachers have developed conceptions of the “teacher’s role, about who can learn mathematics, and about what it
takes to learn and know mathematics” (Ball, 1996, p. 504). In this way, teachers’ past experiences “can often act as obstacles” to changing the nature of the classroom and student learning (Ball, 1996, p. 504). Teachers may encounter problems engaging their students in engineering design because of their theories about learning. Because of their past experiences in schools and their view of how students learn, teachers may be reluctant to accept the constructionist structure of design activities. They may see themselves as “the sole disseminator of knowledge” in the classroom (Ogle & Byers, 2000, p. 5). This has been shown to influence teachers’ use of computers (Ogle & Byers, 2000) and likely influences implementation of engineering activities.

*Content Knowledge*

As mentioned above, engaging students in design activities provides even further challenges for teachers than the traditional classroom because few teachers, especially at the elementary level, have had prior exposure to engineering or the constructionist framework inherent in pedagogy of design activities (Loucks-Horsely, Hewson, Love, & Stiles, 1998). While little research has been conducted in this field, we can draw from the knowledge base of math and science reform movements, and the growing literature about technology. Raizen and Michelsohn (1994) note the lack of preparation in science among elementary teachers. Not only are they uncomfortable with the science content, but they have commonly not been exposed to newer methods of inquiry-based instruction that are popular among reformers and groups like the AAAS (Raizen & Michelsohn, 1994). In mathematics, Liping Ma (1999) has shown the relatively shallow nature of a group of teachers’ understanding of even basic arithmetic. She contrasts that group of American teachers with Chinese teachers who show a deep conceptual knowledge by fluidly
switching from one arithmetic process to another (Ma, 1999). Teachers have a sense of their effectiveness as a teacher, but lack of content knowledge can make a teacher feel “inadequate and ashamed” (Ball, 1996, p. 504). Engineering content knowledge is an even greater challenge since it is a new subject to which teachers have likely not been exposed, as opposed to math and science where they have at least had K-12 instruction.

Effective science teachers have been described as possessing not only content knowledge, but knowledge of students’ likely preconceptions and insight into student learning (Raizen & Michelsohn, 1994). This may be difficult for teachers who have never seen engineering in the classroom, further adding to the need for teachers to undertake an engineering design project themselves. Also, there is little known about students’ preconceptions in technology and engineering. However, efforts should also be made during professional development to inform teachers about research related to students’ conceptions of engineering and the student design process as it becomes available.

**Engineering and Professional Development**

Continually, Deborah Ball has challenged teacher educators in mathematics to rethink what they ‘know’ about teacher learning (Ball, 1996, 2002). One of her most interesting discussions is about the practice of ‘modeling’ pedagogical techniques and curriculum to teachers as they would teach their students (Ball, 2002). The basic idea is that teachers should have the same educational experiences as their students so that they can relate to students better and use the pedagogy more effectively. This idea is commonly held by teacher educators (Ball, 2002), and has been put forth by very prominent figures in educational research (for example Duckworth, 1972). While there is certainly some good reasoning behind this, Ball asserts that “the simple adage that
teachers should be taught as they would teach students, is likely too simple” (Ball, 2002, p. 8-9). Challenging the knowledge of students is “a different pedagogical undertaking” entirely from challenging the knowledge of adults (Ball, 2002, p. 8).

Teachers come to a learning environment with conceptions that are different from that of their students. They have a differing body of knowledge and are at a different developmental level than the students they are teaching, especially in the lower grades. Thus, they are at a different departure point for learning new material. The scaffolding the teacher needs is possibly much different than the scaffolding a third-grader needs in order for each of them to learn the same skill. Preservice teachers have found that models of the design process are helpful for planning design tasks and methods of assessment (Stein, McRobbie, & Ginns, 2001). These models may also prove to be useful methods of scaffolding teachers during open-ended engineering design challenges in a professional development environment, an idea which should be explored through research. Young children are natural engineers, possessing an innate curiosity (Kearns, Rogers, Barsosky, Portsmore, & Rogers, 2001) without many of the preconceptions held by adults. If experience and time have caused adult teachers to gain some negative conceptions of engineering, it is quite possible that the way teachers will most effectively learn about engineering is quite different from the methods that have proved successful with students.

Tobin (1993) proposes that teachers become “reflective practioner[s]” who reflect on their images of practice (p. 219). He posits this as a key aspect of professional development for changing pedagogical methods. Francine Peterman (1993) has shown that such reflection on beliefs, as well as open conversation on these beliefs, can lead to a shift in images of teaching and an adoption of constructivist teaching methods. Shaw and
Etchberger (1993) echo this focus by listing reflection as one of the key components of shifting among concepts of teaching and learning (Shaw & Etchberger, 1993). However, Tom Russell (1993), like Ball (1996, 2002), calls for teacher educators to also be reflective on their process. He also poses the need for teacher education to include and emphasize “learning from experience” (Russell, 1993, p. 256). Professional development in engineering design should clearly include both hands-on design experience for teachers and reflection on pedagogical methods. Teacher educators in engineering should therefore be curious about the inservice teachers’ process of design and how this may differ from the students’ design processes.

**Teachers and Design**

Though there has been much research done about students engaging in open-ended engineering design problems (for example, McRobbie, Norton, & Ginns, 2003; Roden, 1999; Roth, 1995, 1997) and some research about preservice teachers (McRobbie et al., 2000; McRobbie et al., 2001), there seems to be no research about inservice teachers in this area. Campbell McRobbie, Sarah Stein, and Ian Ginns’ (2000, 2001) research with preservice teachers provides the most useful insights for the research I am reporting here. Preservice teachers defined their tasks and stuck with their general plan throughout the activity (McRobbie et al., 2001). This is in contrast to younger students that other research has shown do not adhere to a single plan (Roden, 1999; Welch, 1999). Additionally, the preservice teachers used systematic testing procedures to optimize their solutions (McRobbie et al., 2001), while younger students have a harder time making the transition away from trial and error (Welch, 1999). These differences in tacit strategies may prove to be important for teachers to understand when engaging their students in
design challenges. Furthermore, there may be differences between preservice and inservice teachers that are not yet known because of the lack of research dealing with inservice teachers and engineering design.

Call for Further Research

As engineering continues to be included in more K-12 classrooms, it is clear that professional development in this area will increasingly be needed. This is especially true when considering the how little training and experience K-12 teachers have in engineering. What should teacher education look like in this area? Undoubtedly reflection and hands-on experience should be key elements of any professional development program in this field. However, the relative lack of research in the area of engineering education in the K-12 classroom pose a challenge for the development of teacher education strategies in this field. While knowledge can be gained from the related fields of math, science, and technology education, engineering design is a unique content area that needs to be addressed in future research. For teacher education, a specific need is obvious; the design process of inservice teachers and their reflection on this process needs to be studied. With this knowledge teacher educators can continue to refine their programs to create more effective professional development and ultimately improve learning in the K-12 classroom.

Research Questions

Previous research in this area has shown that perceptions about engineering and technology can change positively after preservice teachers take on their own design projects (McRobbie, Ginns, & Stein, 2000). Little, however, is known about the design processes that teachers use in such projects. Knowing more about these processes, as well
as effective methods of supporting teachers during their learning process in design, will help to inform teacher education efforts. With this in mind, the questions I wish to address in this study are:

For the Massachusetts inservice teachers, grades K- 8, attending the Creative Design Projects Workshop:

1. What kinds of concerns do these teachers have about engaging their students in open-ended engineering design projects?

2. What approaches do they take to solving open-ended engineering design problems presented during the professional development setting and how do they change with varied exposure to the model of the engineering design process provided by the Massachusetts Frameworks (Massachusetts Department of Education, 2001)?

3. How do their self-reported confidence levels in their building, programming, and design skills change over the course of the workshop?

In this section I have defined the engineering design process, discussed engineering education, and presented the relevant previous research. I then identified the gap in the research in the area of professional development in engineering design. This has provided a context for my to present my research questions. In the following chapter I will outline the methods used in the study to explore these questions.
In the previous chapter I looked at previous research, theory, and policy related to engineering education, the design process, and professional development. I outlined my research questions focusing on the nature of the design process of Massachusetts inservice K-8 teachers during a professional development workshop. In the following chapter I describe the workshop I conducted and studied as well as the teachers who participated. Additionally, I present my research design and data collection and analysis methods. I conclude this section with a discussion of the validity concerns and limitations of this study.

The Workshops

My research focuses on professional development workshops conducted during February 2004. The workshops, entitled *Creative Design Projects*, were offered as a professional development opportunity by the Center for Engineering Educational Outreach (CEEO) at Tufts University. The workshops were advertised for teachers who wanted to introduce engineering through creative classroom projects. The workshops aimed to give teachers beginning skills building and programming with the LEGO Mindstorms Construction Kits and ROBOLAB software. Below I discuss the logistics, the curriculum, and the goals of the workshop, as well as the educational tools of the workshop—LEGO Mindstorms and ROBOLAB.

*Location and Structure*

The workshops were held at Tufts University’s Center for Engineering Educational Outreach (CEEO). The CEEO provides many resources for educators in
engineering education such as web resources and training sessions. The *Creative Design Projects* workshops were one of several professional development opportunities offered in 2004. They were advertised through fliers to upper elementary Massachusetts public school teachers, but they attracted a wider range of respondents (as discussed later in this chapter). Each participant received ten Professional Development Points (PDPs) to participate in the workshop, and the workshops were given at no cost to participants.

The workshop met for three sessions with each session lasting three hours. Each session was focused around a main LEGO design challenge, which will be discussed in the next section. The sessions began with a brief lecture describing the building and programming concepts that would be useful for that day’s challenge. Then the challenge was introduced and discussed by the group. When the group felt comfortable with the day’s objectives, the participants would either work in pairs or individually to begin their design. A timeline for a typical session is shown in Table 2.1.

<table>
<thead>
<tr>
<th>Lecture, Introduction of challenge, discussion. (Approx. 30 min)</th>
<th>Design, Building and Programming (Approx. 2 hours)</th>
<th>Design Circle (Approx. 15 min)</th>
</tr>
</thead>
</table>

Table 2.1: Timeline for a typical workshop session

The participants were given full control over the design and how they wished to make their projects. They had access to LEGO Mindstorm Construction kits, extra LEGO bricks, computers, the Internet, and were encouraged to ask questions to their peers or to me, the instructor. At the end of each session there was a design circle where the participants presented and discussed their designs.
The Creative Design Project workshops were structured around three main design challenges aimed to develop both LEGO building and ROBOLAB programming skills. Each challenge was created as an open-ended task with a small number of constraints that required the participants to do certain building and programming tasks. In the first session, the participants were asked to create a “music box.” It had to have at least two moving parts and play music. This challenge was selected because the skills necessary to complete a “music box” were covered during the initial session, and the “music box” theme provided participants with a general direction without requiring a specific end product. In the second session, the participants were asked to create a robotic animal. The robot had to look like an animal and incorporate some behavior common to the animal (a green “turtle” robot that is very slow, for example). This challenge builds on the skills the teachers had developed during the initial session and incorporates knowledge gained during the second session. Again, the robotic animal theme was broad enough to allow the participants to design a project in which they were interested. The third session’s challenge was called “interactive kinetic sculpture,” but was really left open so participants could build whatever they chose. The only requirements were that it had to move and it had to incorporate a sensor. This final challenge allowed the teachers the most creativity and freedom of any of the challenges. Thus the teachers were able to choose any direction of interest for the project.

Because the study was focused around the three-session workshops, I was able to create a pre-assessment, intervention, and post-assessment design for my research, which will be discussed later in this chapter. Each session was designed to look at certain
aspects of the teachers’ design processes. During the initial session, I was interested in gathering information about what the teachers brought with them to professional development experiences—what were their conceptions about engineering and design, and importantly, what were their conceptions about themselves as learners of these topics. With the design challenge in the first session, I was interested in the teachers’ natural design process—without any training or discussion about design, how did the teachers work from idea to prototype? In the second and third sessions, I was interested to see what changed with experience and with our discussions about design. Would their attitudes or concerns about engineering change? Would discussion about design change the teachers’ design process? I hope to explore these issues to gain a better understanding of the teachers engaged in this and similar professional development workshops.

**LEGO bricks and ROBOLAB**

In order to engage the workshop participants in an engineering design challenge, I needed to choose a set of materials that would allow them to design and prototype fairly complex creations relatively easily and at low cost. I also wanted to choose materials that could be used in the teachers’ classrooms, so they had to be sturdy, child-friendly, and widely available. Additionally, it was important for me to choose a set of materials I was familiar enough with to lead the professional development workshops. For all of these reasons I choose the LEGO Mindstorm Construction kits and ROBOLAB software.

LEGO Mindstorm Construction kits contain all the familiar plastic pieces as well as engineering components such as gears, pulleys, wheels, and axles. They also contain motors and sensors that can be controlled by a large LEGO brick containing a microprocessor, the RCX. The RCX has three outputs, three inputs, an LCD display, and
an infrared transmitter for communication with computers and other RCX bricks.

Including the RCX among the workshop materials allows teachers to create robots they can program and interact with.

![Figure 2.1: The LEGO RCX.](image)

The LEGO RCX is a LEGO brick with an embedded microprocessor. The RCX is the major tool used to create robotic design during the workshop.

The RCX can be programmed from a computer using the ROBOLAB software. ROBOLAB is a graphic based programming language created as a partnership between the LEGO Company’s Education Division (formerly LEGO Dacta), National Instruments (NI), and Tufts University. Powered by NI’s LabVIEW software, ROBOLAB was written at Tufts as an educational software for programmable robotics and data acquisition applications. ROBOLAB is commercially available and is used in over 30,000 schools worldwide. The ROBOLAB software has won multiple awards for its innovation, capabilities, and overall design (LEGO, 2004). It is simple enough for students in lower elementary to use, broad enough to cover a variety of projects, and contains enough higher-end components to be used at the university level (Portsmore, 1999). Though the educational research to study the particular impacts of these materials is only beginning, teachers have reported observations of the positive effects of using ROBOLAB and the LEGO Mindstorms construction kits in their classrooms (Cejka, Rogers, & Portsmore, in press; Kearns, Rogers, Barsosky, Portsmore, & Rogers, 2001). These tools were ideal for this research because of their similarity to real engineering
materials while still allowing for quick and easy design changes. Although it was not a requirement, all of the teachers who participated in the workshop had access to this technology at their schools.

Study Design

The study is focused on two aspects: how the participants approached design challenges, and how these approaches changed through different workshop interventions. For the purpose of the study, three groups participated in the workshop. As teachers applied to the workshop, they were randomly placed in one of the three groups. Each group received a varied amount of exposure to the engineering design process:

- **No Design** group: 4 teachers. Did not receive any exposure to the design process during the course of the workshop, stayed for additional discussion after conclusion of the study.

- **Design Exposure** group: 3 teachers. Informed about the design process, but did not discuss it, stayed for additional discussion after conclusion of the study.

- **Design Discussion** group: 5 teachers. Held a lengthy discussion about the design process and was given design worksheets to examine and use if they chose.

Each group was given the same challenges during the workshop sessions. However, each group received varied instruction during the second session. The first and third sessions included the same material for each group (see Table 2.2). The groups originally contained four participants each, but scheduling difficulties caused one teacher to switch from the Design Exposure to the Design Discussion group just before the study began.

The No Design group was the control group. This group was not exposed to any instruction regarding the engineering design process. This group’s work will help to show
the effect of experience in using and developing a natural design process. The *Design Exposure* and *Design Discussion* groups received no instruction about the design process during the initial and final sessions. The *Design Exposure* group received exposure to the design process in the second session, through a handout with an illustration and a description of its steps. They were not instructed to use it, nor were they discouraged against its use. The *Design Discussion* group received the most intense exposure to the design process. They received both the instruction given to the *Design Exposure* group, and materials to scaffold them through each step. They were encouraged to use and think about the design process throughout the second session (see Table 2.2).
<table>
<thead>
<tr>
<th>Group:</th>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 3</th>
</tr>
</thead>
</table>

Table 2.2: Outline of activities for each workshop session by group.
This method is a multi-group pretest-posttest design of the form:

\[
O_1 \times_1 O_2 O_3 \quad (No \ Design)
\]

\[
O_1 \times_2 O_2 O_3 \quad (Design \ Exposure)
\]

\[
O_1 \times_3 O_2 O_3 \quad (Design \ Discussion)
\]

where \(O_n\) represents an observation and \(X_n\) represents an intervention (Spector, 1981). In this case, \(O_1\) refers to the observation of the first workshop session, \(O_2\) the second, and \(O_3\) the third. Each \(X_n\) represents the amount of exposure the groups receive towards the design process, which occurs prior to beginning of the design challenge in the second session. The aim is to explore each group’s natural approach to design problems as well as investigate their reaction to an intervention (the engineering design process) and how information from that intervention impacted their final projects. The data collected during each observation will be discussed in a later section (see Table 2.4).

The study was conceived with the hypothesis that increased exposure to the engineering design process would lead to an increase in self-reported comfort levels with design among the teachers. This hypothesis was based on findings that preservice teachers found a model of the design process to be useful in thinking about assessment and scaffolding for students (Stein, McRobbie, and Ginns, 2002). As the hypothesis suggested that the Design Discussion group would be receiving a higher benefit from the intervention and the workshops than the other groups, this raised an ethical issue of treating each group fairly. To address this, at the conclusion of the study all of the workshop participants were provided with all the materials given to the Design Discussion group. Additionally, the members of the No Design and Design Exposure groups were offered a chance to stay after the conclusion of the final workshop session to
have a discussion of the design process, as the members of the Design Discussion had
done during session two. Each member of the No Design and Design Exposure groups
stayed for the discussion.

Study Sample

The study’s sample was comprised of twelve teachers from Massachusetts
schools—seven from public schools, and five from private. The teachers taught in grades
from kindergarten to eighth. There were eleven females and one male. The teachers
included math and science specialists alongside general education teachers. Both upper
elementary and early middle school teachers were represented (see table 2.3). In this way,
a range of expertise was brought to the workshops, and there were multiple perspectives
to be offered in each session. The teachers all came from schools that had LEGO
materials available, so each teacher could potentially use the technology they were
exploring in their classrooms. Tufts University’s involvement in the development of the
ROBOLAB software has resulted in a large number of nearby schools using the
technology, which likely the explanation of this occurrence.

An advertisement for the Creative Design Projects workshop was sent to schools
close to the Tufts University campus. The teachers who were interested replied to the
advertisement and filled out an application. They were randomly placed in groups on
Tuesday, Wednesday, or Thursday nights. Each group met once per week over the course
of three weeks. These groups were used as treatment groups for the study. Information
about the participants is summarized in Table 2.3.
<table>
<thead>
<tr>
<th>Participant</th>
<th>Group</th>
<th>Grade Level</th>
<th>Public/Private</th>
<th>Subject(s) Taught</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary</td>
<td>No Design</td>
<td>6-8</td>
<td>Public</td>
<td>Computers, Technology</td>
</tr>
<tr>
<td>Kim</td>
<td>No Design</td>
<td>3-6</td>
<td>Private</td>
<td>Math, Science</td>
</tr>
<tr>
<td>Beth</td>
<td>No Design</td>
<td>K-6</td>
<td>Private</td>
<td>Math, Science, Computers</td>
</tr>
<tr>
<td>Sara</td>
<td>No Design</td>
<td>K-8</td>
<td>Private</td>
<td>Technology</td>
</tr>
<tr>
<td>John</td>
<td>Design Exposure</td>
<td>6-8</td>
<td>Public</td>
<td>Math, Technology</td>
</tr>
<tr>
<td>Amy</td>
<td>Design Exposure</td>
<td>2-3</td>
<td>Private</td>
<td>Science</td>
</tr>
<tr>
<td>Linda</td>
<td>Design Exposure</td>
<td>K-6</td>
<td>Private</td>
<td>Science</td>
</tr>
<tr>
<td>Jill</td>
<td>Design Discussion</td>
<td>2-4</td>
<td>Public</td>
<td>General classroom</td>
</tr>
<tr>
<td>Andrea</td>
<td>Design Discussion</td>
<td>3-5</td>
<td>Public</td>
<td>Language Arts</td>
</tr>
<tr>
<td>Jess</td>
<td>Design Discussion</td>
<td>3</td>
<td>Public</td>
<td>General classroom</td>
</tr>
<tr>
<td>Sue</td>
<td>Design Discussion</td>
<td>K-5</td>
<td>Public</td>
<td>Technology</td>
</tr>
<tr>
<td>Jackie</td>
<td>Design Discussion</td>
<td>3</td>
<td>Public</td>
<td>General classroom</td>
</tr>
</tbody>
</table>

Table 2.3: Summary of Participant Data

While the number of participants is small, this study was conceived as an exploratory study to inform larger scale investigations of professional development in engineering design. The sample in this study is obviously too small to draw largely generalizable conclusions, however it includes every participant in the workshop so I am able to draw conclusions regarding this specific workshop and group of educators.

**Data Collection**

Data was collected in the form of videotaped sessions, field notes, pre- and post-surveys, group discussions, personal notes of the participants, and photographs of the artifacts produced. From the videotapes of each session, the design process of the participants will be examined. Quality of the solutions was assessed by both participants and the instructor. Of particular interest is the usage of the design process during session two and three by the Design Exposure group, and during session three by the Design Discussion group. Table 2.4 shows when each data collection method was used.
Surveys

The participants were given surveys at the beginning of each session, as well as at the end of the final session. They were composed of a combination of checkbox and open-ended questions. The first survey aimed to collect baseline data and information to describe the participants. It also included open-ended questions that focused on the teachers’ attitudes towards professional development using technology. The results of the initial survey are presented in Chapter Three. The second and third surveys were only checkbox questions used to track the progress of the teachers through the course of the workshop and explore their attitudes regarding engineering. The final survey included similar check box questions and an open-ended section designed to elicit the teachers’ overall impressions of the workshop. The surveys can be found in Appendix A.

Videotapes

All of the design challenges were videotaped. There was a single camera in the workshop and the participants did not wear individual microphones, leading to some data analysis problems discussed in the validity section. The videotapes were used to capture the design process of the participants. Videotapes were chosen over audio recording because of the nature of the design challenges. The video captures images of each stage of the design as well as the physical gestures of and piece manipulation by the participants. The videos were transcribed in part. Conversations that did not pertain to

Table 2.4: Timeline for data collection

<table>
<thead>
<tr>
<th>Session</th>
<th>Before Design Session</th>
<th>During Design Session</th>
<th>After Design Session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1</td>
<td>Survey 1</td>
<td>Video</td>
<td></td>
</tr>
<tr>
<td>Session 2</td>
<td>Survey 2</td>
<td>Video</td>
<td></td>
</tr>
<tr>
<td>Session 3</td>
<td>Survey 3</td>
<td>Video</td>
<td>Survey 4</td>
</tr>
</tbody>
</table>
LEGO bricks, teaching, students, design, or engineering were omitted from the transcripts, though any discernable work on the design that occurred during those conversations was recorded.

Artifacts and Notes

In addition to the videotapes, I recorded field notes during each workshop session to keep track of my observations and thoughts as the workshops progressed. These field notes allowed me to have a better understanding of the design projects when reviewing the video. Also, pictures of the teachers’ designs and photocopies of participants’ notes were collected.

Data Analysis

Survey Comparisons

The surveys each included many identical questions. Comparisons were made between the teachers’ responses, among each teachers’ responses over time, and among groups. Additionally, questions with a similar focus were combined to create an index score. For example, the teachers were asked about their comfort level with the LEGO bricks, with ROBOLAB, and with design in general. Each response was scaled from a 4, indicating a response of “very comfortable,” to a 1, indicating a response of “not comfortable.” Then each response to the questions regarding the teachers’ comfort with the LEGO bricks, ROBOLAB, and design was combined and then averaged to create the LEGO Design Comfort Index. The LEGO Design Comfort Index will be discussed further in Chapter Seven. By combining many responses, I hoped to see if a larger trend existed across related questions. With a sample size of only twelve, statistically significant results
cannot be found, but interesting trends could be identified nonetheless. Results of the survey comparisons are presented in Chapter Seven.

_Coding of Open-Ended Survey Questions and Video Transcripts_

In order to get the most out of the data, a coding system was developed. The coding system, similar to that used by Welch (1999), helps to organize and correlate the data from the videotapes, field notes, and surveys. This organization has led to the creation of categories related to the design process and concerns about implementing engineering. These categories created from the coding can then be compared across the treatment groups. During the course of the study, new codes were formed while others were shaped, grouped, or dropped based on the data. Moreover, examples that disagreed with the original hypotheses were actively sought. A complete list of the codes and categories can be found in Appendix B.

_Video Concept Mapping_

Analysis of the video taped sessions includes coding transcriptions of relevant conversations held among the participants and with myself, and a mapping of the teachers’ design processes. Conversations that did not pertain to the LEGO bricks, ROBOLAB programming, engineering, teaching, or participant’s attitudes were deemed irrelevant to this research. The mapping method for this research was developed from the system used by McRobbie, Stein, and Ginns (2000) in their study of preservice teachers. Video mapping creates a detailed account of the design process of each participant, providing an insight into how they think through the design process. The mapping system consists of geometric symbols that represent types of ideas and actions. In addition to the symbols adopted from McRobbie et al, I include arrows to indicate when participants
required assistance to move from one step to the next. These symbols are used to try and capture the mental and physical design process on paper. Without doubt even the most observant researcher could not capture every detail of someone else’s design process, but this mapping system provides for a very rich picture that can be analyzed. By mapping each of the design sessions for each participant, I am able to compare the design process used for the creation of each project, as discussed in Chapter Six. A full description of the symbols and mapping system can be found in Appendix C.

Limitations and Validity Concerns

Reactivity

One issue of concern for any research study is how participants will react knowing that they are a part of a research study. An open discussion of the research occurred during the first meeting of the workshops so that all participants were fully aware of the nature of the study and what was involved; in addition, they were assured that they were not being judged on their performance during the workshop. However, because this study included videotaping it is possible that teachers may have altered their behavior knowing that it was being recorded. In an attempt to minimize this, the video camera was kept as unobtrusive as possible so that teachers could move freely in the workshop. The camera was present for the entire workshop so the teachers were accustomed to its presence from the beginning. Also, the participants were assured full confidentiality. All names that appear throughout are pseudonyms.

Impact of the instructor/researcher

One major cause for concern is the nature of my role throughout the study. I was acting as both instructor and researcher during the workshops. This may have influenced
some of the teachers to react to me differently than they would another professional development leader. However, I assured them that I would not view their surveys until the conclusion of the workshops and that I was not trying to evaluate their performance or my teaching, but rather understand the nature of the design process. Also, my position as an education student with a background in engineering could have created biased responses. While I feel it was important to be upfront with the teachers about the nature of my study, they could have altered their responses to try to provide answers they thought I wanted to see. Also, my age may have influenced the responses of some of the participants. With me being younger and still in school, it is possible that the participants did not respect my opinions about education, or may have formed another image of me that could have influenced their responses. Even so, my position as teacher and researcher for each session allowed me to control the interventions and have first-hand knowledge of the design process used by the teachers.

*Self-reported data*

One major source of data for this research was the surveys collected before each workshop session and following the final session. The surveys asked teachers to report about their confidence levels and other feelings about the workshop. While I was interested in how the teachers assessed their own confidence and knowledge during the workshop, they may not have been reporting these assessments accurately. Some participants may have reported a higher confidence to appear more knowledgeable or to give the response they thought I would want to see. On the other hand, some teachers may have reported a lower confidence to not appear arrogant. Though the participants were assured their answers would be kept confidential and that I would not see any of the
answers until the conclusion of the workshop, they may have still been concerned with how their answers would be perceived. Also, because these teachers were novice users of the technology, they may not have been able to accurately assess their own skill. This may have led to initial high confidence levels and a later dip in confidence levels. In Chapter Seven I discuss this issue further.

Another major issue with self-reported data is inconsistency. A response of “moderately confident” may mean different things to each participant. Also, participants may have a varying interpretation of the question or the responses over time. To minimize this problem, the survey questions were designed with clearly-worded responses instead of not a scale that consisted purely of numbers (i.e. “on a scale from one to ten”).

Interpretation of data

One of the goals of this research has been to develop a better understanding of the design process used by teachers and how this evolves over the course of a professional development workshop. However, it is difficult to model each teacher’s process since so much of design is a mental activity. The mapping system provides a good foundation to streamline analysis of the videotapes, however, it was difficult to obtain full concept maps for teachers who did not discuss their design openly, sat far from the camera, or moved around often. For these reasons the examples I present may not be an accurate portrayal of all the workshop participants and I am hesitant to draw conclusions that apply to the group at large from the examples I have selected. However, the video mapping does provide many insights into the individual process of the teachers I have selected to use as examples.
There is a high degree of subjectivity involved with both the video analysis and the coding. To avoid this several discussions were held with other researchers in order to seek out multiple interpretations of transcripts and videotapes. Additionally, my original video concept maps were compared to those made by another researcher who had been trained in the video mapping technique. The results of these comparisons will be discussed along with the data presented in the following chapters. Any discrepancies will also be presented.

**Sample**

The sample size is much too small to achieve statistically significant results. The teachers’ location in Massachusetts presents both a difficulty in generalization and a benefit in usefulness for this study since the state frameworks require engineering as part of the K-12 curriculum. There is little way to account for the participants’ prior experience with the materials and design in general. However, meaningful insight may still be gained and the research could serve as a starting point for future investigations.

In this chapter I have discussed the research design, the workshop that was studied, and my methods for data analysis. Also I noted some limitations and validity concerns for the study. Over the next several chapters I will discuss the findings of the study. Each results chapter will begin with an assertion drawn from the data presented in that chapter. Chapters Three and Seven discuss the findings from the surveys. Chapters Four and Six discuss the design process as illustrated by the coding and video mapping. Chapter Five delves into an issue presented in both survey results and conversations from the workshop.
CHAPTER 3: TEACHER BACKGROUNDS, PRECONCEPTIONS AND CONCERNS

Assertion One: Administrative support, particularly in the form of professional development and classroom volunteers, is important for bringing engineering design problems to the classroom.

In this chapter I will report on the results of the initial survey given to all participants at the beginning of the first workshop session. This information will serve as baseline data for later comparisons. I first discuss teachers’ reports of their confidence in their knowledge of engineering concepts and then move to their confidence in building with LEGO bricks, programming with ROBOLAB, and design. Also, the first survey included questions about the obstacles teachers saw for teaching engineering design, and the support and professional development they thought would be most valuable to help them implement engineering lessons in their classrooms. These questions were asked in order to answer my third research question regarding teachers’ concerns about engineering design.

Initial Survey Answers

The surveys asked the teachers about their confidence using the technology that would be explored during the workshop. This confidence may impact the way in which this technology and related subject matter is approached in the classroom (McRobbie et al., 2000). While this research does not follow the teachers into the classroom to see if the workshop has any impact on implementation, confidence levels were seen as important to
track because of this link. Confidence may also be linked to desire and willingness to learn about the new technologies (Watson, 1998).

*Initial confidence levels in building, programming, and design*

All the teachers reported minimal or no previous experience with LEGO bricks or ROBOLAB on their applications to the workshop, which occurred prior to placing them in groups. However, at the beginning of the first session, after the participants had randomly been placed in groups, the teachers reported a wider range of confidence levels in building, designing, and programming than had been expected after reviewing the applications. At this point, however, teachers were already in treatment groups, so the imbalance of initial confidence levels between groups could not be adjusted. As discussed further in Chapter Two, this is one of the problems with using self-reported data.

On the initial survey, all of the participants rated themselves as beginners—from a choice of beginner, intermediate, and advanced—when it came to building with LEGO bricks. All but one also reported as beginners in ROBOLAB; Kim (*No Design* group) ranked herself as intermediate at this level. However, the expertise ratings did not correspond smoothly into confidence levels. Though each teacher reported being a beginner, there was a range of responses to questions of confidence. The building confidence levels are reported by group in Figure 3.1, where it is clear that the *Design Discussion* group had lower initial self-reported confidence levels than the other groups.
Figure 3.1: Initial Building Confidence Levels. This graph presents each participants response to the question “How confident are you of your LEGO building abilities?” on the first survey. The responses are divided by treatment group.

A similar story was true for the initial confidence levels in ROBOLAB programming, as shown in Figure 3.2. The No Design group reported higher levels of initial ROBOLAB confidence than either of the other groups.

Figure 3.2: Initial ROBOLAB Confidence Levels. This graph presents each participants response to the question “How confident are you of your ROBOLAB programming abilities?” on the first survey. The responses are divided by treatment group.

Another interesting occurrence is the disparity between initial building and programming confidence levels. Despite reporting to be beginners at both, the members of the Design Exposure group reported lower initial confidence in programming than in building. However, one member of the Design Discussion group reported a higher level of
confidence in programming than in building. This hints at the “builder” and “programmer” approaches that will be explored in Chapter Four.

Another variable of critical interest in this study is Design Confidence, in both the participant’s ability to design a solution to a given problem and in their comfort level leading their class in a design activity. The teachers also showed varied levels of initial confidence in their own design abilities, as shown in Figure 3.3. The No Design group reported higher confidence levels than the other groups, with the Design Discussion group having the lowest initial confidence levels in their design abilities. Also, overall the participants showed higher levels of design confidence than building or programming confidence.

![Initial Design Confidence](image)

*Figure 3.3: Initial Designing Confidence Levels.* This graph presents each participant’s response to the question “If given the necessary materials, how confident are you that you could design a solution to a given problem?” on the first survey. The responses are divided by treatment group.

In addition to asking about their confidence in their own skills, I asked about their comfort level in leading their students through a design activity. Figure 3.4 shows the teachers’ self-reported comfort levels with leading design activities in their classrooms. Five of the twelve teachers reported they were more comfortable leading a design activity than they were confident in their own design ability, with only two reporting lower
comfort levels than confidence levels. Again, the Design Discussion group reported the lowest comfort levels with teaching design.

![Initial Teaching Design Comfort Levels](image)

*Figure 3.4: Initial Teaching Design Comfort Levels.* This graph presents each participants response to the question “Would you feel comfortable engaging your students in an engineering design project?” on the first survey. The responses are divided by treatment group.

These data indicate that there will be a problem making comparisons between groups. Because the initial confidence levels showed so much variation between groups, it is not fair to characterize the groups as equal. However, since almost all the teachers rate their expertise as being at the “beginner” level, it will still be interesting to see any changes in the expertise ratings and confidence levels over the course of the workshops. Now I will turn my attention from the teachers’ self-assessment of their abilities to their concerns about bringing engineering design into the classroom.

**Concerns about Engineering Design in the Classroom and Professional Development**

In addition to completing the check-box ratings of expertise, confidence, and comfort on the initial survey, the teachers answered open-ended questions aimed at answering my third research question: What kinds of concerns do these teachers have about engaging their students in open-ended engineering design projects and how can these concerns be minimized? The answers to each question were coded in order to group
similar answers together. Since these concerns were reported before the first workshop session, they do not directly relate to the study’s treatment. The data below are presented for the entire study population and not by treatment group.

**Obstacles to Teaching Engineering Design**

In order to understand the problems teachers face when trying to bring engineering design into their classrooms, I asked the participants “What do you see as the biggest obstacles to including engineering design in your K−12 classroom?” Nearly half of the teachers mentioned problems dealing with limited class time (5). Also, teachers said their lack of materials (3), training (2) and space (1) would hinder bringing design into the classroom. Interestingly, two teachers felt that the curriculum standards kept them from bringing design into the classroom. This response was slightly puzzling as engineering is listed as a major strand of the science frameworks in Massachusetts. This could indicate a need to further explore teachers’ understanding of the frameworks and how they are addressed in the classroom. It is unclear from their responses whether they were unaware of the engineering standards, if they have too many standards to address, or if other standards (specifically the math and literacy standards) are emphasized more than the engineering standards.

The majority of these concerns could be addressed administratively by providing teachers with extended classroom time, more professional development, or more materials. While those solutions are not always easy to carry out, especially on a limited budget, they are not in the control of professional developers. Certainly, professional development could be provided for activities that do not take a lot of class time and use inexpensive materials, however this does not get to the heart of the issue. The two
responses that were most concerning indicated that the teachers felt engineering was hard to teach. These responses showed two different concerns about teaching. One teacher was concerned whether she would “Be able to convey [her] idea/concepts” to her students, touching on the issue teacher confidence, which is explored by the surveys. The other teacher thought, “It’s difficult to ‘teach’ building skills,” such as meshing gears, properly. This brings to mind issues of pedagogical style—the difference between teaching these skills through building a specific model by following building instructions and allowing students to explore pieces through open-ended building. Moreover, this relates to the teachers’ theories of teaching and learning discussed in the literature covered in Chapter One. These issues of pedagogy could be addressed through professional development and may be important areas to concentrate on when constructing teacher education opportunities.

Support

In previous teacher education projects, classroom support was cited as a critical help component during implementation of engineering design in the classroom (Cejka, Rogers, & Portsmore, in press). Classroom support can vary from volunteers to reference materials. When asked what kind of support they would want or need in order to include engineering design in their classroom, several teachers echoed what they thought were the biggest obstacles: materials (3), and knowledge or lack of training (2). Three wanted to be provided with lesson plans. One of those teachers wanted very detailed lessons, with video and still images of how to create the final project. This indicated to me a lack of flexibility. This teacher seemed to believe that the design lessons should have one solution and one “right” way to create it. This idea is explored in-depth in Chapter Five.
One teacher voiced a desire for a support network of other teachers who would be trying similar lessons in their classrooms as a way to share tips, tricks, and lesson ideas. Half of the teachers requested another pair of hands in the classroom in the form of an engineer or engineering student who could help with the lesson or provide technical support. This is certainly an indication of the importance of engineering outreach programs that bring university students and professional engineers into the classroom. Knowing what support teachers would value most in the classroom is a first step for curriculum developers, teacher educators, universities, school districts, and others interested in bringing engineering design to make the best use of their resources. Further research will need to be conducted to find what support is most helpful, and for which teachers in which situations certain support is most effective.

**Professional Development**

One of the underlying goals of this study was improving professional development for teachers in the area of engineering design so that the content would ultimately be implemented in the classroom. In order to learn the topics in which teachers think they need professional development, I asked “What sort of professional development or training would be most valuable to you with regards to engineering design?” Generally the responses fell into two categories—content knowledge and specific project ideas. Six of the teachers requested exposure to hands-on projects that they could bring into the classroom, one mentioned learning how to plan lessons in this area, one wanted to learn how to integrate engineering into what she already did in her classroom, and another desired being given a unit, complete with activities and worksheets, that could be brought directly into the classroom. As far as content
knowledge, five teachers wanted to improve their building or programming skills, while two wanted to learn about engineering concepts. These results are reflected in the initial low reports of confidence shown above. For one teacher, there was no specific request, she simply wanted “Anything, I need training in this area!”

Recommendations

From these data I have drawn a few conclusions that should be considered when implementing engineering design in K–12 education. School systems that wish to develop engineering design programs should be prepared administratively to offer the teachers support in the way of flexible class scheduling, funding for materials, and professional development. Support, particularly well-trained volunteers, should be sought in the form of classroom parents, corporate volunteers, other teachers, or engineering students. These teachers also saw great value in professional development about engineering concepts, curriculum development, and classroom implementation.

In this section I have described the baseline data the teachers reported about their confidence in their engineering knowledge and building, programming, and designing abilities. Also, I reported findings about what teachers concerns were with regard to implementing engineering design in the classroom. This information gives a better understanding of what these teachers brought with them to the workshop. Because of the constructionist framework I have laid out for the workshop and the study, it is important to recognize that the participants will experience the workshop in different ways because of the different knowledge and conceptions they have at the beginning of the study. With
these data in mind, I move to discussing what happened in the workshop over the next three chapters.
CHAPTER 4: BUILDERS AND PROGRAMMERS

Assertion Two, Part A: Teachers came from multiple perspectives entering the workshop, with some displaying a distinct preference for building or programming.

In the previous chapter I looked at the results of the initial teacher survey to find how teachers rated their confidence in their building, programming and design skills, as well as their concerns about bringing engineering into the classroom. These data were gathered before the workshops had begun. In this chapter I look at a trend that emerged in the first session of the workshops, and continued through their conclusion: some teachers had a strong preference for certain aspects of the design activities over other aspects. These preferences appeared in teachers’ comments and their survey answers. With these data, I classified the teachers into one of three categories—they were “builders,” “programmers,” or “mixed.” Through this lens I look at the types of questions that were asked by the study participants and notice an interesting trend.

Emergence of “Builder” and “Programmer” Mentality

Throughout the first session, many teachers expressed that it was difficult for them to build with the LEGO bricks. For some it was simply a matter of not having used LEGO bricks in a long time, or having never seen the specialized robotics pieces like axles and gears. For others, the problem was inspiration. They had an idea, but were having a hard time “getting it out of my head”. They were having difficulty moving from their abstract concept to a concrete construction of LEGO bricks. This prompted comments like “I’m not a LEGO person,” and “I wouldn’t have made it as an engineer.”
Some of the teachers became frustrated, though few initially wanted to simplify their design. As we began programming the first creations, those that were “just not that interested in the construction” began to enjoy themselves a little more because they liked “making it do things.” However, some teachers who had begun to be comfortable with the building expressed some frustration at the programming. They had envisioned how their pieces would move, and were unhappy if they could not get the program to initiate that movement. Parallel comments to those made during building, like “I’m not a computer person,” and “I’m more hands-on,” were made at the computers. It was clear to me that even from early on two groups were emerging amongst the teachers—programmers and builders.

 Builders and Programmers

Participants were divided into three categories: builders, programmers, and mixed. Participants were placed in these categories in two ways: based on their answers to survey questions and comments made during workshop session. If the participant met the qualifications by one method, he or she was assigned to that category, but was still reviewed by the other method. Though it did not happen in this study, conflicting qualifications (being labeled a builder by the survey questions but a programmer by comments) would result in a mixed classification. Failing to qualify in either the builder or programmer category also resulted in being placed in the mixed category. Placement in the builder or programmer category was determined by data from the first session, as the aim of the workshop was to increase participants’ skills in both areas and it was hypothesized (and will be shown in Chapter 7) that this would lead to increased confidence in building, programming and designing. The dual classification methods
allows for a variety in the ways the teachers’ may have expressed their preferences. It should be noted that the *builder, programmer, and mixed* categories do not necessarily correspond to greater expertise in either domain. Rather these categories refer to a preference expressed openly through survey responses or comments. Both of these methods of classification are presented below.

*Self-professed Builders and Programmers*

Some participants were self-declared *builders or programmers*. These participants directly acknowledged their preference for one aspect of the design activities over the other with comments such as:

“I was not interested in the LEGO part at all. I liked the motor part – like making stuff move. And this yellow thing [the RCX] is amazing that you can make it do that… That’s what I like, the computer part.” (Jess, *Design Discussion group*)

and

“It’s amazing how a piece can inspire construction. I really wanted to work with these gears. I really enjoy the building.” Sara (*No Design group*)

For Jess the preference of programming was at the conscious level. She openly expressed a dislike for building with the LEGO bricks, but she excelled at the ROBOLAB programming. Sara’s comment reflects her enjoyment for building. She was happy to explore pieces and work on constructions throughout the workshop. She would become easily frustrated with the programming and usually chose simple programs to move her complex creations.
Survey Answers

Additionally, teachers could be placed in the ‘builder’ or ‘programmer’ categories based on the preferences reported in the surveys. If the teachers reported at least a two-point difference on the initial survey between their building and programming confidence they were placed in the category corresponding to the higher confidence. However, any difference was noted. As explained in Chapter Three, point values were assigned as follows: one for not very confident, two for somewhat confident, three for moderately confident, and four for very confident. Figure 1 shows the building confidence and programming confidence levels reported by each participant in the initial survey. One member of the No Design group can be placed in the programmer category, and one member of the Design Exposure group can be placed in the builder category. Also, two participants, one in the No Design and one in the Design Exposure group, showed a slight preference for building, and one participant in the Design Discussion group showed a preference for programming.

![Building vs Programming Confidence, Initial Survey](image)

**Figure 4.1: Initial Building vs. Programming Confidence Levels.** This graph compares each participant’s initial building confidence to their initial programming confidence. The results are separated by treatment group and an overall average is represented by the last pair of bars. The average is almost even, but several individual rate one higher than the other.
Teacher Classification

From the two methods above teachers were placed in the *builder* or *programmer* categories. Teachers who did not meet the criteria for either category were termed *mixed*. Overall the teachers fell into the categories as displayed in Table 4.1. The last two columns indicate the method by which they were identified as a *builder* or *programmer*. If they met the criteria by that method, an ‘X’ is placed in that row. If they displayed some preference towards building or programming, but not enough to meet the criteria, a ‘+Build’ or ‘+Prog’ was recorded. If the data do not indicate a trend in either direction or show even marks in building and programming a ‘-’ is noted.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Group</th>
<th>Builder or Programmer</th>
<th>Comments</th>
<th>Survey Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary</td>
<td>No Design</td>
<td>Programmer</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Kim</td>
<td>No Design</td>
<td>Programmer</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Beth</td>
<td>No Design</td>
<td>Mixed</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sara</td>
<td>No Design</td>
<td>Builder</td>
<td>X</td>
<td>+Build</td>
</tr>
<tr>
<td>John</td>
<td>Design Exposure</td>
<td>Mixed</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Amy</td>
<td>Design Exposure</td>
<td>Builder</td>
<td>X</td>
<td>+Build</td>
</tr>
<tr>
<td>Linda</td>
<td>Design Exposure</td>
<td>Builder</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Jill</td>
<td>Design Discussion</td>
<td>Mixed</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Andrea</td>
<td>Design Discussion</td>
<td>Mixed</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jess</td>
<td>Design Discussion</td>
<td>Programmer</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Sue</td>
<td>Design Discussion</td>
<td>Mixed</td>
<td>-</td>
<td>+Prog</td>
</tr>
<tr>
<td>Jackie</td>
<td>Design Discussion</td>
<td>Mixed</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.1: Classification of teachers as Builder, Programmer, or Mixed

The distribution across the categories is fairly even, with three *programmers*, three *builders*, and six in the *mixed* category. Also, it is interesting to note that most of the *Design Discussion* group was in the mixed category. As discussed in Chapter Three, the *Design Discussion* group had lower overall levels of self-reported confidence than the other groups. Perhaps they had not had enough exposure to the materials to form a preference.
**Types of questions**

The types of questions that the participants asked during the workshop were a variable for which the transcripts were coded. I was interested to see what sort of help that teachers’ requested. After the coding was completed and the data presented above was analyzed, I wondered if the types of questions asked were related to their *builder* or programmer classification. Questions were classified as “technical” or “conceptual”.

Technical questions had to do with specific pieces or programming elements when the participant had a clear idea of what needed to occur. Technical questions occur because they were not familiar with all the pieces or the programming environment. Questions were deemed conceptual if the participant had a vague idea or no idea about how they wanted to progress. Conceptual questions occurred when the participants either did not have a design plan or did not know how to proceed within a plan. Examples are shown in the Table 4.2.

<table>
<thead>
<tr>
<th>Building</th>
<th>Programming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceptual</td>
<td>“If I wanted to get this to turn like this, how could I do that?” – Mary (<em>No Design</em> group, <em>Programmer</em>)</td>
</tr>
</tbody>
</table>

Table 4.2: Coding scheme for questions

A trend appeared in the types of questions asked. Because this was a learning experience for the teachers, I expected them to ask many questions. However, the type of question (*technical* or *conceptual*) asked showed an inclination towards certain actions. The coded transcripts from the first session were analyzed because this is the same session from which the data were analyzed to develop the builder, programmer, and
mixed classifications. The occurrences of each code during building and also during programming were counted and are shown in Table 4.3. If there was a difference of 3 or more between the occurrences of technical and conceptual questions in either building or programming, the larger number is shaded to help illustrate the pattern.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Classification</th>
<th>Building</th>
<th>Programming</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Technical</td>
<td>Conceptual</td>
</tr>
<tr>
<td>Kim</td>
<td>Programmer</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mary</td>
<td>Programmer</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Jess</td>
<td>Programmer</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Linda</td>
<td>Builder</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Sara</td>
<td>Builder</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Amy</td>
<td>Builder</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Beth</td>
<td>Mixed</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Jill</td>
<td>Mixed</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Andrea</td>
<td>Mixed</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Sue</td>
<td>Mixed</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Jackie</td>
<td>Mixed</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>John</td>
<td>Mixed</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.3: Occurrence of code by each participant

Two of the builders asked more technical than conceptual questions during building, and more conceptual than technical during programming. Conversely, two programmers asked more conceptual than technical questions during building and more technical than conceptual during programming. Kim, a programmer, and Linda, a builder, do not follow this trend. Beth, mixed, does seem to follow the pattern displayed by builders Sara and Amy. The sample size is very limiting with regards to being able to draw any conclusions, however, this trend is very interesting and worthy of further exploration. Is the preference for building or programming a predictor for the types of questions asked during workshops? If so, could this facilitate teacher educators in knowing what sort of support could be most useful for certain teachers and when?
Builders and Programmers in the second and third sessions

This division into builders and programmers continued into the following sessions. It became more obvious when the teachers began planning their animals in the second session. Builders were considering construction aspects—“I’ll need to use something strong to support the weight of the [RCX] brick”—while programmers were considering different details, like how to trigger behaviors. Regardless of their categories, however, some the teachers continued to show confusion about how to make their visions out of the LEGO pieces. One teacher devised a way to get her mental image to become a physical reality—she drew a cat’s face, saying, “We’ll make the face [on paper] and then see how we can connect it [with the LEGO bricks].” This comment showed that the teachers were beginning to use the physical pieces to explore their mental ideas, an idea that has been shown to be of importance for learners of many different age groups (McRobbie et al. 2001; Stein et al. 2002; Welch 1998, 1999). When trying to understand gears, one teacher explained she was “trying to make sense out of something” by using the bricks. She was testing her conception of how things should work with the reality of the LEGO pieces. As their experience with the LEGO bricks and programming grew, the pieces became a tool for the teachers to express and explore their ideas.

In the third session, the differences between the builders and the programmers were again clear. The builders would build structures and find a way to work in their mechanisms later, while the programmers would first build their mechanism(s) to be programmed and then later find a way to connect it to a larger structure. The ideas for the final projects also came from separate places. In the Design Discussion group, Jess, a programmer, was very anxious to use the programming structure called “events”, and
created her entire project around that. She went so far as to plan out her entire program before touching the pieces (see Figure 4.2). When she did build her project and realized she would have to change the location of the motor, she actually went back and noted this on her paper plan of the program.

![Figure 4.2: The School Bus Program. Jess (Design Discussion group) created this plan for her program during the final session before she began building.](image)

The impact of the workshops on confidence levels is discussed fully in Chapter Seven, but here I look again at the difference between self-reported confidence levels in building and programming in the final survey. At the conclusion of the workshops, no teachers displayed a two-point difference between their building and programming confidence levels, though three showed a slightly higher (1 point) confidence in building, and four showed a slightly higher confidence in programming, with five recording equal levels.
Comparing the data from Figures 4.1 and 4.3, no teacher displayed a drop in building or programming confidence, though some remained equally as confident.

Implications

While Jess demonstrated an extreme case of program planning, many participants thought about the program before the construction. However, they had a tendency to view themselves as working “backwards.” It is important for professional developers to be open to multiple perspectives and allow programming and construction to occur when the participants are ready, and allow both to happen at once. When the programmers were allowed in the second and third sessions to work at the computers first before going to the LEGO bricks, they were much more comfortable with their designs. Additionally, this difference should be discussed with the teachers so that their students can also work how they are most comfortable. This point was raised during a discussion of the design process with the No Design and Design Exposure groups after the workshops had concluded. While there may be a process to follow, each individual can interpret that...
process differently, and that planning included thinking about both the building and programming aspects.

In this chapter, I have shown how some of these teachers showed a preference for building or programming which was illustrated by their comments during the workshop or their answers to the survey questions regarding building and programming confidence levels. This allowed for the creation of the 

*builder* and *programmer* categories, with the 

*mixed* category representing participants who did not fall into either. These results indicate two broad ways that teachers think about and work within the design projects, gauging and using their strengths and weaknesses to guide their designs. These categories revealed an interesting trend in the types of questions asked by the teachers during the first workshop session. These questions gave information about how they conceived their designs and in which area they required the most assistance. In the next chapter I will discuss another theme that emerged during the first workshop session—teachers’ search for a *right* answer. Then in Chapter Six, I will discuss the design processes of the teachers and how these trends were represented in them.
CHAPTER 5: THE “RIGHT” ANSWER

Assertion Two, Part B: For some of the teachers, it was difficult to accept the open-ended nature of the design problems because they do not have unique solutions and there is no correct answer.

In the previous chapters I have explored how teachers rated their confidence before entering the workshops and how some gravitated toward either building or programming. In this chapter I will address another theme that became apparent through a discussion between the No Design group and me during the first session. Knowing the answer, which assumes that there is one or at least a limited number of correct answers, was important to some of the teachers. Engineering design problems, however, are evaluated not only on whether or not they work, but also on the efficiency, cost, and simplicity of the solution. Each solution results from individual decisions regarding certain tradeoffs. The teachers struggled in their transition from traditional “right or wrong” classroom activities to the open-ended nature of design problems, which do not have a unique solution. This theme appeared both in conversation and through some teachers’ attempts to find the right answer through examples presented to them.

“I hardly ever say ‘I don’t know’”

After the first session, I asked the participants what was frustrating about their project. For several, they felt that one major problem was not knowing the best way to design their project. Many commented that they would have never found a way to solve
the problem without my help. Part of the frustration, of course, was due to a lack of experience with the pieces, or not knowing that certain pieces existed. However, one teacher described how there was more to it than that:

I really want to be good at this building; I want to be better than a pre-teen aged child. . . . I want to because when they come to me with problems, I want to be able to say I know exactly what you did wrong. When I was doing corporate training . . . and someone would say, “I’m having problems with. . .” I would know exactly what they were having problems with, and I knew how to fix it and want to be able to do that with this too. (Mary, No Design Group)

For Mary, being knowledgeable was very important. It is possible that she held a view of herself as the “sole disseminator of knowledge,” as Ogle and Byers (2000) described the perspective of some teachers. If she did not know how to help her students solve a problem, who would? When asked if she had trouble telling her kids she didn’t know the answer to a question, Mary responded:

I hardly ever say “I don’t know” . . . . They come to me with such heavy hearts because they’re so frustrated that their tower isn’t standing straight, and I want to be able to help them, and be there for them so they won’t feel bad. And they worry about their grades so much, and I have to grade them accordingly. I can’t just say, “Well, I’ll give you an A for effort.” I can’t do that. They have to do what I ask them to do… Don’t forget, technology is part of the MCAS [Massachusetts Comprehensive Assessment System] now. (Mary, No Design Group)
She did not want to tell her students she did not know how to help them. Part of this likely comes from a lack of confidence with the technology. She wants to be able “to fix” the problems her students have. Certainly this can be addressed through more experience and training with the technology. However, part of this may be the notion that there is a “right” answer—one answer or solution that is not only superior to other solutions, but the correct answer. Her students “have to do what [she asks] them to do” and she cannot give good grades for effort, much like Ogle and Byers “sole disseminator[s] of knowledge” (2000, p. 5). This perspective does not leave much room for the flexibility and multiplicity of solutions and designs in engineering. However, with the recent push for “right or wrong” assessment by the No Child Left Behind Act, teachers are placed under heavy pressure to have their students perform on high stakes exams, like the Massachusetts Comprehensive Assessment System (MCAS). These tests are theoretically opposed to the educational philosophy of Constructivism. Open-ended, constructionist problems, aimed to enhance student understanding can lead to the anxiety voiced here by Mary. She may be unsure of how she could assess her students during a design challenge, an area that could be addressed by professional development. Because she is dedicated to helping her students learn and succeed, she feels a tremendous pressure to ensure she always has the answer, which is in conflict with her desire to implement engineering design problems. This is a struggle that needs to be addressed in both professional development and educational policy.

After discussing the design process after the final session, this teacher became more open to the idea of multiple solutions. Mary began to see engineering activities not as something that has to be done one way, but as an exploration that could take many
directions. She said of the design process: “it really makes me think about how to get from here to there, it helps me think of how to organize myself.” I believe that the design process was a tool that gave her the freedom to fail, the freedom to travel down a path she was unsure of, and perhaps the freedom to say “I don’t know”.

Following Examples

Throughout the workshops, it was clear Mary was not the only one who felt this way. I observed five teachers who relied on example projects I provided in order to create their own projects, even though I wanted to provide these examples as inspiration, or as a demonstration of a particular concept, and not as a model to be copied. A few of the teachers, especially those who were uncomfortable with building, requested written directions and more examples, and did not feel comfortable building without a guide. Some teachers would rebuild a mechanism exactly, from a model I had created, before beginning their own creations. In this way I think these teachers wanted to try something that they knew would work, before creating something of their own. I believe this had to do with the desire to have the “right” answer; they did not want to fail. In the last two sessions, this activity was most prevalent among, but not limited to, those teachers in the No Design group who did not discuss the design process. It was very important for all the teachers to see an example of how a piece or a programming concept worked. However, examples of fully built projects seemed to stunt the creativity of the participants, keeping them from exploring on their own. Sara (No Design group), for example decided to build a giraffe because I provided a giraffe as an example (see Figure 5.1).
Figure 5.1: Sara’s Giraffe. Sara (No Design group) copied her design for a giraffe from an example presented. Its body is composed of a car with decorative features to make it look like an animal. Sara did not experiment with her own ideas during building, despite being classified as a builder.

Somewhere in between a lack of examples and copying examples there must be a balance between these teachers’ comfort with building and their ability to be creative. In the future, I need to find a “safe” zone, which lies between me providing no examples, leaving the teachers feeling lost, and me providing too many examples, causing the teachers to not think creatively. The teachers may need to imitate working designs first to gain comfort before being able to create a unique design of their own. The role of imitation in learning about design is an issue that needs further exploration in future study.

Following an example may have actually kept groups from understanding some of the building concepts, such as gear choice and sturdy building. For Jackie, Jill, and Sue (Design Discussion group) this was the case during the third session. In this session, they copied an example but could not figure out exactly how it worked. They encountered problems with its function that may not have occurred if they had designed their own solution. They decided to build a Merry-Go-Round and chose to follow a model of a gear
train to build their structure. Jackie, who proposed the Merry-Go-Round, did not know how to begin: “I can picture building it, but how do we make it move?” Sue suggested building the gear train in the example I provided, just turned on its side: “It doesn’t have to be sideways like this, it could be tipped.” Sue agreed, saying, “Why don’t we replicate something like that?” They proceeded along this plan but ran into problems recreating the exact structure. When they missed a piece, their gears did not mesh. At first they mistakenly believed that the gear they had (which was the same size as the example gear, different color) did not mesh because of its size, not their placement. If they had been doing their own building, and not recreating the example, they would have had to think about which gears to use, how the different gear choices could affect the structure of the gear train, and where they should be placed. Much like the students and preservice teachers in the previous research (Crismond, 2001; Roden, 1999; Roth, 1998; Stein et al., 2002), these teachers needed scaffolding or support in order to gain explicit content knowledge about how geared mechanisms work. Copying examples gave Jackie, Jill, and Sue a starting point, but kept them from meaningful building.

Possible connection to “Builder” and “Programmer” approaches

Is this hunt for knowledge and the “right” answer related to why Builder and Programmer approaches exist? Are they both manifestations of the desire for expertise and preference for what one knows rather than the unknown? Jess and Mary, who are self-identified programmers, both see programming, at least at first, as “backwards” or “left-brained.” They prefer to program first before building, even though they see this as unusual. They like programming better because they believe they are skilled at it, yet they do not seem to value their preferred design process as much as what they believe to be
the normal process. Efforts should be made to steer all teachers away from thinking that one style of design (building then programming, or programming then building) is normal or more valuable. They think one process is correct, and the other is not, when this is not the case. The teachers may be copying examples in the areas in which they are less confident, and may need encouragement to try new things. Since these differences exist among the teachers, they may also exist among students. For this reason, the builder and programmer mindsets should be openly discussed.

Implications

The teachers in this study repeated concerns that others have found when trying to affect classroom change, as were discussed in the literature review. These teachers were struggling to make a conceptual shift from unique correct solutions to multiple solutions for an engineering problem, unlike the problems they experienced in school (Anderson & Roth, 1989; Ball, 1996). Introducing a new technology they feel they must master further complicated their concerns. For these reasons, it is important for professional development to address not only the technological content teachers seem to need to lessen their anxiety, but also the nature of open-ended engineering design problems, as other research has shown professional development can be affective in successfully making a shift in the learning and teaching theories held by a teacher (Peterman, 1993; Stein, et al., 2001). The importance of the multiple design paths and solutions should be emphasized to assure teachers it is all right if they do not know all the answers.

In this chapter I have looked at a mental obstacle teachers must overcome, or at least deal with, in order to employ engineering design activities in their classroom, and also to fully
engage in these activities themselves within this professional development workshop.

This obstacle is the desire to know the right answer, which stems from the idea that there are a distinct number of correct solutions to a problem. In engineering design, however, this is not true, as a multitude of solutions may exist for a problem often varying about some set of tradeoffs (cost versus quality, for example). I have illustrated this obstacle through teachers’ words during discussion and the use of examples by teachers during design. I have theorized on the connections between this idea and that of Chapter Four. In the next chapter I turn my focus to the heart of the study—teachers and the engineering design process.
CHAPTER 6: THE ENGINEERING DESIGN PROCESS

Assertion Two, Part C: The teachers had a variety of natural design processes that were minimally affected with exposure to a model of the engineering design process. However, the teachers showed a greater comfort with generating multiple possible solutions after exposure to the design process model.

In the previous two chapters I have discussed the “Builder/Programmer” mentality and the desire to know the “right” answer. Now I turn my focus to the design processes used by the participants during the workshop. The data presented in this chapter are mainly from video mapping analysis. First I look at how the teachers initially approached design problems during session one, before exposure to the model of the engineering design process, and how these processes evolved with experience for the No Design group. Next I look at how the Design Exposure and Design Discussion groups reacted to the engineering design process in the second session. Then I discuss the design processes used in the final session of the workshop. Finally, I conclude with the teachers’ reflections of the design process during discussion.

Video Concept Mapping

As discussed in Chapter Two, I used a video mapping technique, adopted from the work of McRobbie, Stein, and Ginns (2000) in order to reveal the design process used by the teachers during the workshop. The process allows me to show how the participants moved from the original problem statement to their unique solutions. Five of these video concept maps are presented throughout this chapter. Figure 6.1 provides a key to the
symbols used, adopted from McRobbie et al. (2000). This key is also located in Appendix C. The symbols illustrate the variety of activities and ideas the participants explore during the design process. In addition to the symbols and connectors used by McRobbie et al. to display the design process, I have added technical and conceptual help connectors from the definition presented in Chapter Four.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Example</th>
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<tbody>
<tr>
<td>'\n'</td>
<td><strong>Problem Statement</strong>&lt;br&gt;What is being designed</td>
<td>&quot;I'm thinking about doing a cantilevered bridge&quot;</td>
</tr>
<tr>
<td></td>
<td><strong>Physical Observation</strong>&lt;br&gt;LITERAL REPORT</td>
<td>&quot;This one uses crown gears&quot;</td>
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<tr>
<td></td>
<td><strong>Idea to try (mental)</strong>&lt;br&gt;A proposal of an idea</td>
<td>&quot;Ok, so I have to get it so it goes back and forth somehow&quot;</td>
</tr>
<tr>
<td></td>
<td><strong>Idea to try (physical)</strong>&lt;br&gt;Trying an idea with pieces. The connection between a mental idea and the physical reality of Legos</td>
<td>&quot;We should add this piece to secure the motors&quot;</td>
</tr>
<tr>
<td></td>
<td><strong>How it works</strong>&lt;br&gt;Looking at something that is built and understanding why</td>
<td>&quot;When I turn this, it turns the gear, and it spins on top.&quot;</td>
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<thead>
<tr>
<th>Type of Connections</th>
<th>Ordinary</th>
<th>Hypothetical</th>
<th>Technical Help</th>
<th>Conceptual Help</th>
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<tr>
<td>Actions that lead from one to another</td>
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<td>Actions that do not lead from one to another</td>
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<td>Actions that move from one task to another</td>
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Figure 6.1: Key to symbols and connectors. These shapes, lines, and arrows are used to present the design processes used by the workshop participants and were adopted from McRobbie et al. (2000).
I have elected only to discuss a few of the video maps in depth, however the results of the video mapping for each participant is taken into consideration when any conclusion or generalization is made. I chose to present only certain examples because they either typify a particular design activity or give a more complete picture of the design process of that participant than maps of others in their group.

One issue with the video collection and mapping techniques was that much of the clues to the participants’ thoughts were given verbally, though some information can be gathered from seeing how the participants manipulate the pieces. Some participants were more talkative than others and therefore had more complete and descriptive concept maps. Also, since the purpose of the mapping system was to try and gain insight into the mental conceptions of the participants, there may have been some missed steps that occurred to the participant but were not obvious to the researchers.

In order to decrease the subjectivity of the concept maps, two other researchers prepared concept maps from the video and transcripts. These maps were compared and there was some group discussion of the video. Overall, most discrepancies that occurred between the researchers’ maps and my own consisted of separating one action into multiple actions. In the examples presented below, the maps contain each action separated into as many pieces as were perceived by any of the researchers.

Three steps of the design process display themselves well in the concept maps. Multiple problem statements and mental ideas appearing at the beginning of a challenge or task illustrate the first step of “brainstorming.” The second step, “testing and evaluation,” often appear as a physical idea or mental idea followed by a physical observation or a how-it-works statement. Usually occurring after a Testing and
Evaluation step, “redesign,” step three, occurs when a physical observation leads to a mental or physical idea to try. The designer sees a problem and tries to fix it. Now I will look at how these steps fit into the design processes of the participants.

Session One

In the first session the workshop participants were asked to create a “music box.” Each robot needs to have a moving part and play music. In analyzing this session, I was looking to see what design processes that participants used without any guide to design. I will look at the design process of Mary from the No Design group and Amy of the Design Exposure group. However, it should be noted that at this point in the workshop neither had received any exposure to the design process during the workshop.

Mary (No Design group) was a “programmer” who initially reported to be moderately confident in both her LEGO building and ROBOLAB programming skills. She set out to build a music box with a fairly clear picture in her head, but had a hard time moving from mental ideas to the physical reality of LEGO bricks. We can see from her concept map (see Figure 6.2) that she required help to move from each of her mental ideas, and that both of the times she required conceptual help, she was moving from an idea in her head to a physical observation or idea. Additionally, we see for Mary no initial brainstorming and only one example of trying a physical idea that she did not proceed with. The map shows Mary’s only physical observations occurred within the design of the spinning mechanism for her music box. In both instances, the observation led to a physical idea to try. Also, Mary’s two “how it works” moments come after she had built her mechanism and was working on its decoration; they occur as she made her mechanism move.
Amy, unlike Mary, started out with building the Music Box. She also did not show any initial brainstorming (see Figure 6.3). Amy began by trying to rebuild a crown gear model that I had shown to the class, but ran into problems recreating the structure similar to the problems of Jackie, Jill, and Sue discussed in Chapter Five. After asking for help, Amy was able to brainstorm another solution in addition to the one I had recommended. This was the same case when she noticed a problem with her structure. Amy wanted to incorporate a monkey figure into her music box, but it was too large for the structure she had built from the model. Amy decided to use a different decorative element that fit into the structure. She had a hard time separating the building and programming elements involved in using sensors.

Amy: “Does this have to have a sensor on it?”

Erin: “Well, it depends on how you program it, right?”

Amy: “Oh.”

When she did create a program, she began to test, evaluate, and redesign her project to find the speed she wanted it to spin at. She again showed a disconnection between building and programming with sensors. When her program was not working as she would like, I offered some insight:

Erin: “The way the program is written you need a light sensor, but you can change it to something else if you’d like.”

Amy: “Ok. Well, what do I want it to do?”

Her response indicates that she was having trouble conceptualizing the programming aspects of her design. After deciding on using a light sensor, testing her music box, and modifying the program to run continuously, Amy was able to explain both the
programming and physical aspects of her music box. Amy needed to work with the physical LEGO bricks and actual ROBOLAB program to clarify her mental model of how the technologies worked and interacted. After this experience, she was able to conceptualize the system she had created and explain it verbally to the other workshop participants.
Figure 6.2: Mary’s Session One Concept Map
Figure 6.3: Amy’s Session One Concept Map
In general, there was little initial brainstorming among the participants. Perhaps this was because the instruction to build a “music box” gave participants a narrow image of what they wanted to (or could) build. Linda (Design Exposure group, builder) was the only person to break away from the crown gear mechanism represented by the models that I presented as examples. Her gear structure was unique and well designed.

Also, the video concept maps were fairly linear, suggesting that the projects were broken into few tasks and there were few actions that were unconnected to the previous action. Disconnects between the building and programming aspects of the robotics activities, as shown by Amy’s concept map above, were common among participants throughout the workshops, but decreased in number by the final session, likely because the teachers were becoming more familiar with the materials.

Changes to the Design Process during Session Two

The challenge presented for the second session was to build a robotic animal. It was in this session that the model of the engineering design process (see Figure 1.1) was presented to the Design Exposure group and presented to and discussed with the Design Discussion group. Looking at this session, I was interested to see if there were any changes from the initial design processes and any differences among groups.

Design Exposure group

Linda tried several ideas, but did not think them through before beginning. This caused her to have to take apart things she built and start over. She was encouraged though by thinking about it as experimenting and redesigning as opposed to failure: “I abandoned my other idea, so I’m just experimenting with this. I feel like I get so far and say ‘that won’t work’ and start over. I guess that’s redesign!” Linda, identified as a
builder, needed to ask only one technical question during the building process, while she needed help four times, twice technically and twice conceptually, to complete the program. Linda’s session two video concept is shown in Figure 6.4.
Figure 6.4: Linda's Session Two Concept Map

Linda builds structure for animal
- Animal
  - Linda builds basic structure

Linda starts a mechanism
- "How can I make this go back and forth when it moves along?"
  - Erin: "You can put some flat pieces on there"
- Linda finishes mechanism

Now if I want to get these to move, I'll have to attach this motor
- "I abandoned my other idea"

Linda tries building a different tail mechanism
- Linda builds a different mechanism
- Linda attaches a third motor to control a tail
- Linda notices the tail will hit the body
- "OK, so I have to get it so it goes back and forth somehow"
- "I just have to decide the direction of the wheels, right? So should I have them on A and B or 1, 2, and 3?"
  - Erin: "The motors should be on A, B, C"
- Linda programs the wheels

Linda programs animal to move around
- "Now if I want to add that one on motor B..."
  - Erin: "Well, it depends on how you want to do it..." (explains task split)
  - Linda programs task split

Linda programs tail
- "Oh, that's going way too fast, how can I slow that down?"
  - Erin: "We can put in a modifier to change the speed"
- Linda changes speed

Linda modifies program
- "OK, so now what's this going to do?"
  - Erin explains program.
  - "Oh, I get it"
- Linda adds an extra wait for to complete her program
In the second session, Jess and Andrea, members of the *Design Discussion* group, decided to work together. They began the session by brainstorming which animals to make, which is shown in Figure 6.5 by the number of initial problem statements and mental ideas. They would think of an animal and how it could function, then think of another until they finally decided to build a groundhog. They made the program asking only one technical question, and thought of two possible solutions for their program. To start building their creature, Jess required some conceptual help for how to create four moving “legs” (in their case, wheels). After this help, they were able to move from their ideas to a working solution. This pairing seems to work exceptionally well because Jess was a self-identified “programmer” and Andrea fell into the mixed category. Jess’s confidence in her programming was balanced by Andrea’s willingness to experiment with building.

For members of the *Design Discussion* and *Design Exposure* groups, the steps of the design process were in their minds as they started the project. The concept maps showed that brainstorming and hypothetical mental and physical ideas to try occurred more often than in the video concept maps produced during the first session. This could be due to the nature of the activity being fairly open-ended or to the discussion of the design process. I lean towards the latter as the concept maps for the members of the *No Design* group exhibited little of the brainstorming activity throughout the three workshop sessions. There were also fewer occurrences of conceptual help needed to move from
mental ideas to try to physical ideas to try, suggesting an increased comfort with and knowledge of the technology.
Figure 6.5: Jess and Andrea's Session Two Concept Map
Design Process during Final Session

The challenge for the final session was very open ended. In fact, the only limitations were that the robot needed to move and it had to incorporate sensors. This allowed participants to pursue whatever directions they chose. However, sometimes these decisions meant an increased need for help. Some chose projects based on their strengths—Jess, the programmer, chose a project based on a complex programming structure as described in Chapter Four—and some on their weaknesses. Mary and Kim, both programmers, wanted to try a project that involved building with gears because they saw this as an area for personal improvement. Kim chose to rebuild models of a gear train and a gear rack and combine them into one system (see Figure 6.6). For her, building and playing with the gear systems helped her develop an understanding of the functions of the pieces. While working with the gear rack during the third session, Kim exclaimed “I’ve been looking at this piece for weeks and wondered… what do you do with it? This is great practice!”

Figure 6.6: Kim’s gear rack project.
Since participants began with different reasons for choosing their problems, they required different kinds of help. Those like Jess who chose to expand an area of expertise asked more technical questions. On the other hand, those like Mary who chose to work on a weakness required more conceptual help.

For this challenge, Mary wanted to work with gears. She began with an idea to make a drawbridge, but did not know how to start. A discussion with Sara led to a new idea, using a kind of arm, which she tried until she encountered her first major problem. Another discussion with Sara led to a second idea, but this was also shortly abandoned. Mary then decided to work on an amusement park ride, similar in nature to the mechanism used in the first challenge. Again, Mary had specific ideas of how she would like her robot to move, but required some assistance translating those mental ideas into physical ones (see Figure 6.7). However, at the end of the session she could explain how her design functioned.

Mary’s development of solutions one at a time as the session progressed, as opposed to brainstorming many at the beginning of the session, is a trait that was seen among middle school students in a study of engineering design by Malcolm Welch (1999). This of course is in contrast to Jess and Andrea in session two who developed many possible solutions at the start of the session.

Mary’s design process in the second half of the final session resembles her first project. Like others in the No Design group, she seemed to gain technical knowledge, but her design process did not evolve. Members of the Design Discussion and Design Exposure groups maintained a higher number of brainstorms and hypothetical ideas to try during the third session than they had in the initial session. Otherwise, their design
processes did not change greatly. From these results I suggest that the exposure to the
design process can be related to the generation of alternative solutions. This is important
when considering the disinclination to considering multiple solutions suggested in
Chapter Five.
Mary works on a bridge design

"I'm thinking about a cantilever bridge..." (moves arms like a drawbridge) "...but I don't know if I can do it."

Sara: "You could do something like this, where you could have... like if it rotated, if the wheel rotated... and it would go like..." (shows motion)

"Yeah that's it"

Mary begins working with a gear box

Mary notices her pieces do not fit as she inteded

"I would love to get this to kind of sit down on this, but it's not doing it"

Erin provides some building suggestions

Mary tries a few more pieces, but eventually disassembles what she has and begins building a new structure.

"I wanted to do a bridge with an arm that opens, and I'm just not having a lot of luck figuring out how to do that"

Sara suggests that Mary use a certain piece as an arm.

Again Mary tries a few things and clears what she has already built.

Mary begins working on a new idea for an amusement ride.

Mary builds and hooks up motors. She starts to decorate.

Mary wants to have things spin

Erin suggests crown gears

Mary completes construction

Mary works on amusement ride design

Mary wants to have axle spin a certain number of times.

Erin suggests rotation sensor

Mary adds rotation sensor

"How would I tell it to turn 4 times?"

Erin explains 'wait for rotation'

Mary completes program

Mary explains design

Mary programs her robot

Figure 6.7: Mary's Session Three Concept Map
Conclusions about the Design Processes Used During the Workshop

Similar to the participants in Malcolm Welch’s study of middle school students engaged in engineering design (1998), the teachers in the Creative Design Projects workshops placed an importance in working with materials to form ideas, with the materials even inspiring some of the designs. This same importance was found in a study of elementary school students (Stein, et al, 2002) and preservice teachers (McRobbie, et al, 2001). Working with materials to form ideas appears to be constant across age groups.

Most often, new steps in a design began with mental ideas. When participants had not personally defined an objective, step one of the engineering design process, a physical idea sometimes initiated the first step due to a necessity that was revealed. Often “How it Works” observations appeared at the end of the program. The teachers may not have been able to understand how things worked until they had gone through the process of designing.

Reflections on the Design Process

Before we begin any activity, we form a mental plan for how to attack the problem we are facing. It is my belief that the conceptual model of the design process helped to guide the participants to form their mental plans, giving them a structure they felt was strong. This formation of a mental model of the engineering design process is something I believe to be a key step in attaining comfort with bringing engineering design to the classroom. For Sue, the engineering design process helped her “to wrap [her] mind around it all”. Teachers may not known what specific direction the projects would take, but through their conception of the design process they knew what steps they must take in order to reach a solution, regardless of what that solution was.
Understanding the design processes used by the teachers sheds light onto what aspects of design teachers gravitate towards and what parts they avoid or do not understand. It can provide insight into what the teachers are learning, and where they are struggling. Developing these understandings is key in setting the foundation for improving professional development in this area. What was discovered in this study is only a small step in understanding the development of the design process during teacher education. Further implications will be presented in the final chapter.

In this chapter I have presented the design processes used by the teachers during this workshop, answering my first and second research questions. Several examples of the video concept mapping technique were given to illustrate these processes. It was suggested that exposure to the engineering design process encouraged the participants to generate multiple solutions to a problem. In the next chapter I will present the results of the final surveys and look at the changes made from the beginning of the study.
CHAPTER 7: OVERALL RESULTS – SURVEY COMPARISONS

Assertion Three: For these teachers, the workshop was a valuable experience that led to increased confidence in their use of the LEGO and ROBOLAB tool set.

In the previous three chapters I have described what happened during the workshops and looked at the trends and issues that arose through video analysis. In this chapter I will return to the survey data, looking at how teachers’ self-reported confidence levels changed over the course of the workshop. First I discuss some limitations about the survey data, and then look at the data for confidence in engineering knowledge, building, programming, design, and teaching design. I also introduce the LEGO Design Confidence index, which combines some of these measures. Comparisons are made between groups, and the overall value of the workshop is discussed.

Concerns about survey data

Before I look at the comparisons between the teachers’ initial and final surveys, I want to restate some concerns about these data. First, I am hesitant to draw conclusions based on the teachers’ group (and therefore exposure to the engineering design process) because of the variation in initial confidence levels as shown and discussed in Chapter Three. Second, there is some concern over these data because they are self-reported. It is possible that the teachers’ survey answers do not accurately reflect teachers’ feelings of confidence. While this issue of reactivity, also discussed in Chapter Three, may affect the reported confidence levels, I believe the affect to be minimized because the teachers were assured that I would not see their answers until after the workshops and their personal
information would remain confidential. However, another problem with self-reported data is each teacher’s ability to assess their own skills. While asking about their confidence, which is more subjective than skill level, is one way to minimize this issue, I still saw some evidence that may indicate that the teachers initially over-estimated their skills and thus their confidence. This is clearly shown in the data from the teachers’ design confidence. Over the course of the four surveys—one given before each of the three sessions and one following the final session—the teachers design confidence levels revealed the pattern shown in the Figure 7.1.

![Average Design Confidence](image)

**Figure 7.1: Average Design Confidence.** This graph displays the average of the twelve participants’ answers to the question “If given the necessary materials, how confident are you that you could design a solution to a given problem?” over each survey (the x-axis). The y-axis reports the average score. Answers of “not very confident” were given a score of 1 and “very confident” a score of 4.

There was a minor dip in the average after the first session. I believe this is due to participants’ overestimating their skill before engaging in design. Overall, though, from the first session through the final session, there was consistent improvement. After the participants had an opportunity to reflect on their actual skills during the first session, they may have been better able to assess their confidence. However, throughout the remainder of this chapter I look at the data from only the first and fourth surveys to be
conservative about any conclusions. Even if the teachers had originally over-estimated their skills and reported a higher confidence, by the final survey they have gained enough experience to more accurately reflect on their skills leading to more reliable reports of confidence. Finally, as stated earlier, statistically significant results could not be obtained because of a small sample, however, some interesting trends came from comparing the teachers’ surveys.

Building, Programming, and Designing

In Chapter Three I looked at the initial Building Confidence levels reported by the teachers and noted that the Design Discussion group had lower levels of confidence than the other groups. After the workshops, the average Building Confidence level had raised as shown in the Figure 7.2. Five participants raised their confidence level by one step, two by two steps, and five stayed at the same confidence level. No participants reported a decrease in confidence level.

![Building Confidence Before and After](image)

*Figure 7.2: Building Confidence Before and After.* This graph compares the initial and final answers by each participant to the question “How confident are you of your LEGO building abilities?” The results are separated by group and the last set of bars presents an average across all participants.
An increase in the average level of programming confidence was also shown between the initial and final surveys (see Figure 7.3). Nine participants raised their confidence level by one step and one by two steps. On the final survey, every teacher reported being at least somewhat confident in his or her programming skills, and again no participants noted a decrease in confidence levels.

![Figure 7.3: ROBOLAB Confidence Before and After](image)

Figure 7.3: ROBOLAB Confidence Before and After. This graph compares the initial and final answers by each participant to the question “How confident are you of your ROBOLAB programming abilities?” The results are separated by group and the last set of bars presents an average across all participants.

The Design Confidence levels did not improve as well as the Building and Programming Confidence levels. There was a smaller increase in the average Design Confidence level. While one member each of the No Design and Design Exposure lost one step of Design Confidence, none of the members of the Design Discussion group had a decrease in Design Confidence. Overall, one participant moved up two steps in Design Confidence, six participants moved up one step, three remained the same, and two decreased a step. Both of the participants that showed a decrease started above the initial average over all the groups. It is possible that these participants had never had the experience of designing a project in full or that they were not satisfied with the solutions they reached during the final design session, negatively impacting their survey answers.
The *Design Discussion* group, that experienced no losses, could have gained confidence through the extended discussion of the engineering design process. However, this is only speculation. Further interviews that were out of the range of this study would be required to determine the cause to the decline in their self-reported confidence data. The lack of information about how participants’ reach their survey responses is another problem with self-reported data.

Figure 7.4: *Design Confidence Before and After.* This graph compares the initial and final answers by each participant to the question “If given the necessary materials, how confident are you that you could design a solution to a given problem?” The results are separated by group and the last set of bars presents an average across all participants.

**LEGO Design Confidence Index**

While the previous three figures have shown how the teachers reported their confidence over the variables of Building, Programming, and Design, another variable was created to look at the overall difference in confidence over these three variables combined. This was done in order to account for the difference between builders and programmers. If there is an increase in this variable, the *LEGO Design Confidence Index*, it shows that in general they felt more confident using the system of LEGO robotics used as a tool in this workshop as a whole - for building, programming, and designing - not
just one piece of the system. The LEGO Design Confidence Index was created by combining the teachers’ responses to questions concerning their confidence in their building, programming and design skills according to the following formula:

\[
\text{LEGO Design Confidence Index} = \frac{\text{Building Confidence} + \text{Programming Confidence} + \text{Design Confidence}}{3}
\]

The scale goes from a low score of 1, indicating responses of “not confident” to a high score of 4, indicating responses of “very confident”. If a participant had a LEGO Design Confidence Index of 4, that would indicate they answered “very confident” on all three of the indicator variables.

![Lego Design Confidence Index](image)

**Figure 7.5: LEGO Design Confidence Index.** The LEGO Design Confidence Index is a composite of the participants’ answers to questions regarding their confidence with their building, programming, and designing abilities. In this graph the LEGO Design Confidence Index of each participant is presented, organized by group. The last set of bars represents the average of all twelve participants.

While four participants made no gains, they were all participants who had a higher than average confidence at the beginning of the workshop. Additionally, no teachers showed a loss. The members of the Design Discussion group showed the greatest gains, though they also had the lowest initial LEGO Design Confidence Index.

*Teaching Design*
The other important variable the participants were asked to rate was their comfort with leading a design activity in their classroom. In Chapter Three, I showed that five teachers reported that they were more comfortable teaching design than they were confident in their own design skills. In the final survey the data again indicate a higher average comfort level with teaching design than the average design confidence level. As Figure 7.6 illustrates, five participants reported one-point gains in comfort level, two reported one-point drops, and five remained even (though two of these participants had initially reported already being very comfortable teaching design in the initial survey).

![Comfort with Teaching Design Before and After](image)

**Figure 7.6: Comfort with Teaching Design**: This graph compares the initial and final answers by each participant to the question “Would you feel comfortable engaging your students in an engineering design project” The results are separated by group and the last set of bars presents an average across all participants.

Overall Workshop Value

Despite variances in gains among the teachers, all of them responded that they found the workshop to be a valuable experience. They were able to make connections to real life engineering problems and sympathized with the frustrations their students felt during activities that were new and unfamiliar. All but one of the teachers, Jackie of the
Design Discussion group, said they would definitely use something they learned in the workshop in their classroom. Jackie was indifferent to this question.

In this chapter I have presented the results from the final survey and made comparisons with the initial surveys. I have shown that, on average, the teachers in this workshop experienced a gain in their confidence building, programming, and designing with the technology presented to them. In the next chapter I will discuss the implications of the data presented throughout the past five chapters. In particular I will discuss questions raised by this research, such as ‘What makes a teacher comfortable in their knowledge in MSTE subject areas?’ and ‘What are the connections between confidence, knowledge, and classroom implementation?’.
**CHAPTER 8: IMPLICATIONS AND FURTHER RESEARCH**

In the previous seven chapters I have reviewed the related literature, described my research methods, presented my data, and discussed the results. I have looked at how twelve Massachusetts teachers progressed over the three sessions of a professional development workshop, and how a model of the engineering design process impacted the path the teachers took to solving design challenges. In this chapter I will restate the findings and present the implications of this study, both in professional development and for bringing engineering into the classroom. Finally I will recommend some directions for future research.

**Implications**

*Implications for Professional Development*

Professional development and classroom change can be a source of anxiety for teachers. It is important for those involved in teacher education at both the preservice and inservice levels to recognize the concerns of teachers. Creating an environment where multiple approaches and solutions are not only accepted but also encouraged is important for teachers to improve their skills and confidence. For the teachers in this study, having the opportunity to engage fully in design projects was a valuable experience. The teachers in the *Design Discussion* group who had engaged in meaningful discussion of the design process described this experience as very helpful for thinking about design in terms of classroom planning and assessment. It also allowed them to feel it was acceptable to make mistakes and try new solutions, as this would lead to learning and success. How this occurs and at what point confidence increases are questions this study cannot yet
answer. Already the findings of this study have affected some of the professional
development workshops held by Tufts University’s Center for Engineering Educational
Outreach by increasing the focus on the design process, which the participants met with
great approval.

Implications for Engineering Inclusion in Curricula

For school systems that are interested in bringing engineering into the classroom,
I believe, at the most general level, it is important to focus on design. However, in order
for engineering design activities to be implemented, teachers must be given some
flexibility in curriculum. It may take more time to engage students in a design project
than it does to give a lecture, but design projects can provide opportunities to gain rich
knowledge and to integrate multiple fields. Teachers must be given administrative
support in the way of flexible class scheduling, funding for materials, and professional
development. Connections should be made with other institutions, such as local business
and universities, who provide classroom outreach so that teachers can have an extra pair
of hands during design activities or a person to contact if a problem or question arises.
The field of engineering design may make some teachers nervous, but many are also
excited about the rich learning opportunities that may be introduced in the classroom.
These changes can be brought to the classroom if school systems and teacher education
programs are willing to work together to provide the support and knowledge in answer to
teachers’ concerns.

Future Research

As I stated in the first chapter, very little is known about teachers as designers or
as participants in professional development about engineering education. I view this work
as an exploratory study that has provided a small glimpse of these two issues. I was able to reveal a good deal about these teachers’ concerns and how they designed solutions to open-ended challenges. However, there are lessons to be learned from my methods that could lead to better data collection in future studies. As most research does, this project raised more questions to me than it seems to answer. Below I present my recommendations for future research methods and directions.

Data Collection Methods

A population of twelve teachers allowed for an intimate learning environment and the collection of rich data about the design processes of these teachers, but could not produce the quantity of data required for statistical analysis. A larger scale study would be necessary to see significant results and to reveal any true differences between the three treatments I used. At the same time, having several teachers and only one camera, which I needed to control, caused the video gathered to be less than ideal. Multiple cameras, or fewer teachers per session, would do a great deal to solve this problem, as would individual microphones.

Directions for future study

Causes of ‘Builder’ and ‘Programmer’ Mentality

One of the strong themes that arose in this research was the concept of a builder or programmer mentality, as described in Chapter Four. However, the present research could not discover the causes of these mentalities, but understanding how experience or personality feeds into them would help to understand how to best address them during the workshop. This connection between skills and confidence is an area that needs to be
further explored. It is intuitive to link improving skills and greater confidence, but to what extent is unknown.

*Extending Research Beyond the Workshop*

While this research’s focus was on the inservice teachers as learners in a professional development setting, the goal of most professional development is to affect classroom change and ultimately student learning. It would be interesting to investigate if confidence levels in the teachers are related to classroom implementation (e.g. “Do the teachers who are more confident implement engineering in their classrooms more readily than teachers who are less confident?”). If teachers do implement the engineering activities in their classrooms, I hypothesize that the ways that they do this would be quite varied, leading to the question: “How do teachers implement what they learn in a professional development workshop, and what obstacles must they overcome?”

Student learning should also be addressed. Do increased teacher confidence levels affect student outcomes, and in what way? Increased confidence could lead to more effective lesson design or to simply better presentation of the material, resulting in the question, “How are teacher confidence and student outcomes related?” If certain types of engineering activities improve student understandings, it is important to learn the connection between teacher education and implementation so that effective activities can reach more students.

In Chapter Three I presented the concerns these teachers had with implementing engineering design in their classroom. Support, especially having additional adults in the classroom, was highly requested. Investigating the interplay of roles in the classroom by
looking at the classroom as a system could provide great insight into effective classroom practice and support.

“Tipping Points”—When Does a Teacher Become Comfortable?

One teacher in the Design Discussion group, Jackie, had among the lowest levels of confidence in all the survey indicators discussed in Chapter Seven. What kept Jackie at the “not very comfortable” level in teaching design? Is there any way to increase her comfort with engineering design activities, or are such activities not for every teacher? It seems that each teacher has a distinct moment where they step from one level of understanding to the next—a moment where the knowledge seems to “sink in.” Future research should address the nature of these tipping points and when they occur. This knowledge could aid teacher educators in helping teachers reach these tipping points.

Conclusions

The research conducted in this study has been a small step in understanding engineering education for teachers. I have described the concerns held by the twelve teachers in this professional development workshop and shown patterns in their design processes. Throughout I have presented findings and recommendations from the data. In this final chapter I have laid out the implications that I believe this research has for teacher education and including engineering design in the K-12 classroom. However, engineering design in the K-12 classroom is a fairly new area for educational research. Methods of assessment and analysis are still being developed and there are many questions left to investigate. The directions for research that have developed from this small scale study have laid a path for developing understanding of professional development and the engineering design process.
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APPENDIX A: SURVEYS

Creative Design Projects Workshop
Survey, Week 1

1. In LEGO building, do you consider yourself to be a(n)
   - beginner
   - intermediate
   - expert

2. How confident are you of your LEGO building abilities?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

3. In building with other materials (wood, popsicle sticks, etc), do you consider yourself to be a(n)
   - beginner
   - intermediate
   - expert

4. How confident are you of your building abilities with other materials?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

5. In ROBOLAB programming, do you consider yourself to be a(n)
   - beginner
   - intermediate
   - expert

6. How confident are you of your ROBOLAB programming abilities?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

7. How confident are you of your computer programming abilities overall (including other programming languages such as C++ or BASIC)?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident
8. How confident are you in your knowledge of basic engineering concepts (such as force)?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

9. If given the necessary materials, how confident are you that you could design a solution to a given problem? (Such as constructing a mousetrap)
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

10. Would you feel comfortable engaging your students in an engineering design project?
    - Very comfortable
    - Moderately comfortable
    - Slightly comfortable
    - Not very comfortable

11. Approximately how many class periods did you spend doing engineering/technology-related activities with your students?
    a. this year ____________________________________________________________
    b. in previous years ____________________________________________________

12. Please briefly describe any engineering/technology related activities and projects that you used in your classes this year.
    _________________________________________________________________
    _________________________________________________________________
    _________________________________________________________________

13. What sort of professional development or training would be most valuable to you with regards to engineering design?
    _________________________________________________________________
    _________________________________________________________________
    _________________________________________________________________
14 What do you see as the biggest obstacles to including engineering design in your K-8 classroom?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

15. What kind of support would you want/need to include engineering design in your classroom?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

16. Are there any topics or concepts being taught in this course that you are concerned you will have difficulty learning? If so, which ones?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

17. Are any of your close relatives (parents, children, spouse, etc) involved in an engineering or technology related profession?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
Creative Design Projects Workshop
Survey, Week 2

1. Compared to last week I am _____________ in my LEGO building abilities?
   - Much less confident
   - Slightly less confident
   - Equally as confident
   - Slightly more confident
   - Much more confident

2. Compared to last week I am _____________ in my building abilities with other materials?
   - Much less confident
   - Slightly less confident
   - Equally as confident
   - Slightly more confident
   - Much more confident

3. Compared to last week I am _____________ in my ROBOLAB programming abilities?
   - Much less confident
   - Slightly less confident
   - Equally as confident
   - Slightly more confident
   - Much more confident

4. Compared to last week how confident are you in your knowledge of basic engineering concepts (such as force)?
   - Much less confident
   - Slightly less confident
   - Equally as confident
   - Slightly more confident
   - Much more confident

5. If given the necessary materials, how confident are you that you could design a solution to a given problem? (Such as constructing a mousetrap)
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident
6. Would you feel comfortable engaging your students in an engineering design project?
   - [ ] Very comfortable
   - [ ] Moderately comfortable
   - [ ] Slightly comfortable
   - [ ] Not very comfortable

7. Using the LEGO bricks helps to understand basic engineering concepts (such as force).
   - [ ] Strongly disagree
   - [ ] Disagree
   - [ ] Indifferent
   - [ ] Agree
   - [ ] Strongly agree

8. Using ROBOLAB helps in understanding the process of design.
   - [ ] Strongly disagree
   - [ ] Disagree
   - [ ] Indifferent
   - [ ] Agree
   - [ ] Strongly agree

9. Studying engineering helps to improve math and science skills.
   - [ ] Strongly disagree
   - [ ] Disagree
   - [ ] Indifferent
   - [ ] Agree
   - [ ] Strongly agree

10. Engineering is a valuable subject for my students.
    - [ ] Strongly disagree
    - [ ] Disagree
    - [ ] Indifferent
    - [ ] Agree
    - [ ] Strongly agree

11. Engineering is a creative field.
    - [ ] Strongly disagree
    - [ ] Disagree
    - [ ] Indifferent
    - [ ] Agree
    - [ ] Strongly agree
Creative Design Projects Workshop  
Survey, Week 3

1. Compared to last week I am _____________ in my LEGO building abilities?
   [ ] Much less confident
   [ ] Slightly less confident
   [ ] Equally as confident
   [ ] Slightly more confident
   [ ] Much more confident

2. Compared to last week I am _____________ in my building abilities with other materials?
   [ ] Much less confident
   [ ] Slightly less confident
   [ ] Equally as confident
   [ ] Slightly more confident
   [ ] Much more confident

3. Compared to last week I am _____________ in my ROBOLAB programming abilities?
   [ ] Much less confident
   [ ] Slightly less confident
   [ ] Equally as confident
   [ ] Slightly more confident
   [ ] Much more confident

4. Compared to last week how confident are you in your knowledge of basic engineering concepts (such as force)?
   [ ] Much less confident
   [ ] Slightly less confident
   [ ] Equally as confident
   [ ] Slightly more confident
   [ ] Much more confident

5. If given the necessary materials, how confident are you that you could design a solution to a given problem? (Such as constructing a mousetrap)
   [ ] Very confident
   [ ] Moderately confident
   [ ] Slightly confident
   [ ] Not very confident
6. Would you feel comfortable engaging your students in an engineering design project?
   - Very comfortable
   - Moderately comfortable
   - Slightly comfortable
   - Not very comfortable

7. Using the LEGO bricks helps to understand basic engineering concepts (such as force).
   - Strongly disagree
   - Disagree
   - Indifferent
   - Agree
   - Strongly agree

8. Using ROBOLAB helps in understanding the process of design.
   - Strongly disagree
   - Disagree
   - Indifferent
   - Agree
   - Strongly agree

9. Engaging in engineering projects helps to improve math and science skills.
   - Strongly disagree
   - Disagree
   - Indifferent
   - Agree
   - Strongly agree

10. Engineering projects would be/are valuable for my students.
    - Strongly disagree
    - Disagree
    - Indifferent
    - Agree
    - Strongly agree

11. Engineering projects involve creativity.
    - Strongly disagree
    - Disagree
    - Indifferent
    - Agree
    - Strongly agree
12. Engineering problems have one correct solution.
   [ ] Strongly disagree
   [ ] Disagree
   [ ] Indifferent
   [ ] Agree
   [ ] Strongly agree

13. I feel comfortable telling my students I do not know the answer to a question.
   [ ] Strongly disagree
   [ ] Disagree
   [ ] Indifferent
   [ ] Agree
   [ ] Strongly agree

14. I would feel comfortable engaging my students in a problem if I did not know what path we would take to reach a solution.
   [ ] Strongly disagree
   [ ] Disagree
   [ ] Indifferent
   [ ] Agree
   [ ] Strongly agree
Creative Design Projects Workshop
Final Survey

1. In LEGO building, do you consider yourself to be a(n)
   - beginner
   - intermediate
   - expert

2. How confident are you of your LEGO building abilities?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

3. In building with other materials (wood, popsicle sticks, etc), do you consider yourself to be a(n)
   - beginner
   - intermediate
   - expert

4. How confident are you of your building abilities with other materials?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

5. In ROBOLAB programming, do you consider yourself to be a(n)
   - beginner
   - intermediate
   - expert

6. How confident are you of your ROBOLAB programming abilities?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

7. How confident are you in your knowledge of basic engineering concepts (such as force)?
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident
8. If given the necessary materials, how confident are you that you could design a solution to a given problem? (Such as constructing a mousetrap)
   - Very confident
   - Moderately confident
   - Slightly confident
   - Not very confident

9. Would you feel comfortable engaging your students in an engineering design project?
   - Very comfortable
   - Moderately comfortable
   - Slightly comfortable
   - Not very comfortable

10. This workshop was related to what I teach/would like to teach in my classroom.
    - Strongly disagree
    - Disagree
    - Indifferent
    - Agree
    - Strongly agree

11. I will use something I have gained from this workshop in my classroom in the future.
    - Strongly disagree
    - Disagree
    - Indifferent
    - Agree
    - Strongly agree

12. This workshop was a valuable experience for me.
    - Strongly disagree
    - Disagree
    - Indifferent
    - Agree
    - Strongly agree
13. Which activity or aspect of this workshop (all 3 sessions) was most valuable to you?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

14. Which activity or aspect of this workshop (all 3 sessions) was least valuable to you?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

15. If you were to engage your students in an engineering design challenge, how would you describe your role in the classroom?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

16. What changes would you suggest for this workshop if it were taught again in the future?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

17. Any additional comments on the workshop:
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
APPENDIX B: CODING SCHEME

The some of codes used had major and minor categories and are displayed below as follows:

**Code Group**: description

*Major Code*: description
*Minor Code*: description

**Questions**: These codes were used for any time a participant asked the instructor or another participant for assistance

- **Building**: Questions asked about building with the LEGO pieces
  - **Technical**: Questions about using a specific piece
  - **Conceptual**: Questions where the participant needs assistance moving from a mental idea to physical construction
- **Programming**: Questions asked about programming in ROBOLAB
  - **Technical**: Questions about a specific programming icon or task
  - **Conceptual**: Questions where the participant needs assistance moving from a mental idea to a computer program

**Design Activity**: These codes were used to describe particular behaviors and discussion during the design sessions

- **Example**: Participants refer to a model or example program provided by instructor
- **Discussion of Future Steps**: Participants discuss steps they will need to take in another part of the design.
  - **Building while Programming**: Participants discuss building tasks while programming
  - **Programming while Building**: Participants discuss programming tasks while building
  - **Disconnect**: Participants have trouble connecting their construction to their program (particularly the use of sensors).
- **Discussion of EDP**: Participants directly discuss the engineering design process

**Attitude**: These codes were used to describe statements about what participants liked or did not like about building and programming

- **Building**: Participants discuss attitude toward building
  - **Positive**: Participants express an inclination for building
  - **Negative**: Participants express a dislike for building
- **Programming**: Participants discuss attitude toward programming
  - **Positive**: Participants express an inclination for programming
  - **Negative**: Participants express a dislike for programming
### APPENDIX C: VIDEO CONCEPT MAPPING

#### Appendix C:
Key to Video Concept Mapping Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>▲</td>
<td><strong>Problem Statement</strong></td>
<td>&quot;I'm thinking about doing a cantilevered bridge&quot;</td>
</tr>
<tr>
<td>□</td>
<td><strong>Physical Observation</strong></td>
<td>&quot;This one uses crown gears&quot;</td>
</tr>
<tr>
<td>○</td>
<td><strong>Idea to try (mental)</strong></td>
<td>&quot;Ok, so I have to get it so it goes back and forth somehow&quot;</td>
</tr>
<tr>
<td>□</td>
<td><strong>Idea to try (physical)</strong></td>
<td>&quot;We should add this piece to secure the motors&quot;</td>
</tr>
<tr>
<td>□</td>
<td><strong>How it works</strong></td>
<td>&quot;When I turn this, it turns the gear, and it spins on top.&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Connections</th>
<th>Ordinary</th>
<th>Hypothetical</th>
<th>Technical Help</th>
<th>Conceptual Help</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actions that lead from one to another</td>
<td></td>
<td></td>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>Actions that do not lead from one to another</td>
<td></td>
<td></td>
<td>→</td>
<td>→</td>
</tr>
<tr>
<td>Actions that move from one task to another</td>
<td>\</td>
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<td>\</td>
</tr>
</tbody>
</table>
APPENDIX D: ENGINEERING DESIGN PROCESS WORKSHEETS

Guide to the Engineering Design Process

Step 1: Identify the need or problem.

We are building a robotic zoo that needs animals. The robots need to resemble the animals and have behaviors.

Step 2: Research the need or problem.

Resources- KIME website, examples on table, constructopedia pages
Notes:
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Additional things to consider:
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Step 3: Develop possible solutions.

Possible animals and behaviors I could build:
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Step 4: Select the best possible solution.

I will build:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Step 5: Construct a prototype.

Notes:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Step 6: Test and evaluate solutions.

What works well:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

What doesn’t work:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
**Step 7:**
**Communicate the solution.**

Report to the group on your animal.

Notes:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

**Step 8:**
**Redesign.**

If you were to rebuild or reprogram your animal, how would you change it?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
APPENDIX E: WORKSHOP ADVERTISEMENT AND APPLICATION

Creative Design Projects Workshop
for upper elementary teachers

- Learn about engineering and design by engaging in LEGO building projects!
- Learn to use LEGO Mindstorms construction kits and ROBOLAB software
- Participate in a study to help improve professional development
- Participants completing the study will be offered assistance and materials for a one-day custom LEGO project in their classroom
- Earn 10 PDPs
- FREE!

The workshop will consist of 3 three-hour sessions on Tuesdays, Wednesdays or Thursdays in February from 5pm to 8pm. Each session will be structured around a creative design challenge. The FREE workshop is designed for elementary teachers, grades 3-5, with little or no prior experience with LEGO Mindstorms or ROBOLAB. Participants will gain experience in design and building with LEGO bricks along with learning programming and engineering skills. The workshop is being conducted as part of a master’s thesis research project focused on design and professional development. Participation in the study is voluntary. Participants’ names and personal information will be kept confidential in the research.

Space is limited! To reserve your spot, please return the attached application as soon as possible to:

Erin Cejka
Center for Engineering Educational Outreach
Tufts University
474 Boston Ave
Medford, MA 02155

Workshop Instructor:
Erin Cejka is a graduate student in Tufts University’s Department of Education. She is pursuing a M.A. in Educational Studies with a focus on Math, Science, Technology, and Engineering Education. She received her B.S. in Mechanical Engineering from Tufts University in May 2003. She has worked for the Center for Engineering Educational Outreach since 2001 collaborating with teachers on curriculum and assisting with professional development workshops. She has additionally run workshops for educators in North Carolina and Texas.

Workshop Location:
The workshop will be held at Tufts University’s Center for Engineering Educational Outreach (CEEO). The CEEO is located in the basement of Curtis Hall on Tufts University’s Medford campus. For directions, please visit http://www.ceeo.tufts.edu/about/directions.asp

Additional Questions can be directed to Erin at:
Erin.Cejka@Tufts.edu
617-627-3418
Creative Design Projects Workshop

Application

Name:_________________________________________
Address:_______________________________________
____________________________________________
Telephone: (_____)________-__________Email Address:_________________
School:________________________________________
School’s Address:________________________________
____________________________________________
School phone: (______)________-____________

Workshop session: Please rank your 1st, 2nd, and 3rd choice. If you cannot attend
one session, please mark with an “X”
_______ Tuesdays, 5pm to 8pm. February 3, 10, and 24
_______ Wednesdays, 5pm to 8pm. February 4, 11, and 25
_______ Thursdays 5pm to 8pm. February 5, 12, and 26

Grade(s) taught:_________ Years of teaching experience:______________

Any prior experience with LEGO Mindstorms or ROBOLAB: (circle one)
Yes   No
If yes, please describe:____________________________________________
___________________________________________________________

In general, please describe your prior experience with LEGO:
___________________________________________________________
___________________________________________________________

Prior experience with computers:________________________________
___________________________________________________________
___________________________________________________________
Objective:
Build a music box in which figures twirl (or move in some other way) while a tune plays.

Challenge:
1. Decide on a theme for your music box.
2. Build a music box with figures that move in different ways—in opposite directions, at varying speeds, etc. If you wish, you can even have a figure move back and forth instead of turning.
3. Program a tune on your RCX for the music box. Your tune should play two or more times whenever you press Run.

**Bonus**: 
1. Add a touch sensor or light sensor to your music box that begins the music and movement.
2. Design a lid for your music box that, when opened, activates the touch or light sensor (starting the music and dancing).
Robotic Animals

During this challenge we will create a robotic zoo. Each animal will be unique.

Each robotic animal should look like the real thing. Both LEGO materials and paper/craft materials can be used.

Each robot should move like the animal would move (bird’s wings flap, rabbits go fast, and turtles go slow…)

Each robot should have a special behavior to give it personality. For example, if you pat the rabbit on its back, its head will turn.

Try to:
- Use type of motion other than just wheels turning
- Incorporate a sensor
- Use gears or pulleys

Look at the KIME exhibit for more ideas:
http://www.ceeo.tufts.edu/KIME/exhibits/zoo/zooexhibit.asp

Most importantly: Be creative!

Extension: Build a habitat for your animal or a structure to complete our zoo. Again, try to use a sensor (to trigger a gate? or a feeding mechanism?)
Interactive Sculpture

• Must include at least one sensor
• Must display at least two different moving parts
• Think about different kinds of motion
• Create a name or theme
• Extension
  • Include music / lights