Inservice Teachers and the Engineering Design Process

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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 adopt technology/engineering standards as part of the state curriculum frameworks in 2001. This significant policy change has produced an increased need for professional development and teacher education efforts in engineering and technology. The overall lack of content knowledge and experience in engineering and technology among teachers, especially at the elementary level, will impact the ways these teachers address the frameworks in their classrooms. Previous research in this area has shown that perceptions about engineering and technology can change positively after preservice teachers took on their own design projects[1]. Little, however, is known about the design processes that teachers use in such projects. Additionally, there is a significant lack of research in this area regarding inservice teachers. Knowing more about these processes, as well as effective methods of supporting teachers during the learning process, will help to inform teacher education efforts.

This paper outlines a research project aimed at developing an understanding of the design process of inservice teachers. This project focuses on twelve Massachusetts teachers in grades 3 to 8 who participated in a professional development workshop in engineering design. Their learning process and concerns about implementing engineering design activities in the classroom are studied through analysis of video taped design sessions and survey data. Directions for further research in this area, as well as preliminary conclusions to inform teacher education, are presented.

Literature Review

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. Ultimately, the goal of any teacher education program is create a classroom change to improve the learning environment for the students. To do this, professional development in engineering needs to enhance teachers' content knowledge, discuss conceptions of engineering (held by students and adults alike), and delve into constructionist pedagogy.

The Engineering Design Process

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The engineering design process is a central component of the ITEA standards[2] as well as the technology/engineering standards in Massachusetts[3]. 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"[4]. The engineering design process has been modeled in a number of ways, each containing the key phases. However, there is some argument about what the correct model of the design process would look like, and some argue that no model can describe the reality of design accurately [5,6].

So why do we use a model at all? In working with preservice teachers in Australia, Sarah Stein, Campbell McRobbie, and Ian Ginns 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". The preservice teachers found models useful for identifying opportunities to scaffold their students and insight into ways the students' work may be assessed[7]. Perhaps, these models may also be useful in scaffolding 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.

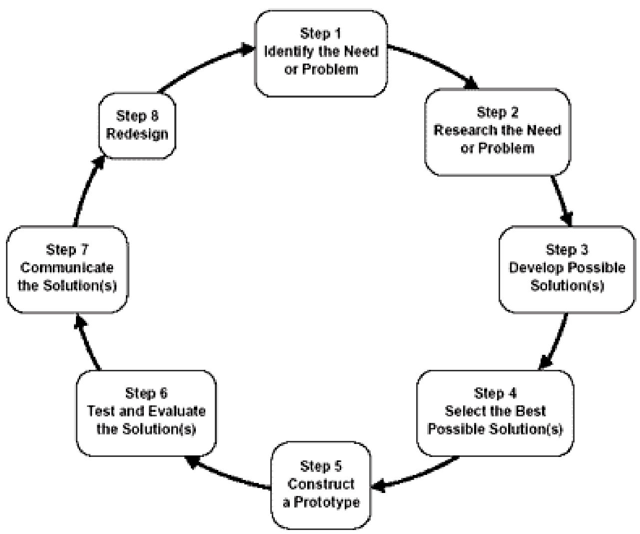

Figure 1: Steps of the Engineering Design Process. From the Massachusetts Department of Education Curriculum Frameworks[8], this is the model of the engineering design process used throughout the study.

The eight steps laid out here cover the process involved in creating a solution to an 'open-ended engineering design problem'. This model was chosen because the target audience for the workshop was Massachusetts teachers, and this model is a part of the frameworks they are very concerned about addressing. I anticipated (and the results below indicate) that including the process as laid out by the frameworks would be a source of comfort for these teachers.

Teachers' Concerns and Preconceptions

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Teachers often hold practical concerns about implementing engineering design activities. They wonder where they will fit in an already overburdened curriculum[9], 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[10]. They require support from the administration to both implement these activities and receive training [11]. 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[12]. 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'" [13]. Finally, teachers wonder what the students are learning from such projects, especially if they do not hold constructivist theories of learning[14]. Though this same question- what are the students learning? - has been posed about traditional teaching methods that are often focused on fact and procedure memorization [15]. However, teacher education and professional development programs can influence both these concerns about the content of engineering[16,17] and theories of learning and teaching[18].

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[19]. 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[20]. 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 [21]. They generally have only a superficial knowledge of the related subject matter of technology[22] and do not possess much knowledge of engineering [23]. It is of little surprise then that they do not value engineering education and wonder what their students learn from engaging in design activities[24]. 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[25]. 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[26,27].

What preconceptions do teachers hold about engineering, design, and technology? McRobbie, Stein, and Ginns 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[28].

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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[29,30]. When teachers have to venture into new and unfamiliar territory, extra work, additional commitment, and flexibility within the new environment are required from them[31,32,33]. For these reasons, and often a lack of administrative support, teachers often prefer traditional methods[34]. The teachers who do venture into this new realm must have both strong pedagogical and content knowledge to remain comfortable in their classrooms[35]. These challenges however can be overcome with support and professional development so that the rewards, evident in the students' learning, can be achieved.

Professional Development and Classroom Change

In her work studying teachers and mathematics reform, Deborah Ball 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". In this way, teachers' past experiences "can often act as obstacles" to changing the nature of the classroom and student learning[36]. Teachers may encounter problems engaging in 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[37]. This has been shown to influence teachers' use of computers[38] and likely influences implementation of engineering activities.

Continually, Deborah Ball has challenged teacher educators in mathematics to rethink what they 'know' about teacher learning [39,40]. One of her most interesting discussions is about the practice of 'modeling' pedagogical techniques and curriculum to teachers as they would teach their students. 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 [41], and has been put forth by very prominent figures in educational research[42]. 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". Challenging the knowledge of students is "a different pedagogical undertaking" entirely from challenging the knowledge of adults [43].

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 [44]. 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[45] without many of the preconceptions held by adults. If experience and time have caused adult teachers to gain some negative conceptions

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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.

Teachers and Design

Though there has been much research done about students engaging in open-ended engineering design problems [46,47,48,49] and some research about preservice teachers [50,51], there seems to be no research about inservice teachers in this area. Campbell McRobbie, Sarah Stein, and Ian Ginns' research with preservice teachers provides the most useful insights for the proposed research. Preservice teachers defined their tasks and stuck with their general plan throughout the activity[52]. This is in contrast to younger students that other research has shown do not adhere to a single plan [53,54]. Additionally, the preservice teachers used systematic testing procedures to optimize their solutions[55], while younger students have a harder time making the transition away from trial and error[56]. 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.

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 poses 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.

Study Overview

Many organizations are calling for children to be exposed to engineering and design before they reach the college level, even in elementary school (ITEA, AAAS, etc). Massachusetts has even included engineering/technology as a strand of their frameworks on a level equal to biology. But are the teachers prepared for these changes? Do they feel comfortable leading their students in the design activities these organizations recommend? What can be done to help these teachers meet the new standards that they are faced with? These were the questions I was hoping to address when designing this study. As someone who has been involved with professional development in Massachusetts for several years, I wondered about these things. I decided to look at these questions during a professional development workshop in February 2004. Specifically, my questions were:

1. What approaches do Massachusetts inservice teachers, grades 3 – 8, take to solving open-ended engineering design problems presented within a professional development setting?

2. In what ways will their personal design processes change with varied exposure to the model of the engineering design process provided by the Massachusetts Frameworks[57]?
3. 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?

Study Population and Design

The participants for this study were drawn from a professional development workshop held in February 2004. The workshop, entitled Creative Design Projects, was advertised to Massachusetts educators as an opportunity to learn about engineering and design using the LEGO Mindstorm Construction Kits and ROBOLAB software. The study's population comprised of 12 teachers from Massachusetts schools - seven from public schools, and five from private. The teachers taught in grades from 3 to 8. There were 11 females and 1 male. While the number of participants is small, this study was conceived as a pilot study to inform larger scale investigations of professional development in engineering design. The sample in this study is obviously too small to draw many 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.

The study was focused around the workshop with three sessions, allowing for a pre-assessment, intervention, and post-assessment design. During the initial session, I was interested in gathering information about what the teachers brought with them to professional development. 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 hoped to shed light onto these issues so that I could better understand the audience of similar professional development workshops.

Workshop

The workshop was advertised as a professional development opportunity for teachers who wanted to introduce engineering through creative classroom projects. The workshop aimed to give teachers beginning skills building and programming with 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. Additionally, they contain motors and sensors that can be controlled by a large LEGO brick containing a microprocessor, known as the RCX. The RCX can be programmed from a computer using the ROBOLAB software. ROBOLAB is a graphic based programming language used in over 50,000 schools worldwide. 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. Although it was not a requirement, all of the teachers who participated in the workshop had access to this technology at their schools.

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The workshop met for three sessions with each session lasting three hours. Each session was focused around a main design challenge. 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 be introduced and discussed by the group. When the group felt comfortable with the objectives, the participants would break off into pairs or individually to begin their design. The participants were given full control over the design and how they wished to make their final project. They had access to extra LEGO pieces, computers, the internet, and were encouraged to ask questions to their peers or the instructor. At the end of each session there was a design circle were the participants presented and discussed their designs.

Each session was focused around a design challenge. In the first session, the participants were asked to create a "music box". It had to have at least 2 moving parts and play music. In the second session, the participants were asked to create a robotics animal. 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.

For the purpose of the study, three groups participated in the workshop. Each group received a varied amount of exposure to the engineering design process. The *No Design* group, containing four teachers, did not receive any exposure to the design process during the course of the workshop. The *Design Exposure* group, containing three teachers, was told about the design process, but did not discuss it. The *Design Discussion* group, with five teachers, held a lengthy discussion about the design process and was given design worksheets to examine and use if they chose.

Data Sources and Analysis

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 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 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 LEGOs, 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'. The each response to the questions regarding the teachers' comfort with the LEGOs, ROBOLAB, and design was combined and then averaged to create the Lego Design Comfort Index. 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 may be identified nonetheless. The surveys can be found in appendix A.

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All of the design challenges were videotaped. 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. The mapping system was developed from the system used by McRobbie, Stein, and Ginns[58] in their study of preservice teachers. It creates a detailed account of the design process of each participant, hopefully providing an insight into how they think through the design process. Additionally, some teachers provided lesson plans that they planned to use in their classroom. At this time, analysis of the videotapes is still being conducted, so I will focus my results on the survey data and my notes from the workshop sessions, adding some details from the video. Full results of the video analysis will be presented later.

Results

Preconceptions and Concerns – Survey One

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?" A large number 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. For me, this indicates 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, 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. This touches on issues of both teacher confidence and student ability. 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 and allowing students to explore pieces through open-ended building. These issues of pedagogy could be addressed through professional development and may be important to areas to concentrate on when constructing teacher education opportunities.

In previous teacher education projects, classroom support was citied as a critical help component during implementation of engineering design in the classroom[59]. Classroom support can vary

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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 lessons. 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.

Also, 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 will allow curriculum developers, teacher educators, universities, school districts, and others interested in bring engineering design to make the best use their resources.

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 what topics teachers think they need professional development in, 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!"

Builders and Programmers

Throughout the first session, many teachers expressed that it was difficult for them to build with the LEGOs. For some it was simply a matter of not having used LEGOs in a long time, or having never seen pieces like axles and gears. For others, the problem was more of 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 LEGO construction. 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

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program to initiate that movement. Similar comments, like “I’m not a computer person” and “I’m more hands-on” were made at the computers. Two groups were emerging – programmers and builders.

This division continued into the following sessions. It was 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. There was still some 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 LEGOs]”. They were beginning to use the physical pieces to explore their mental ideas. 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. The teachers in both the second and third groups (who had been exposed to the design process) were more likely to write some sort of plan – either for the programming or the construction – than those in the group that did not discuss the design process at all. This may have allowed them to create projects that were closer to their original conception. However, the quality of the projects (their sturdiness, complexity) was not different among the groups.

In the third session, the difference between the builders and the programmers was 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 third group, one programmer was very anxious to use the programming structure called Events, and created her entire project around that. On the other hand, one builder really wanted to explore the gear rack, so she spent the majority of the session designing a construction incorporating that piece, and only used a very simple program. One programmer went so far as to plan out her entire program before touching the pieces (See figure 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.

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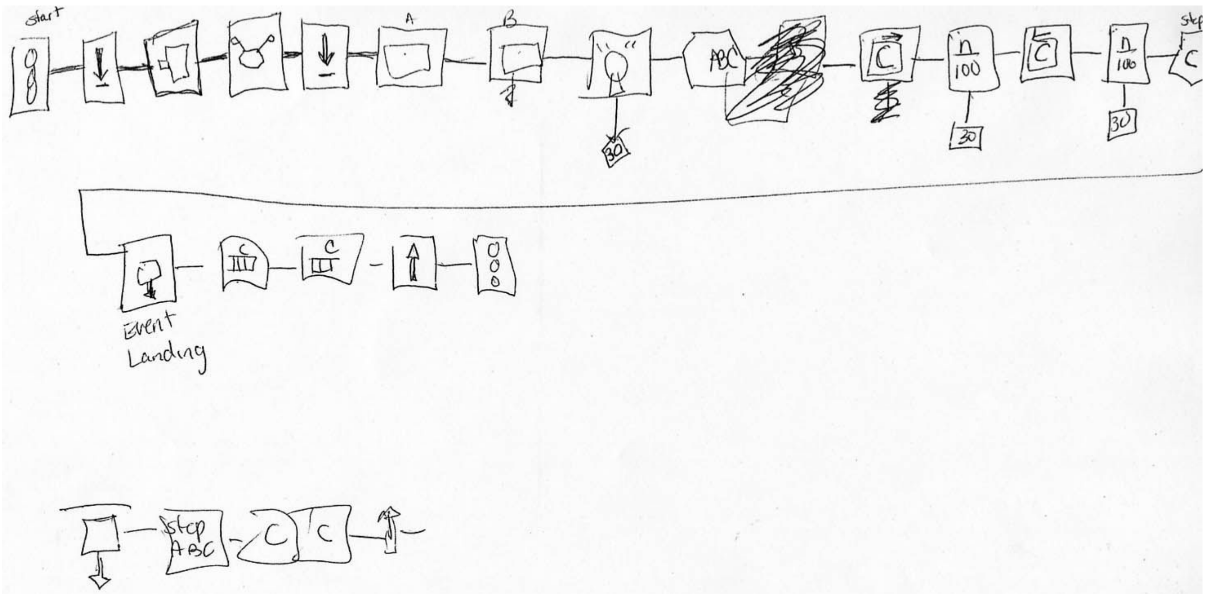

Figure 2: The School Bus Program. One of the members of the *Design Discussion* group created this plan for her program before she began building during the final session.

While this is 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 LEGOs, 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 first and second 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.

The *Right* Answer

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

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> they were having problems with, and I knew how to fix it and want to be able to that with this too."

For this teacher, 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[60] 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, she 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."

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. This perspective does not leave much room for the flexibility and multiplicity of solutions and designs in engineering. 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.

After discussing the design process during the second session, this teacher became more open to the idea of multiple solutions. She 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".

Throughout the workshops, it was clear she was not the only one who felt this way. One interesting thing was how many of the teachers relied on example projects I provided to create their projects. I wanted to provide these examples as inspiration, or 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 I had created an example of exactly 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

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last two sessions, this activity was most prevalent among, but not limited to, those in group one 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. 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.

Overall Results – Survey Comparisons

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. Generally, teacher confidence increased from prior to the workshop to its completion. The Lego Design Confidence Index, which was created by combining the teachers' responses to questions concerning their confidence in their building, programming and design skills. In the graph below, each teachers' Confidence Index is plotted from the initial and final sessions. The results are presented for each participant, separated by group, and the overall average is shown as the last set of bars. 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". An index of 4 would indicate "very confident" responses to all questions. While some 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.

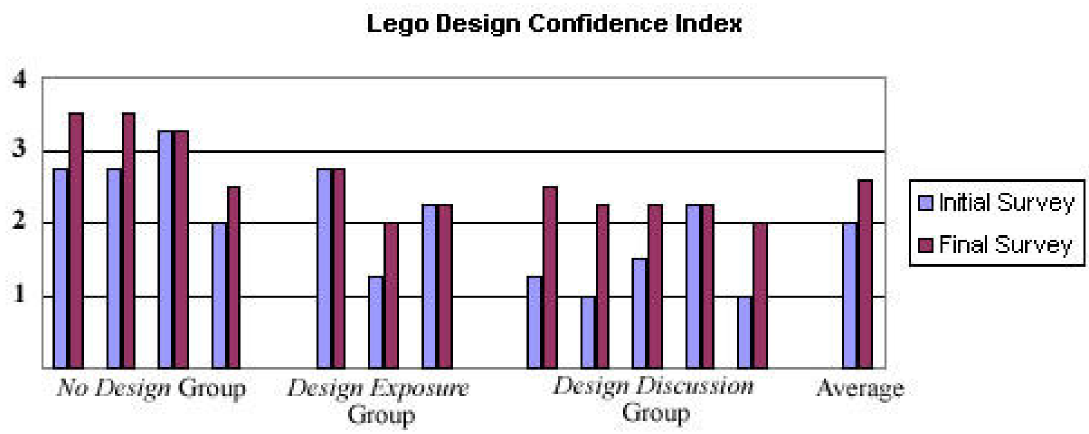

Figure 3: Lego Design Confidence Index. The Lego Design Confidence Index is a composite of the participants' answers to questions regarding their confidence with their building, programming, and designing abilities.

I was interested in comparing these gains across groups. However, I noticed that the groups did not start out evenly. The *No Design* and *Design Exposure* groups held most of the participants with originally high confidence. The *No Design* group showed some gain in confidence index, while group two showed little gains. The *Design Discussion* group showed many people with large gains. Again, however, they stared with a lower overall confidence. These results therefore cannot be said to be related to the group and exposure to design process, but it can be said that the workshop overall was successful in raising the confidence of those who were not confident or only slightly confident to a level of moderate confidence.

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This same trend was noticed in two other important indicators. This workshop was created to improve the design skills of the participants, with the ultimate goal of helping these teachers bring engineering design into their classroom. To gauge the success of these objectives, participants' answers to questions regarding their confidence in their design skills (Figure 4) and their comfort with teaching a design activity (Figure 5).

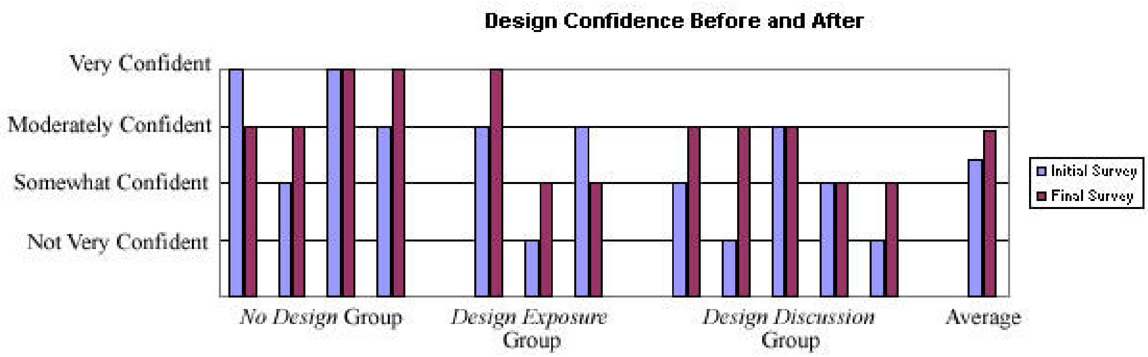

Figure 4: Design Confidence. This graph compares the initial and final answers by each participant to the question "If given the necessary materials, how confident are you that you could design a solution to a given problem?"

The participants in the *No Design* group started with a higher than average confidence, and all ended the workshop reporting high or moderate confidence levels in their design skills. The *Design Discussion* group started with mainly low levels of confidence, but by the final sessions, all participants reported slight to moderate confidence in their design skills as well.

How did these skills translate into the teachers' comfort with teaching design? Overall, teachers reported a higher level of confidence with leading their students in an engineering design activity than in their own design skills, which was a surprising result. This may be due to the wording of the questions asked. Teachers may not have been confident in their ability to solve a problem on their own, but felt comfortable leading their students through the design process.

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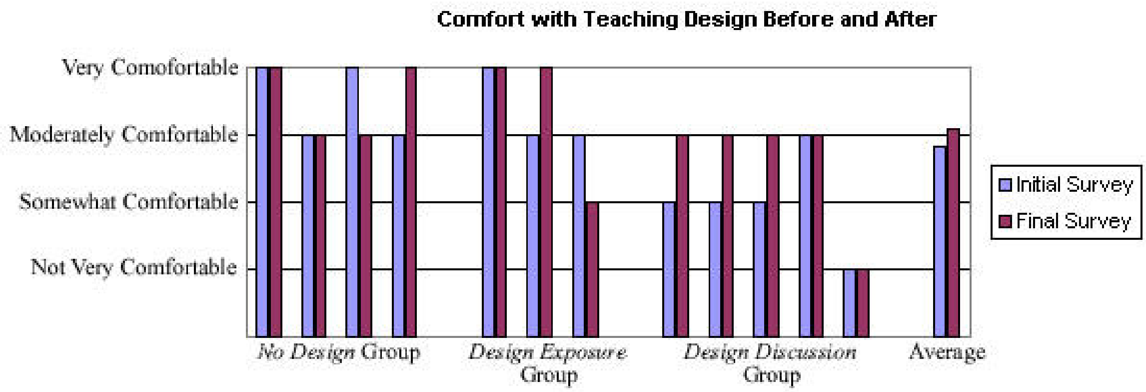

Figure 5: Comfort with Teaching Design: This graph compares the initial and final answers by each participant to the question "Would you feel comfortable engaging your students in an engineering design project?"

The *No Design* group started and finished with higher than average comfort levels. By the last session, all reported high to moderate levels of comfort with teaching design to their students. The *Design Exposure* group also started with higher than average confidence. In the last session, most of the *Design Exposure* group reported they would be very comfortable leading their students in a design activity, but one reported being only somewhat comfortable. In the *Design Discussion* group, most participants started with a lower than average confidence, but ended with a moderate confidence in leading their students in an engineering design activity. However there was one participant who reports no confidence in each of the surveys. In future studies, it would be interesting to investigate through discussion with the teachers what lead to their improved confidence, or what kept them from gaining confidence during the workshop.

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, a member of the *Design Discussion* group, said they would definitely use something they learned in the workshop in their classroom.

Conclusions

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 describe 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 different 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. In the future, research will be conducted with a larger sample of teachers. Additionally, this study has no way of indicating the affects on students. Further study should be

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done about what aspects of such a professional development workshop make their way into the classroom and how this affects students. 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. This has been met with great approval by the participants. Future studies will allow the workshops to be further refined and made more effective.

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First of all I would like to thank the participants in my study for their openness and enthusiasm. Without the help of many people, this work would not have been possible. I would like to thank Merredith Portsmore, Emily Ryan, Analucia Schliemann and everyone at CEEO and TUFTL for their contributions, as well as my advisors Chris Rogers and Barbara Brizuela for their continual support.

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Appendix A

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

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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?

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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?

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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

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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

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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:

____

____

____

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