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To Pop or Not to Pop: Elementary Teachers Explore Engineering Design with Pop-Up Books

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Abstract: What is engineering? What do engineers do? What is the engineering design process? What is the relationship between engineering and the liberal arts? Why should we teach engineering in the elementary school classroom? What should engineering education look like in the elementary school curriculum?

This paper describes how a group of elementary school teachers pursued and answered these questions by exploring, experimenting with, and engineering pop-up books during a two-week professional development summer institute, held at a four-year liberal arts college in the northeastern United States. A team of faculty and students from the college's departments of Engineering and Education and a secondary school technology education teacher led the project-based institute.

The power and potential of pop-up books to teach teachers about engineering principles and design is the primary focus of the paper. The paper includes rich descriptions and examples of the pedagogical methods, models, and materials used to engage the teachers in paper engineering through their immersion into the world of pop-up books. The pedagogical strategies and project-based curriculum design of the institute reflect "best practices" as informed by the current cognitive science literature on teaching and learning. For example, the theoretical grounding for the instructional approach is rooted in inquiry-based teaching and learning models that foster and support the kind of discourse community essential for knowledge construction to take place. The paper illustrates how the social-collaborative context created during the summer institute guided and supported the teachers' developing understandings and skills in engineering education. Teachers report how the exploration and engineering of pop-up books teaches them about engineering principles and design processes and further inspires them to begin to integrate engineering education in their classrooms.

The Context for the Professional Development Institute: Background and Introduction
The Smith College Picker Engineering Program, the Department of Education and Child Study, and the Office of Educational Outreach at Smith College have formed the Engineering Education Partnership (EEP). This innovative partnership seeks to enhance the quality and expand the reach of engineering education for preK-16. The EEP's goals are to 1.) support the integration of engineering education into the preK-12 curriculum; 2.) respond to the call for engineering education reform at the college and university level; and, 3.) address the need to recruit and retain women and underrepresented minorities in science, engineering, and technology. Founded in 1999, Smith's Picker Engineering Program was created to establish Smith College as a center for excellence and innovation in engineering education, building on its leadership in

supporting women and minorities in science and engineering. As the nation's largest liberal arts college for women, Smith College encourages students to excel in fields that women have not traditionally entered in large numbers, thereby offering a unique environment for engineering education. The Picker Program's faculty of eight, five of whom are women, share a common vision for engineering education reform.

Within the Department of Education and Child Study at Smith, research programs focus on education in the sciences, mathematics, and technology. The Department's undergraduate and graduate teacher preparation programs and the Smith College Campus School (preK-6), which serves as a laboratory for education research, provide fertile ground for developing and field-testing K-12 engineering education initiatives. Department of Education and Child Study faculty members are working closely with the Picker Engineering Program to ensure that best educational practices are followed in developing a learner-centered curriculum that is well-aligned with the *Massachusetts Science and Technology/Engineering Framework* (2001). Department faculty members similarly are looking to Picker Engineering Program educators for assistance in their efforts to prepare and support future teachers to teach engineering education.

The Engineering Education Partnership (EEP) is currently engaged in a number of initiatives to support the development and delivery of K-12 engineering curricula based upon the *Massachusetts Science and Technology/Engineering Framework*. By becoming the first state to adopt a statewide *Science and Technology/Engineering Framework* for K-12 education, Massachusetts is leading our nation in recognizing the need to integrate engineering into K-12 education. . Beginning in 2002, the *Technology/Engineering Framework* became a major mandatory component assessed by the Massachusetts Comprehensive Assessment System (MCAS) Test. Although the *Science and Technology/Engineering Framework* now exists, few teachers, curriculum coordinators, or administrators throughout Massachusetts are familiar with technology/engineering content or how it can be implemented in the classroom. The Engineering Education Partnership is focused to help meet this need by working closely with school districts to develop and field-test K-12 engineering curricula, develop a certification program in technology/engineering, and develop professional development opportunities for in-service teachers. Of greatest relevance to this paper is a focused effort to discern and develop successful engineering pedagogies, and to bring them to K-12 students and teachers. The Summer 2004 Institute for Educators at Smith is an example of this effort.

Description of Summer 2004 Institute and Participants

The 2004 Summer Institute for Educators entitled Designing the Future for Teachers: Engineering Education K-12, was held on the Smith College campus for eight full days in July. The instructional team for the Institute included Smith faculty from the Picker Engineering Program and the Education and Child Study Department, the Director of Educational Outreach at Smith, and the head of the technology/engineering department at Amherst Regional High School. Smith undergraduate students in Engineering and Education served as student research and instructional assistants during the Institute.

The Institute instructional team sent the call for teacher participants to school principals of public schools from western Massachusetts, as well as the principal of the Smith College K-6 laboratory school, the Campus School. Twenty-one elementary, middle, and high school teachers from urban, rural, and suburban western Massachusetts schools answered the call and participated in the summer professional development institute. They represented newcomers to the field of engineering education as well as those who already teach engineering. Each teacher participating in the Institute had a colleague from his or her school also participating so that they could support each other in their engineering education initiatives when they returned to their classrooms in the fall. The Institute instructors believe that teachers need this kind of built-in support network to support and sustain new pedagogical practices in their respective schools and classrooms.

Before attending the Institute, the teachers completed a questionnaire to provide baseline data of their current conceptions about engineering, their experiences teaching engineering education, and their expectations for the summer institute. Specifically, teachers responded to the following questions:

- Brainstorm a list of ways that problem-solving is integrated into your classroom.
- What's your perspective on engineering? What do engineers do?
- How does engineering connect/fit with what you currently teach?
- What are your expectations/goals for your work in the summer institute?

The Institute instructors outline the following intended learning goals for teachers who attended the 2004 summer institute:
- Become familiar with the field of engineering and the *Massachusetts Science and Technology/Engineering Curriculum Frameworks*;
- develop a basic understanding of the engineering design process;
- develop an understanding of engineering as a pedagogical tool that integrates various academic disciplines and provides a mechanism for contextual learning; and,
- understand the relationship between engineering and the liberal arts.

The Summer Institute program included hands-on activities such as laboratory explorations of *Science Technology/Engineering Curriculum Framework* content knowledge and delivery according to grade level, as well as applications of the engineering design process through a variety of small design challenges such as re-engineering a pill bottle to accommodate people with physical disabilities and designing the longest flying paper airplane. Dr. Domenico Grasso, the Director of the Picker Engineering Program, delivered a lively and informative talk to the teachers about engineering and the human spirit. Following Dr. Grasso's talk, the participants viewed a video entitled The Deep Dive, focusing on the nature of an engineering design workshop environment. The Institute participants and instructors also calculated their ecological footprints and took a field trip to the lifelong kindergarten laboratory at MIT and artificial intelligence laboratories at Harvard. During the last days of the Institute, each teacher was required to develop a curriculum plan to integrate engineering into his or her classroom during the 2004-05 school year.

Each participating teacher received a monetary stipend, professional development points, and seed money to use for his or her curriculum project during the academic year. In November 2004, the teachers returned to the Smith campus for one day to report on their progress applying their engineering curriculum plans in their K-12 classrooms.

Ten of the twenty-one participants were elementary school teachers, representing grades kindergarten through six from urban, rural, and suburban schools throughout western Massachusetts. One of the ten elementary teachers taught visual arts, K-6; another of the ten was a science specialist who traveled from classroom to classroom teaching science throughout the school year; and yet another was a reading specialist who provided support instruction for children experiencing difficulty with reading in all content areas. During the Institute, the ten elementary teachers participated in a special design project focused on the engineering of pop-up books. The paper will now turn to a discussion of this design project.

Theoretical Framework and Methodology

The pedagogical strategies and project-based curriculum plan for the pop-up book institute reflect "best practices" as informed by the current cognitive science literature on teaching and learning. In this section, we will describe the three theoretical underpinnings of these "best practices" as they were implemented in the project design: the role of prior knowledge in learning; the power of inquiry-based teaching and learning; and, the importance of supportive social contexts and discourse communities for learning.

Why pop-up books?

"What you know first stays with you…" So says Newberry award winning author Patricia Maclachlan in her beautifully written picture book, *What You Know First*. It is in this spirit that the project-based summer institute for teachers to explore engineering design through the world of pop-up books was born. The role of prior knowledge in learning is well established in the cognitive science literature (Resnick, 1983; von Glaserfeld, 1984). Prior knowledge and experiences impact learning. Learning happens when one's prior knowledge is challenged, deepened, reshaped, revised, and/or transformed, eventually resulting in conceptual change (Posner, Strike, Hewson, & Gertzog, 1982).

Elementary school teachers tend to see themselves as being confident and knowledgeable in the language and visual arts and less confident and knowledgeable in mathematics, science, and technology. This claim is supported in the anecdotal and empirical literature addressing math and science anxiety among novice and veteran elementary school teachers (Trujillo & Hadfield, 1999; Tobias, 1990). Exploring engineering through an immersion in pop-up books is a way of building on the teachers' prior knowledge and confidence in literacy and the world of children's books. Our goal was to introduce teachers to technological literacy in engineering by building on their strengths and experiences in verbal literacy, thereby connecting the liberal arts and humanities to engineering. The pop-up book became the tool for introducing, teaching, and applying the engineering design process.

It is not that pop-up books are novel (pun intended), but we believe that the ways in which we worked with teachers to explore engineering through a pop-up book immersion experience are novel. Pop-up books have long fascinated children and adults alike, arousing their curiosities and inviting them to play and problem solve. The pop-up mechanisms in such books produce a plethora of intriguing possibilities and movements such as rotation, reflection, pulleys, and enlargement. We used the mechanisms of paper engineering to invite teachers into the engineering design process, with a sense of playfulness and intrigue. Using the pop-up book as an instructional tool helped to connect engineering to other parts of the elementary school curriculum, thereby making meaningful and authentic connections to the teachers' "real classroom worlds" and helping them see the interdisciplinary possibilities and potential.

The anecdotal research on teaching and learning in elementary school science, technology, and engineering is replete with teachers' calls for authentic and meaning-based professional development experiences. The ASEE K-12 website presents the following statement on its introductory webpage: "Many teachers agree that hands-on learning is the best method for attracting more students to engineering. Interactive experiments and lessons help make engineering come alive for students. Engineering education needs to become less theory-based and more context-based, to demonstrate engineering's relevancy in the 'real world.' While many teachers do believe engineering is important in their classrooms, they often do not have the time or resources to implement engineering lessons. A more 'interdisciplinary approach,' whereby a technological spin is added to other subjects, and vice-versa, can allow teachers to add engineering without drastically altering their lesson plans. This can add to the hands-on nature of the lessons as well, making engineering fun for students."

The pop-up book immersion engaged teachers in such active, hands-on, constructive experience. Our intention was to model an inquiry-based teaching and learning climate for the teachers in which experimentation, discussion, and collaboration were central. The use of inquiry-based teaching methods occupies a prominent position among recommendations for reform and improvement of science curricula and instruction (American Association for the Advancement of Science, 1993; National Research Council, 1996; *Massachusetts Science and Technology/Engineering Curriculum Framework*, 2001). Science education reform initiatives at both national and state levels consistently call for "inquiry-based teaching and learning." The *National Science Education Standards* (1996) advocate inquiry that goes beyond "science as a process," or just the learning of skills associated with the scientific method, such as observation, inference, and experimentation. Instead, the *Standards* promote the "processes of science," requiring students to develop an understanding of science by combining process and knowledge through the use of scientific reasoning and critical thinking. The *Standards* specify for grades K-12 the development of understanding about and abilities necessary to do scientific inquiry. State curriculum frameworks also emphasize inquiry. For example, *The Massachusetts Science and Technology/Engineering Curriculum Framework* (2001) calls for "lifelong learners who are able to use the methods of inquiry to participate in scientific investigation and technological problem solving".

The theoretical grounding for this project-based pop-up book instructional approach is also rooted in an inquiry-based teaching and learning model that fosters and supports the kind of discourse community essential for knowledge construction to take place. Bereiter and Scardamalia (1997) discuss and describe scientific inquiry as consisting of a set of commitments. Their contention is that what distinguishes science is not a method but rather the way scientists conduct themselves as a community. In particular, the scientific community is committed to advancing their shared understanding. The notion of a community of scientific inquirers who subscribe to these commitments should be part of the explicit goals of teaching inquiry.

Bereiter, Scardamalia, Cassells, and Hewitt (1997) describe scientific inquiry as a set of commitments shared by the participants in the enterprise. Their contention is that helping learners grasp the nature of these commitments is an essential outcome of instruction which purports to teach scientific inquiry. They cite four specific commitments that are essential for discourse intended to advance knowledge (pp. 333-334):

1. Participants must be committed to mutual advances in understanding.
2. Participants must be committed to framing questions and propositions so that evidence may be brought to bear on them.
3. Participants must be committed to expanding discussion from the facts and ideas that the community already accepts.
4. Participants must be committed to being open to having one's ideas challenged.

Incorporating these discourse considerations into classroom instruction means that teachers must take into account not only individual student's understanding but how the students-as-scientists conduct themselves as a community. This entails planning for a classroom culture where discourse is a natural occurrence. Needed are regular opportunities for students to engage in meaningful discourse. Moreover, it means planning to instruct students in the commitments necessary for this discourse to be "scientific". These instructional considerations are prominent in the guidelines we have developed for designing inquiry units.

We worked hard to create a social-collaborative context during the summer institute that would guide and support the teachers' developing understandings and skills in engineering education. Seeking an instructional approach that would nurture this awareness and type of learning led us to employ Brown & Campione's (1996) Facilitating Communities of Learners (FCL) as an instructional model. At the heart of FCL, students engage in research, in order to share what they have learned, in order to perform a consequential task. This cycle of research-share-perform meshed perfectly with what we were trying to achieve. FCL helps teachers create the classroom atmosphere in which a community of inquirers can flourish.

These methods are also grounded in *design-based research methodology* (The Design-Based Research Collective, 2003), reflecting The Collective's five characteristics of design-based research:

1. The central goals of designing learning environments and developing theories or 'prototheories' of learning are intertwined.
2. Development and research take place through continuous cycles of design, enactment, analysis, and redesign (Cobb, 2001; Collins, 1992).
3. Research on designs must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers (cf. Brophy, 2002).
4. Research must account for how designs function in authentic settings.
5. The development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest. (The Design-Based Research Collective, 2003, p.5)

Our research methodology draws on Collins' discussion (1999) of design-experiment methodology. Collins notes that there are three types of variables in design-based research: 1. *Climate variables*, such as engagement of learners, cooperation among learners, and risk taking by learners; 2. *outcome variables*, including the learning of knowledge, skills, strategies, and dispositions; and, 3. *system variables*, such as spread of sustainability and ease of adoption. Collins asserts that "climate variables can be studied by observation, interviews, and surveys; outcome variables can be studied by giving pre- and post-tests or evaluating performances and, system variables can be studied by follow-up observations, surveys, interviews, and longitudinal studies" (Collins, 1999).

Thus, a considerable proportion of the theoretical framework underlying the creation of this approach to teaching inquiry is grounded in sophisticated conceptions of the meaning of inquiry and in instructional theory that supports the development of understanding through design-based projects, pursued in social-collaborative contexts in which teachers are expected and encouraged to work together and talk aloud about their developing understandings, struggles, and successes.

Chronology and Description of the Pop-up Book Design Project:

We began the weeklong concentration on pop-up book engineering with a Gallery Walk of pop-up books. We selected twenty pop-up books representing a good variety of theme, form, and technical sophistication. (See list of books in Appendix A.) The pop-up books that we used were chosen specifically to give the teachers a look at the wide variety of mechanisms and book subjects that are available. For the Gallery Walk, we set the books on a very large square table so that teachers could move freely from one to the next. There was enough room to open the book and explore its contents and for teachers to reflect in their notebooks. We told teachers that there would be no talking or sharing during the Gallery Walk, that this was intended to be a singular activity to provoke close looking and reflection.

To foster their thinking in three-dimensional ways, the teachers looked closely and kept a list of the many and varied forms, techniques, and structures used to create the design and mechanics of the pop-ups. After this initial period of exploration, the teachers discussed what they had observed. They talked about the various mechanisms such as wheels, supports, hinges, tabs, and sliders, and they also discussed the effect that the pop-up illustrations had on the text itself. They discussed the idea that pop-ups enhance the relationship between the reader and the text by making the reading process more interactive. They also noticed that in some cases, the illustrations were clearly the main focus of the book to the point that the text seemed to be an afterthought. Furthermore, pop-ups sometimes added to the learning goals of the book by allowing the reader to see and experience a given subject in three-dimensions rather than through the typical illustrations of the picture book format.

On this same day, teachers received the materials that they would be working with for the rest of the week, as well as a copy of the book *The Elements of Pop-Up* by David Carter and James Diaz (1999). This Carter/Diaz book serves as an excellent resource for creating pop-ups by outlining and providing working examples of the basic elements and mechanisms of pop-ups, such as parallel folds, angle folds, wheels, and pull-tabs. After the teachers had a chance to look over the book, we assigned each teacher a partner and gave them their first design challenge: Recreate one of the pop-ups featured in the book by using the process of reverse engineering. We defined "reverse engineering" as the process of "inspecting an existing product to look for engineering or design features that can be incorporated into one's own product" (patentcafe.com). Each design team was to choose one of the pop-ups shown in the book and create a working model of it.

They were to avoid the ones that had a star next to them indicating they were easier models to complete. This experience allowed teachers to go through the engineering design process from defining the problem to developing a prototype, testing it, and finally refining if necessary, all while communicating with a design partner. After each of the teams successfully created a pop-up model, they shared their successes and struggles with the rest of the group.

On day two, we introduced the teachers to the pop-up engineering project that they would be working on for the remainder of the week. The goal was for each teacher to take a double-page spread of a children's book (chosen by us), and convert it into pop-up form. The book we used was chosen for its charming text, its wonderful yet simple illustrations, and its pop-up potential. After a lively read aloud of the picture book, teachers were given envelopes at random that contained the original spread from the actual book, several photocopies of the pages, as well as the form for the final page. They were to look first at the illustration(s) on their pages and brainstorm possibilities for movement and pop-ups. We gave the following Engineering Design Challenge to each teacher:

- After receiving your page spread, brainstorm ideas of how you may want to set up your page. What do you want to move? How will the page be set up? What kind of mechanisms/pop-up elements would you like to incorporate? The Carter/Diaz book may help you generate ideas.

- Switch pages with your design partner and brainstorm ideas of how you would design his/her page if it were assigned to you.

- Have a discussion with your design partner about the ideas that were generated for both page spreads. Be sure your plan is "doable." That is, it should not be too easy or too difficult, but it should involve at least one aspect that will be a challenge to you.

- Sketch your ideas into a "workable layout". This should show placements of objects, as well as ideas of how they will pop. The Carter/Diaz book should be used as a resource during this entire process.

- Share and discuss your layout with your design partner.

- Create a plan of action for how to proceed.

- Get Popping!

As the teachers worked towards developing their final design, they traveled through the engineering design process (see Figure 1). They developed and tested prototypes, communicated their successes and struggles with their design partners and the larger group, and ultimately created the page that would be contributed to the final pop-up book. Throughout this design phase, teachers consistently confronted and worked though various engineering problems, such as: How can I make this pop from the page? How can I make this piece move across the page without it interfering with this other part? What can I do with this piece of the picture?

The final product was an eclectic collection of pop-up mechanisms, each with its own unique style and charm. (The final pop-up book and photographs of the teachers engaged in each piece of the design project will be presented at the ASEE paper presentation session.) For example, some pages were activated by the opening of the page, and others required certain actions by the reader such as pulling a tab or lifting a flap. While still honoring the original story, the newly engineered book is quite different in feeling and appearance. The static picture book format of the original has been transformed into an interactive, dynamic, three-dimensional experience. It is a testament of the learning of engineering principles and processes through the wonder of pop-up books.

Results

The overall success of the July 2004 Summer Engineering Education Institute for Educators (serving twenty one elementary, middle, and high school teachers) is evident with the following results:

-- Familiarity with the field of engineering jumped from 19% to 71%.
-- A basic understanding of the engineering design process--increased from 19% to 100%.
-- A basic understanding of engineering as a pedagogical tool--increased from 10% to 95%.
-- A basic understanding of the relationship between engineering and the liberal arts--increased from 10% to 100%.
-- The intention to teach engineering as part of course curricula increased from 55% to 90%.
-- 100% of participants found the course "very useful."
-- 95% of participants rated the course "excellent" (5% rated it "very good").
-- 100% would recommend it to others.

Specifically, we asked the elementary teachers to respond to and reflect on the pop-up book project. The protocol for this reflection was as follows:

1. Reflect on your process during the pop-up experience: What were your challenges and constraints? How did the Engineering Design Process apply to your work? What did you learn (concepts, skills, habits of mind, affects, etc.)? How might you apply, integrate, and/or use pop-ups in your classroom?

2. Begin to draft a plan-of-action for curriculum development in your classroom, based on your work in this Summer Institute for Engineering Education.

3. We would like some feedback on the pop-up workshop. As we look ahead to refining and repeating the pop-up workshop design and experience, what should we keep, delete, revise, add, etc.?

Following is a sample response, written by a grade three teacher. The themes present in this teacher's reflection and assessment are representative of the sample at large:

1. Reflect on your process during the pop-up experience: What were your challenges and constraints? How did the Engineering Design Process apply to your work? What did you

learn (concepts, skills, habits of mind, affects, etc.)? How might you apply, integrate, and/or use pop-ups in your classroom?

The third grade teacher responds:

(A poetic response)

Gallery Walk
Beauty and genius
To notice
Forms, techniques, formats, structures
Of design and mechanics.
(Mechanics?) Yes, mechanics.

"Oh no!" I think. "I don't know anything about mechanics! I'm mechanically illiterate. How will I even know what to look for? What am I supposed to be paying attention to?"

Reverse engineering
Go back
Figure it out
What makes it POP UP?
Shiny new books
And a toolbox to help
Explore
Parallel folds
Angle folds
Wheels and pull-tabs
Movement from kinetic energy
(Kinetic energy?)
Yes, kinetic energy.

Maybe I can figure this out…with a partner…with support…with time to experiment and play and with a little imagination

Design challenge of the week
Felix Feels Better
But I don't.
I'm worried
Self-doubt and uncertainty
But planning helps and so does sharing
Then get to it
With lots of support
With time alone
With time to
    Clarify the problem
    Research it

Think of possibilities to develop solutions
Select the best at the moment with advice, suggestion, and support from others
Construct prototypes to
Test…placed in position…
And evaluate in relation to the book gutter and to the energy produced
Satisfied?
Or re-design?

Which mechanisms will I use? How are they made? Where will they go on the page? Wait…isn't that engineering? Isn't that the Design Sequence in the Frameworks? Maybe I **am** *getting this. Maybe I* **can** *figure out what I'm supposed to be paying attention to. Maybe engineering can offer me another way to look at the world and consider how things work.*

The finished product and deadlines approach.
Templates help, but still
Cutting and scoring and attaching
At angles for impact and interest
Overwhelm even at night
At home in my own head
So hard to visualize
We've heard from IDEO that
"Being playful is key to being innovative."
I'm not being playful enough
Where's my innovation?
Popped-out perhaps, by insecurity; perhaps, but the pressure to finish.

Why is this so hard for me? I'm not feeling very artistic or creative. So much trial and error and tinkering! Will I let the group down? Will my page hold up to the high standards and expectations we've generated from our excitement this week?

Nearing the end, accomplishing tasks I've set.
Gaining some confidence from small successes,
Momentum to go on
To invent new ways
Less reliant on following recipe
More comfortable trying something new
Being playful…
Innovating an angle pull-tab!
Thinking of how I could redesign improvements…
But, for now, satisfied that I've learned
Lessons about engineering and movement and energy
Lessons about myself, about teaching and learning, about my students

I think the poem conveys many of the challenges and constraints I faced during this project. I guess I both surprised and disappointed myself, but mostly, I learned a ton! I have a renewed respect and empathy for the struggles of the novice learner. I was again made conscious of how frustration plays a role in learning, and how much satisfaction comes from the struggle when the frustration is not allowed to move to despair. I appreciated the freedom/responsibility I was given to "challenge myself," because I could enter at my own level and set my own goals. That helped me persevere and control the difficulty.

Every stage in the Engineering Process applied directly to my work in many ways.

To **identify the problem,**
I brainstormed possible places on my page where I could incorporate movement

To **research the problem,**
I sketched and planned and referenced my print-resources (our new books!)

To **develop solutions,**
I gathered ideas from my own planning and from my partner's advice/suggestions

To **select the best solutions,**
I thought about what was do-able and what appealed to me

To **construct prototypes,**
I used scrap paper, tape, templates, and lots of trial and error
This stage was crucial, and made all the difference to me to help me develop some confidence…Low stakes, low risk

To **test and evaluate,**
I worked and reworked my prototypes and tried them out in mock-ups

To **communicate my solution,**
I shared with partners and classmates, as I sought advice and suggestions at the prototype-stage

To **redesign,**
I had to analyze the glitches that I found as I was sharing my design. Using the results from those prototype trials, I knew what needed to be resolved, and I tried new solutions.

I learned directly and authentically from being immersed in the Engineering Process. Besides all that I've already described, I also learned concepts about physical science, specifically the idea of kinetic energy. Prior to this experience, I never even knew that pop-up books were even remotely related to physical science. As a way of thinking, this experience has opened my eyes to new possibilities. I am paying attention to how everyday-things work, and how they are constructed. Science and math in service to humanity…

I have a few initial ideas about how I will apply, integrate, or use pop-ups in my classroom. These include:

- Early in the year, using paper engineering to familiarize my students with some basic folds of pop-ups (to be used during the year in other projects), to introduce the idea of studying and noticing movement, and to introduce reverse engineering, leading to an ongoing "deconstruction unit."

- Using some paper engineering to create class books or displays related to content areas we study (for example, animals of the Connecticut River Valley, river features, and language arts connections). I especially like the idea of students using paper engineering to help them learn about, for instance, how an animal's body construction determines its movements. ("How does an eagle's beak work?" or "How must a fish's fin be attached/constructed if it moves like that?") I also like the idea of having students design paper movements to model the movement of water. After they research specific river features, I usually have them draw a diagram of them; but the problem has been the static constraints of the 2-D representation. Now, I'm thinking of how some pull tabs might allow students to represent the direction and flow of water down a waterfall, over rapids, through meanders, or in a flood. The dynamic nature of water flow had been missing from my students' representations, but now I'm seeing some new possibilities that will help them learn more deeply about their river features as they confront the challenge of trying to replicate it with paper engineering.

2. Begin to draft a plan-of-action for curriculum development in your classroom, based on your work in this Summer Institute for Engineering Education.

Besides the above application of pop-ups in my classroom, I am looking forward to developing curricula based on the work we have done in this Summer Institute for Engineering Education. My school colleagues (who also attended the Institute) and I will continue to collaborate and support each other in our own individual applications, but also, we are looking for ways to coordinate students' experiences with this from K-6. We realize that we are not necessarily looking to add new content to what we already have, although in some cases we might take that route. Right now, we are starting small, and looking for ways to integrate and highlight these ideas in what we already do, and, in some cases, extend and explore new possibilities.

So far, we have discussed some of the following, which includes both general and specific plans:

- Playing around with the idea of **movement** as an organizing concept. What do students notice about how things move? What questions do they have? What explanations can they offer? How do these fit into our planned content and inquiry units? This connects well to our river work and to pendulums.

- Taking the year to learn what to pay attention to as students interact with these ideas and experiences. Now that we have an increased awareness about engineering content, what might we notice about our students' interaction with it?

- Emphasizing the qualities of/nature of materials. This seems very important in the development of engineering knowledge, and there are many ways that I could emphasize observation, description, and analysis of materials in the river study (rocks, soils, etc.) and other aspects of my classroom.

- Making more explicit the Engineering Design Process across the curriculum. Really, that cycle is so present already in everything we do in the content areas, in work with metacognitive strategies and reflection, and in the social curriculum. Just connecting the process to that structure will connect students to important engineering ways of thinking. For example, this year, when I have students create a river, I will implement the ideas of the Design Sequence to help shape that experience.

- Providing students with opportunities to "tinker" and find inspiration through their "tinkering." All the people we met this week who were involved in engineering had this habit of mind and could recall it as an early formative experience. Since I don't come by this naturally, I have an obligation to my students to more planfully and consistently provide for it. I hope to create a "deconstruction" strand for independent exploration and focused work. This will include "dissection-like" experiences in taking things apart, observing and drawing them, analyzing the parts and the relationships of the parts to each other, and asking questions. I will ask parents to provide old appliances and other electronics to stock these materials. Also, I plan to look for "wind-up" toys (not animals, though!) that students could take apart to look at the "simple" mechanisms and devices that can be used to create movements of this type.

3. We would like some feedback on the pop-up workshop. As we look ahead to refining and repeating the pop-up workshop design and experience, what should we keep, delete, revise, add, etc.?

Although I don't want to come across as one who is not being a thoughtful examiner, I would honestly say that this experience is just about perfect as it is. The whole process from the gallery walk to the planning to the community work-times to the independent pursuit was just right. Thank you for shaping such a tremendous experience.

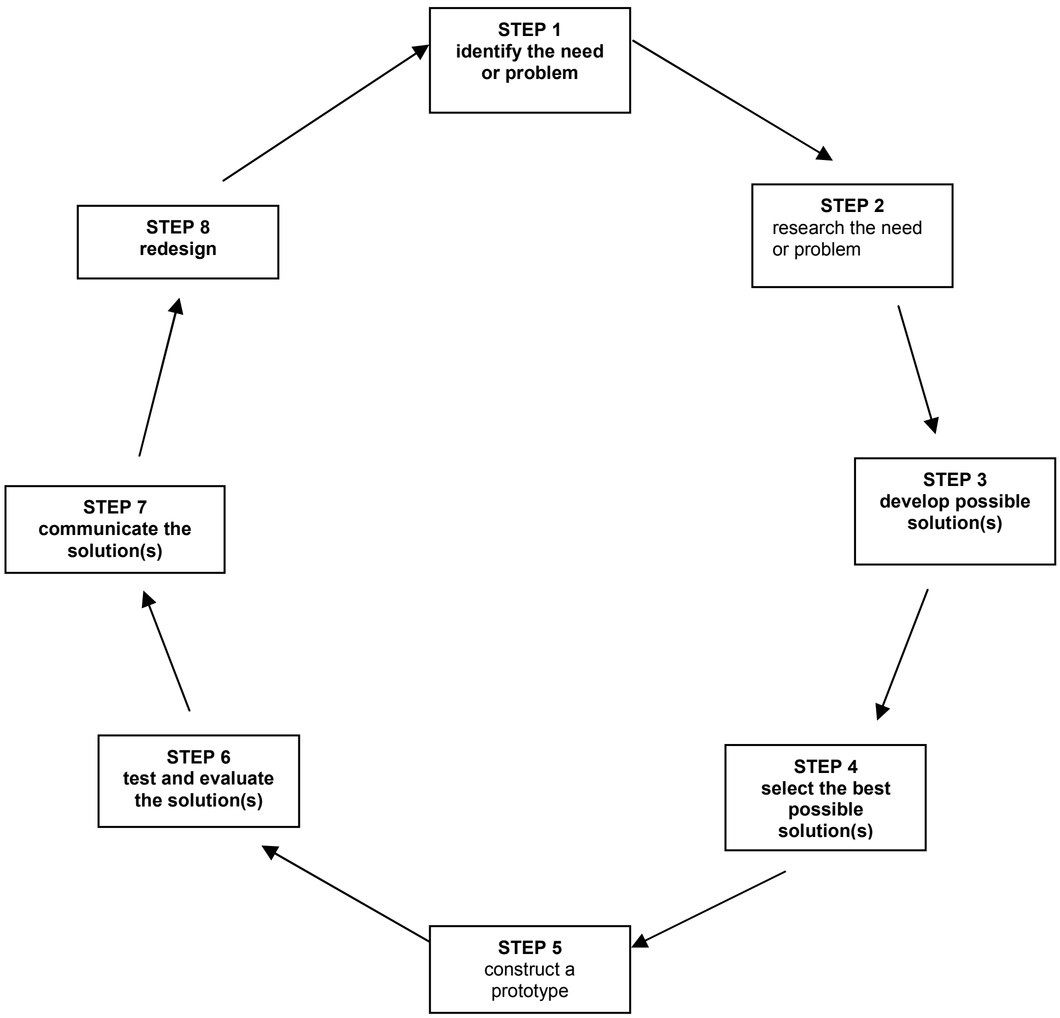
Having said that, I suppose that only aspect I would add would be an early session about "Group Norms" for how members of the group will work to be responsible to both their own learning and the learning of others. Some discussion about what works and what interferes with either of those commitments might be useful for building community and modeling the process for teachers.

Conclusions and Next Steps: Where Do We Go from Here?

We are very encouraged by the power and potential of using pop-up books to teach teachers about engineering principles and design processes. The elementary teachers in the Summer Institute reported inspiration and plans-of-action to integrate engineering education into their classroom curricula. We are currently following teachers into their classrooms, documenting their progress as they attempt to integrate and apply the content and pedagogical practices learned in the summer professional development institute. We will continue to gather the teachers' stories as mini-case studies of teachers pursuing engineering design projects for the first time with their elementary school-aged students.

We are aware that the teachers' "new knowledge" is fragile and, for professional development to be beneficial and productive, teachers need continuing support to build and apply this new knowledge into their classroom practices. We look forward to the challenge. We will continue to build this network of teachers and make possible ways for them to meet and communicate their ongoing successes and struggles in integrating engineering education in their schools.

Figure 1
(Massachusetts Science and Technology/Engineering Curriculum Framework, May 2001, page 53)
Steps of the Engineering Design Process



1. Identify the need or problem
2. Research the need or problem
   - Examine current state of the issue and current solutions
   - Explore other options via the Internet, library, interviews, etc.
3. Develop possible solution(s)
   - Brainstorm possible solutions
   - Draw on mathematics and science
   - Articulate the possible solutions in two and three dimensions
   - Refine the possible solutions
4. Select the best possible solution(s)
   - Determine which solution(s) best meet(s) the original requirements

5. Construct a prototype
   - Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
   - Does it work?
   - Does it meet the original design constraints?
7. Communicate the solution(s)
   - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
   - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   - Overhaul the solution(s) based on information gathered during the tests and presentation

Appendix A: Pop-up Books Used during the Gallery Walk

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Benelmans, Ludwig. Madeline. New York: Viking, 1987.

Browne, Anthony. Animal Fair: A Spectacular Pop-Up. Mass.: Candlewick Press, 2002.

Carter, David A. Alpha Bugs. New York: Little Simon, 1994.

Cousins, Lucy. Maisy Goes to School. Mass.: Candlewick Press, 1992.

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Hewitt, Sally. Pop-Up Bugs. New York: Abrams, Inc., 2003.

Hoy, Ken and Isabel Bowring. Strange Scavenging Creatures. Tennessee: Ideals Children's Books, 1994.

The Lion King. Simba's Journey. The Walt Disney Company, 1995.

Pienkowski, Jan. Haunted House. New York: Dutton Children's Books, 2001.

Pienkowski, Jan. Oh My a Fly! California: Piggy Toes Press, 1998.

Pienkowski, Jan. Pizza! Mass.: Candlewick Press, 2001.

Priceman, Marjorie. Little Red Riding Hood. New York: Little Simon, 2001.

Prokofiev, Sergei and Barbara Cooney. Peter and the Wolf. New York: Viking, 1986.

Rey, H.A. Curious George. New York: Houghton Mifflin, 1993.

Sabuda, Robert. Alice's Adventures in Wonderland. New York: Little Simon, 2003.

Seibold, J. Otto. Alice in Wonderland. New York: Orchard Books, 2003.

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Tobias, S. (1990). Math anxiety: An update. *NACADA Journal, 10(1)*, 47-50.

Trujillo, K.M. & Hadfield, O.D. (1999). Tracing the roots of mathematics anxiety through in-Depth interviews with preservice elementary teachers. *College Student Journal, 33(2)*.

von Glaserfeld, E. (1984). An introduction to radical constructivism. In P. Watzlawick (Ed.), *The invented reality*. New York: Norton.

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