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## Changes in Teachers' Adaptive Expertise in an Engineering Professional Development Course

Taylor Martin  
*National Science Foundation*

Stephanie Baker Peacock  
*University of Texas at Austin*

Pat Ko  
*University of Texas at Austin, contactpatko@gmail.com*

*See next page for additional authors*

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# Changes in Teachers' Adaptive Expertise in an Engineering Professional Development Course

## Abstract

Although the consensus seems to be that high-school-level introductory engineering courses should focus on design, this creates a problem for teacher training. Traditionally, math and science teachers are trained to teach and assess factual knowledge and closed-ended problemsolving techniques specific to a particular discipline, which is unsuited for teaching design skills for open-ended problems that may involve multiple engineering disciplines. Instead, engineering teacher training should use the more fluid framework of adaptive expertise which values the ability to apply knowledge in innovative ways as well as recall facts and solve problems using conventional techniques. In this study, we examined a 6-week program to train math/science teachers to teach high school design engineering. For each curriculum unit, we had a pre-posttest to assess the teachers' factual knowledge and ability to solve typical problems (termed "efficiency") and their ability to apply their knowledge to reason through open-ended problems (termed "innovation"). In addition, we conducted a pre-posttest to see whether teachers' attitudes and beliefs related to adaptive expertise changed over the course of the program.

## Keywords

professional development, engineering education, design-based instruction, challenge-based instruction, design engineering, adaptive expertise, innovation, efficiency, high school engineering, secondary school engineering

## Document Type

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## Authors

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Taylor Martin<sup>2</sup>, Stephanie Baker Peacock<sup>1</sup>, Pat Ko,<sup>1</sup> and Jennifer J. Rudolph<sup>1</sup>

<sup>1</sup>University of Texas at Austin

<sup>2</sup>National Science Foundation

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### Abstract

Although the consensus seems to be that high-school-level introductory engineering courses should focus on design, this creates a problem for teacher training. Traditionally, math and science teachers are trained to teach and assess factual knowledge and closed-ended problem-solving techniques specific to a particular discipline, which is unsuited for teaching design skills for open-ended problems that may involve multiple engineering disciplines. Instead, engineering teacher training should use the more fluid framework of adaptive expertise which values the ability to apply knowledge in innovative ways as well as recall facts and solve problems using conventional techniques. In this study, we examined a 6-week program to train math/science teachers to teach high school design engineering. For each curriculum unit, we had a pre-posttest to assess the teachers' factual knowledge and ability to solve typical problems (termed "efficiency") and their ability to apply their knowledge to reason through open-ended problems (termed "innovation"). In addition, we conducted a pre-posttest to see whether teachers' attitudes and beliefs related to adaptive expertise changed over the course of the program.

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### Introduction

In recent years, there has been tremendous interest in teaching engineering courses in American schools. Already, several different curricula exist or are in development, including *Project Lead the Way* (PLTW, 2011) and *Engineering the Future* ("Engineering the Future," 2014). In 2009, Texas amended its recommended high school graduation criteria to require a fourth year of math and science. In addition, the state required the development of an introductory high-school-level engineering class to become one of the options to fulfill the science requirement. Assuming an even demand for each of the approved fourth-year science courses, Texas can expect that 15,000 students per year will wish to enroll in the engineering course. To meet this demand, Texas aims to have at least one engineering teacher in each of its high schools, creating a need

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for nearly 2000 engineering teachers in that state alone. It is unrealistic to expect that these positions in Texas and the rest of the country will all be filled by teachers with an engineering degree or engineering job experience. We expect that to fill the gap between the demand for engineering teachers and the available supply, math and science teachers will need to be trained to teach these classes.

Furthermore, engineering is not a single, monolithic subject, but a set of disparate disciplines, such as mechanical, electrical, and chemical engineering, each with their own set of content knowledge. The consensus seems to be that instead of teaching any particular type of engineering, high school engineering classes should focus on teaching engineering design (Katehi, Pearson, & Feder, 2009). However, this choice creates a difficulty. Design often uses open-ended problems where each student (or team of students) may take a different approach to the problem, and have a different, but also valid, solution. Instead of guiding everyone down the same path, teachers need to quickly understand each student's solution method and offer customized help. Operating in these conditions requires a level of understanding that goes beyond the ability to solve common content problems accurately and efficiently. To help their students, engineering design teachers need to have a deeper, more fluid understanding of the core material that they can quickly apply to the unique circumstances that each student brings. A level of expertise that is flexible enough to function in novel situations is known as adaptive expertise (Hatano, 1988).

Martin, Petrosino, Rivale, and Diller (2006) showed that challenge-based instruction (CBI) is effective in developing adaptive expertise in engineering problem solving. In this paper, we examine the effects of in-service high school math and science teachers participating in a six-week summer professional development course, the Engineering Summer Institute for Teachers (ESIT). The course used design-based instruction (DBI), a variation of CBI. The questions we aim to answer are:

1. Can DBI increase teachers' engineering innovation and efficiency?
2. Can DBI improve teachers' beliefs about the design process and cognitive dispositions toward engineering so that they are more consistent with the beliefs of adaptive experts?

## Background

### *Expertise*

Expertise has been studied in a number of domains (Chi, Feltovich, & Glaser, 1981; Feltovich, Prietula, & Ericsson, 2006). Hatano and his collaborators (Hatano & Inagaki, 1986; Hatano, 1988; Hatano & Oura, 2003; Inagaki & Hatano, 1977) divided experts into two categories: routine experts and

adaptive experts. Routine experts are proficient and accurate at performing common tasks in a particular knowledge domain. Amaiwa and Hatano (1983) (as cited by Hatano (1988)) use fourth-grade abacus students as an example. Many of the students had become proficient in using an abacus for arithmetic, including one who could calculate 30 three-digit multiplication problems in less than one minute. In the expertise literature (Schwartz, Bransford, & Sears, 2006; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009), routine experts are sometimes described as "efficient" because they possess "procedural efficiency" (Hatano, Ericsson, & Hoffman, 2002, p. 763) and they "apply their problem-solving skills efficiently" (Hatano, 1988, p. 55).

Unfortunately, although the abacus students were "efficient" in executing the steps of the calculations, many could not explain the reasons for the calculation steps. Furthermore, when given arithmetic problems that could be easily simplified, the students did not simplify, but computed the answer directly. Although these abacus students were capable and efficient at performing the common operations, they did not have deep understanding of the underlying mathematics and were not able to use simplifications to make their task easier. Although fast and accurate, routine experts are not able to solve problems in the domain that are unusual or novel (Hatano, 1988).

Like routine experts, adaptive experts are able to efficiently solve common problems, but they also have more accurate conceptual understanding of their knowledge domain (Hatano, 1988). Where routine experts are limited to executing predefined procedures, the adaptive expert's deeper knowledge allows a more flexible level of understanding about why the common procedures work, allowing them to modify common solutions as needed, and create new procedures when common procedures are not sufficient (Hatano & Inagaki, 1986). As adaptive experts are able to create and "invent" new procedures they have not previously learned, they are sometimes described in the literature as being "innovative" (Bransford, 2007; Hatano & Oura, 2003). Using the term "innovative" helps focus on the learner's ability to draw on employing deep understanding to be flexible when solving novel tasks. People who achieve adaptive expertise in their field tend to hold certain beliefs and practices, such as considering multiple perspectives and successfully assessing their own knowledge (Fisher & Peterson, 2001).

It is important to note that in the context of the relevant expertise literature, terms such as "new," "novel," and "innovative" are used with respect to the subject's experience, not the experience of all of humanity. A novel problem does not mean that it has never been seen by anyone before, but merely that the subject is unfamiliar with it. Likewise, when a person invents a new procedure (or is described as innovative), their invention is not necessarily a scientific breakthrough for society, but simply a useful procedure that the person creates instead of repeating something that was taught

to them. The innovation may be an observable phenomenon indicating the person thinks differently than an efficient learner on a meta-level, going beyond practiced knowledge with a tendency to create novel ways of combining and using information provided by the situational environment. An innovator may use the same information in different ways, or add information that has not been previously considered in a particular context. Teachers who have these abilities and can use them to teach students may be more successful in teaching topics such as engineering design.

### *Teaching for Adaptive Expertise*

Several instructional methods have been designed to deepen learner understanding of course material, and to increase adaptive expertise. Itakura's Hypothesis-Experiment-Instruction method is a highly structured technique whereby a class is presented with a question they have not seen before, along with several plausible explanations or solutions. Each student casts a vote on which explanation is correct. Then, the learners discuss each explanation, providing arguments for and against the solution's viability. After the discussion, each student votes again with the option to change their vote from the first time. Finally, the teacher reveals the correct answer through a live demonstration or a recorded video (Hatano, 1988).

The Fostering Communities of Learners (FCL) program (Brown, 1997) uses techniques to promote metacognition, an essential trait of adaptive experts, often using jigsaws and other forms of reciprocal teaching. A typical task requires students to individually research different topics, present their findings to a small group or the entire class, and the entire group uses the collected information to solve a larger problem.

Another technique is to use challenge-based instruction, which is an inquiry method related to problem-based learning. In challenge-based instruction, a class is presented with a real-life challenge to solve, typically in small groups, by following a solution process. One such approach is the STAR.Legacy Cycle based on the work in Schwartz, Brophy, Lin, and Bransford (1999). Studying ninth-grade math students working on a statistics lesson, Schwartz and Martin (2004) found that students who used challenge-based instruction scored similarly to a traditionally taught group on a content posttest, but scored higher on a novel problem.

### *Adaptive Expertise in Teacher Education*

Recently, there has been a growing acceptance that adaptive expertise is a good lens in which to view teaching and teacher development (Anthony, Hunter, & Hunter, 2015; Berliner, 2004; Crawford, Schlager, Toyama, Riel, & Vahey, 2005; De Arment, Reed, & Wetzel, 2013; Feiman-Nemser, 2008; Timperley, 2012; Yoon, Koehler-Yom,

Anderson, Lin, & Klopfer, 2015). A few teacher education and professional development programs, e.g. Lin, Schwartz, and Hatano (2005) and Mason-Williams, Frederick, and Mulcahy (2014), are even using some adaptive expertise principles in their training.

However, there is an important difference between the context and adaptive expertise goals of these studies and the program that we used for the setting of our study. In the aforementioned articles, the main goal of the programs was to improve the teaching and classroom skills of the participants. Both Lin et al. (2005) and Mason-Williams et al. (2014) studied pre-service teachers. In the professional development that we used, our participants were typically veteran in-service teachers and the goal of the program was to convey disciplinary knowledge, specifically, principles of engineering design, rather than classroom skills.

### *This Study*

In this paper, we will focus on design-based instruction (DBI), a variation of challenge-based instruction adapted for engineering design classes. Here, the challenge presented to the class is an open-ended real-life engineering design problem with multiple acceptable solutions. Instead of the STAR.Legacy Cycle, the teachers follow a process modeled after the design flow used by working engineers. Figure 1 shows the design cycle that was used in this study.

Presented with the design challenge, the teachers start with the "Understand the problem" step where they ask questions to understand the scope and breadth of the challenge. In "Quantify the need," they identify the success criteria for the project, including writing design specifications. Brainstorming ideas and evaluating designs occurs in "Engineer the concept." The "Embody the concept" step involves planning how to construct the design while making further design decisions. Constructing a prototype and testing it occurs in "Implement the design." "Finalize the design" involves collecting information and making decisions about issues such as the robustness of the design and designing for production. At each step in the process, students may need to return to an earlier step because of problems that may develop or situations that arise that the students had not previously considered.

We are interested in whether or not teacher professional development using DBI can increase teachers' engineering innovation and efficiency and whether it can increase teachers' adaptive beliefs about engineering and learning. To address these questions, we assessed learning as improvements in adaptive expertise (both efficiency and innovation) in the ESIT program, which centered on DBI. The ESIT program is one aspect of the teacher training in engineering offered by the Master of Arts in STEM Education – Engineering (MASEE) program.

## THE ENGINEERING DESIGN PROCESS

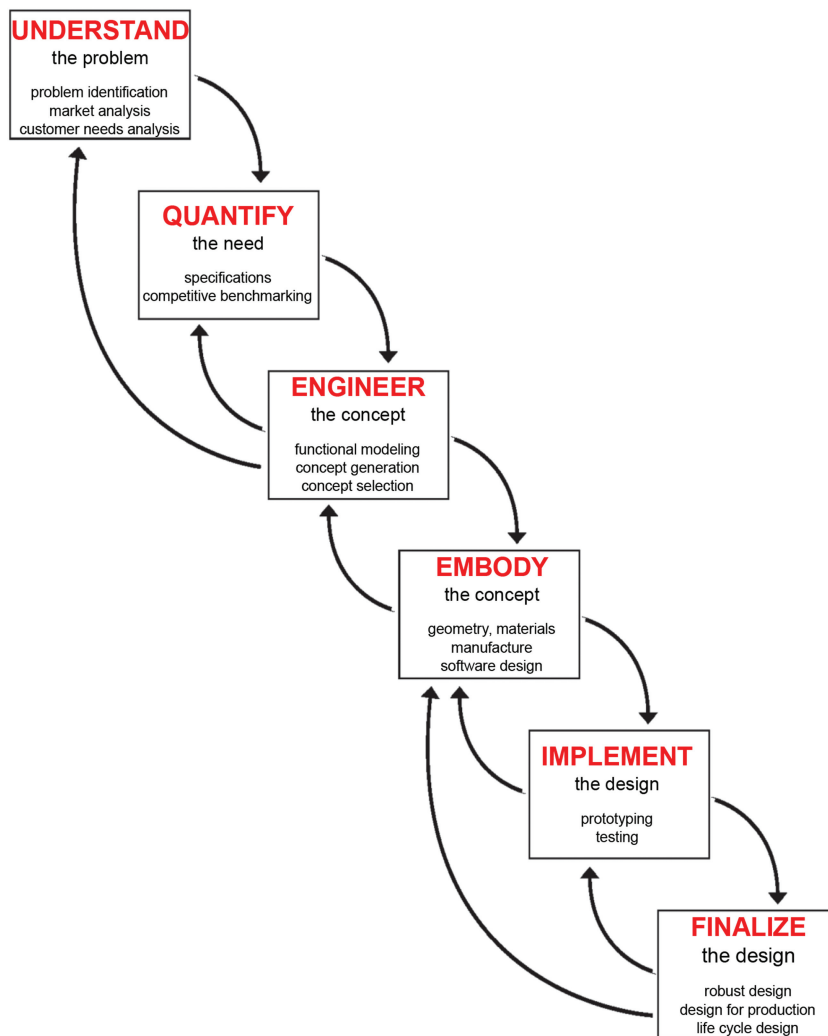


Figure 1. The Design-Based Instruction (DBI) engineering design process used by this study.

### Methods

#### Participants

Thirty-three in-service high school math and science teachers participated in a six-week ESIT summer program. The gender ratio was nearly equal: 56% male to 44% female. Seventy-two percent of the teachers self-reported as Caucasian. The participants were experienced teachers, with an average of more than seven years of teaching experience. Twenty-seven percent already held a Master's degree, while 15 participants were at that time enrolled in the Master's program. It is unknown whether any of the teachers had previous experience with DBI.

#### Instructional Intervention

For this study, we concentrated on the course *Fundamentals in Engineering and Design* (the core of the ESIT program),

which is also required for all MASEE teachers. The class met daily, four hours per day, for six weeks. Teachers formed small teams to accomplish these challenges. The main goals of the class were to introduce the basic concepts and processes of engineering design, and to exemplify the use of DBI through the hands-on design activities discussed below.

The ESIT consists of four major units, offered sequentially and drawn from different engineering disciplines. Each unit has its own unique design challenge. The first three units each lasted approximately one week and the Final Design Challenge lasted approximately two weeks. In total, during the six-week institute the teachers participated in learning sessions, assessments, final presentations, and a few extra make-up days.

#### Vehicle Design

This unit starts as a review of simple Newtonian mechanics and progresses to basic aerodynamics. As this

is the first module, it also serves as an introduction to the engineering design process (EDP) and DBI. The challenge given to the learners was:

Working in teams, students use engineering and kinematic principles to design and fabricate a super-structure on top of a dynamics cart that maximizes the volume (carrying capacity) and minimizes drag. Teams must characterize their designs with respect to drag coefficients for a variety of wind speeds and must develop quantitative predictions of design performance. Measurements are made using a variety of probe ware.

In this challenge, each team of teachers built a cargo carrier on top of a wheeled platform, with the goal of maximizing cargo space while minimizing drag. To characterize the drag coefficient of their design, the teams used a wind tunnel with sensors.

#### *Reverse Engineering and Product Redesign*

The focus of this unit was the process of creating design requirements, designing the product, and using observation data for improving the design. Over the course of the unit, teachers learned to conduct a needs analysis, create design specifications with performance metrics, hypothesize and compare designs, and collect performance data. To make the concepts more concrete, the teachers practiced their skills on a common consumer appliance, in this case, a hair dryer. The design challenge was:

Working in teams of two, the students are asked to conduct a customer needs analysis interview about a widely used consumer product and to map the results to quantifiable performance metrics. Teams sketch predicted internal structures of their product then disassemble the product and compare to their prediction. Functional models are created and the product is reassembled. Quantitative performance metrics are specified and measured, and the students then attempt a variety of redesigns.

#### *Robotics*

Using LEGO MINDSTORMS kits, teachers created robots to perform a variety of tasks. The lessons progressed from basic physics and mechanical engineering concepts (e.g. torque, gear ratios), to controlling sensors and motors, and finally to programming the microcontroller with LABVIEW. The design challenge was:

Working in teams teachers are asked to design, build and control, through programming, a robot to accomplish a particular scenario. The robots will sense and maneuver around obstacles in a maze to obtain access to the task.

Completion of the task will require the engagement of a set of different sensing and manipulation skills. Teachers will also investigate societies' definitions and uses of robots, past, present, and future.

#### *Final Design Project*

Similar to a senior capstone design project for undergraduate engineering programs, the last third of the class was reserved for a final design project. Teachers worked in small groups and chose their design project, subject to approval of the course instructors. They consulted with the professors about ideas, materials needed, and deliverables. At the end of the course, the teams presented their projects to the class. While each team's requirements and final product was individually negotiated with the professor, the written challenge presented to the teachers was:

During the initial weeks of class, teachers are encouraged to keep an invention journal in which they record thoughts about new or improved products in their everyday activities. Although they are not required to pursue any of their invention ideas, the exercise provides a resource from which they can draw ideas for their final project. They are asked to develop preliminary plans for this project, inventive, redesign or otherwise that can be embodied into a working prototype suitable for testing against specifications. Working in groups or individually, they meet with the professors and make presentations to their peers.

#### **Measures and Analysis Plan**

##### *Unit Tests*

We gave the teachers content tests on the first (pretest) and last day (posttest) of each of the first three design units (Vehicle Design, Reverse Engineering and Product Redesign, Robotics). Each test question is either a direct measure of the material learned or an analysis of whether the teacher could adapt content knowledge for a new situation. In the former case, we are concerned with whether each teacher could accurately follow the procedures and information explicitly provided, which maps to the expertise concept of "efficiency" as previously defined. The latter case relates to whether each teacher could use his or her knowledge to create new procedures to answer the question, which is consistent with the adaptive expertise usage of the term "innovation." Engineering faculty on the project helped create test questions to reflect content and constructs the instruments were aimed to measure. Copies of the three content tests are included in Appendix A.

### Vehicle Design Test

The Vehicle Design test had four questions, and measured teacher understanding of the forces acting upon a moving vehicle and how those forces affect position and speed. Efficiency questions such as, “What forces are acting on the vehicles?” assessed basic content knowledge using skills that are explicitly taught in class. For teachers not already proficient in this area, we expected a significant improvement in these questions between the pre- and posttest results since this material was directly covered in the Vehicle Design unit, and would indicate that DBI had a positive effect on efficiency. The innovation question, “Which of these forces are negligible and can be ignored and why?” required the teachers to think about what they learned and observed in class—how the forces interact with one another, how each might be measured, and what their relative magnitudes are—and combine that knowledge to answer a question not previously considered. An improvement in innovation between the pre- and posttest measures would signify a positive effect of DBI on innovation for this particular unit.

### Reverse Engineering Test

The Reverse Engineering test consisted of eight short-answer questions measuring teacher knowledge of the engineering design process and its related components, and contained an equal mix of innovation and efficiency questions. An example of an efficiency question is, “Briefly explain how you decide when an aspect of a product would be a constraint and when it would be a performance metric.” This question addresses whether the teachers know the definitions of constraint and performance metric, which was taught in class. Unless these concepts were part of our teachers’ prior knowledge, we expected an increase between the pre- and posttest efficiency measures. An example of an innovation question asked the teachers to extend their knowledge of constraints to the notion of weight: “Identify an engineering situation or product in which weight might be a constraint.” Improvements on these types of questions that require extension or transfer of knowledge to new situations would suggest an effect of the curriculum on innovation.

### Robotics Test

The Robotics test focused on basic ideas of automation and controls, as well as specifics related to LABVIEW programming. The test was heavy on efficiency, with five

efficiency questions and just one innovation question. An example efficiency question asked teachers to “Suppose the robot described [in a previous question] has a touch sensor and a LEGO MINDSTORMS NXT controller. How will the robot behave if the program below (in Figure 2) is loaded and run?”

As the Robotics unit included direct instruction and hands-on practice with programming, the teachers were expected to perform well on this type of posttest measure for which they were asked to identify the meaning of particular codes.

The innovation question asked the teachers to “Explain why a ‘wait for’ programming construct (one that waits for a sensor to trigger) cannot be used when monitoring more than one sensor.” Answering this question required a deeper understanding of the programming construct and the ability to think about its possible application in a way not directly discussed in class.

### Surveys

In addition to the unit tests, we also used two online surveys as pre-posttests, the *Design Survey* and the *Fisher Survey*, to address our second research question: Does DBI increase the teachers’ adaptive beliefs about engineering and learning? We administered the *Fisher Survey* (Fisher & Peterson, 2001) on the first day of class and the *Design Survey* at the start of the teachers’ final design project. Both surveys were used as post-measures, given during the final week of class.

### Design Survey

The *Design Survey* is part of a longer survey created by Mosborg et al. (2005), and consists of 27 Likert scale belief statements on a scale of 1 (strongly disagree) to 5 (strongly agree) about engineering design. In a study, they aligned certain survey items to expert engineers’ definitions about design. Based on the adaptive expertise literature, we separated the survey statements into categories. Beliefs, such as “Design is a goal-oriented, constrained, decision-making activity” and “Good designers get it right the first time,” represent a view of design as a goal-oriented activity to be completed expediently, and were categorized as efficiency statements. Beliefs, such as “Design is not description of what is, it is the exploration of what might be” and “Engineering design impacts every aspect of

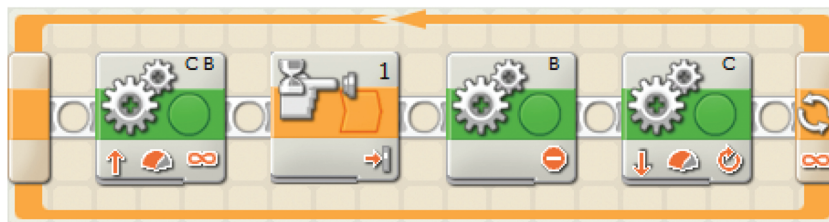


Figure 2. Example efficiency question from the Robotics content test.



society,” are consistent with design as an exploratory, fluid thinking, and holistic endeavor, and were categorized as innovation statements. Four of the 27 beliefs in the survey were labeled as efficiency statements and 17 were labeled as innovation statements. The remaining six beliefs were not applicable to either view of design and were not used in the data analysis. Neither reliability nor validity information was available to us about the survey. A copy of the Design Survey is included in Appendix B.

*Fisher Survey*

The *Fisher Survey* (Fisher & Peterson, 2001) is a 42 question self-reported Likert scale survey ranging from 1–5 (strongly disagree to strongly agree). It measures four constructs (Multiple Perspectives, Metacognitive Self-Assessment, Goals and Beliefs, and Epistemology) that reflect the cognitive dispositions of adaptive experts, i.e., “dispositions that augment and enhance their ability to effectively utilize and extend their content knowledge” (Bransford, Brown, & Cocking, 2000; Fisher & Peterson, 2001; Hatano & Inagaki, 1986; Wineburg, 1998). The survey creators validated the survey by administering it in multiple iterations to different, but related, groups of people (a sophomore statistics class with mostly biomedical engineering (BME) undergraduates, engineering faculty, engineering freshmen, BME seniors).

Multiple Perspectives statements, such as “When I consider a problem, I like to see how many different ways I can look at it,” involve a willingness to use different approaches and representations when problem solving. Metacognitive Self-Assessment statements, such as, “When I know the material, I can recognize areas where my understanding is incomplete,” are related to the ability to monitor one’s own understanding. Goals and Beliefs statements, such as, “One can increase their level of expertise in any area if they are willing to try,” are related to expertise and learning goals. Epistemology statements, such as “Scientists are always revising their view of the world around them,” are concerned with the subject’s belief about the creation of knowledge. Fisher and Peterson (2001) lists the Cronbach  $\alpha$  reliability of the four subscales range from 0.66 to 0.80 for the different test groups, with an overall measure between 0.85 and 0.89, but does not include additional information on validity. Appendix C contains of copy of the Fisher Survey.

**Findings**

*Content Tests*

We used the Vehicle Design, Reverse Engineering, and Robotics content tests to determine whether the design challenges in the ESIT would increase the teachers’ engineering innovation and efficiency. The tests were four to eight questions each, and two researchers scored the

questions from 0–3 points. Inter-grader reliability was established at 82% consistency, which was sufficient for our research and exceeded the typical 80% consistency threshold. Each test was analyzed using a  $2 \times 2$  repeated measures ANOVA (analysis of variance) with two within-subjects factors: time (pretest, posttest) and measure (innovation, efficiency). Our criterion for significance was  $p < 0.05$ .

*Vehicle Design*

The Vehicle Design test means and standard deviations are listed in Table 1. The result of the Vehicle Design pre/posttest showed that the teachers significantly improved in efficiency,  $F(1, 28) = 7.04$ ,  $MSE = 0.26$ . Although there was some improvement in innovation, it was not statistically significant. Main effects of time and measure were not significant.

*Reverse Engineering*

Table 2 shows the means and standard deviations of the Reverse Engineering pre/posttests. Efficiency scores improved significantly from pretest to posttest, while improvements in innovation scores were not significant. The main effects of both time,  $F(1, 28) = 9.11$ ,  $MSE = 0.31$ , and measure,  $F(1, 28) = 5.79$ ,  $MSE = 0.48$ , are dependent upon each other, as is indicated by the significant interaction,  $F(1, 28) = 6.01$ ,  $MSE = 0.24$ .

*Robotics*

Teachers improved significantly on both innovation and efficiency, as is seen with the main effect of time,  $F(1, 32) = 28.14$ ,  $MSE = 0.80$ . Efficiency averages were higher than innovation averages, but there was not a significant main effect of measure or a significant interaction between time and measure. Table 3 lists the results of the Robotics test.

*Content Test Summary*

For the Vehicle Design Challenge, teachers exhibited a significant increase in their efficiency when dealing with

Table 1  
Vehicle Design innovation and efficiency means and standard deviations (N=29, 0–3 points).

Vehicle Design	Time	
	Pretest	Posttest
Innovation		
<i>M</i>	1.41	1.79
<i>SD</i>	1.45	1.42
Efficiency		
<i>M</i>	1.67	2.02
<i>SD</i>	0.60	0.77

Table 2  
Reverse Engineering innovation and efficiency means and standard deviations (N=29, 0–3 points).

Reverse Engineering	Time	
	Pretest	Posttest
Innovation		
<i>M</i>	1.71	1.79
<i>SD</i>	0.61	0.62
Efficiency		
<i>M</i>	1.17	1.71
<i>SD</i>	0.82	0.78

problems related to the content of the unit. Prior to beginning the Reverse Engineering Challenge, the teachers approached the content covered in the Reverse Engineering unit in significantly more innovative ways than efficient ways. However, they showed significant improvements from the beginning to the end of the week in their efficiency. As such, at the end of the unit, they were just as efficient as they were innovative. During the third week, the Robotics Challenge week, they were both significantly more innovative and significantly more efficient from beginning to end of week. In other words, during the third week, their adaptive expertise related to that week's content showed a significant increase.

#### Beliefs Surveys

The *Design Survey* and the *Fisher Survey* assessed whether professional development using DBI would increase the teachers' adaptive beliefs about engineering and learning. Both Likert scale surveys have a scale from 1–5 with 1 as strongly disagree and 5 as strongly agree.

#### Design Survey

We divided the questions into those that indicated innovative attitudes, and those indicating efficiency attitudes. Questions that did not indicate either innovation or efficiency were excluded. Since there were a different number of innovation questions than efficiency questions, for each participant, we used the mean score for each group as their innovation and their efficiency score. Table 4 lists

Table 3  
Robotics innovation and efficiency means and standard deviations (N=31, 0–3 points).

Robotics	Time	
	Pretest	Posttest
Innovation		
<i>M</i>	1.11	1.70
<i>SD</i>	1.29	1.20
Efficiency		
<i>M</i>	0.94	2.00
<i>SD</i>	0.77	0.73

Table 4  
Design Survey innovation and efficiency means and standard deviations (N=30, scale=1–5).

Design Survey	Time	
	Pretest	Posttest
Innovation		
<i>M</i>	3.89	4.05
<i>SD</i>	0.43	0.34
Efficiency		
<i>M</i>	2.71	2.92
<i>SD</i>	0.63	0.49

the means and standard deviations of these two groups of questions. The analysis was done using a  $2 \times 2$  repeated measures ANOVA with two within subjects factors: time (pretest, posttest) and measure (innovation, efficiency). On the pre- and post-measures of design understanding, teachers improved significantly on both innovation and efficiency, exhibited by a significant main effect of time,  $F(1, 29) = 6.95$ ,  $MSE = 0.14$ ,  $p < 0.05$ . There was also a significant main effect of measure,  $F(1, 29) = 130.97$ ,  $MSE = 0.31$ ,  $p < 0.05$ , with innovation averages being significantly higher than efficiency averages.

The teachers related engineering more closely with innovation than efficiency. Interestingly, from the initial survey to the final survey, teachers demonstrated significant increases in their beliefs about how both efficiency and innovation are linked to engineering, signaling that their beliefs changed in that timeframe and they were thinking more like adaptive experts.

#### Fisher Survey

We used a  $2 \times 4$  repeated measures ANOVA with two within subjects factors: time (pretest, posttest) and dimension (Multiple Perspectives, Metacognitive Self-Assessment, Goals and Beliefs, and Epistemology). Similar to the Design Survey, because each category had a different number of questions, each participant's overall score in a category is the mean of all the questions in that category. Table 5 summarizes the Fisher Survey means and standard deviations.

Although the mean scores rose from pretest to posttest, the difference was not statistically significant,  $F(1, 25) = 1.49$ ,  $MSE = 0.19$ ,  $p > 0.05$ . Interestingly, teachers rated significantly higher in the categories Epistemology and Metacognitive Self-Assessment than in the categories Goals and Beliefs and Multiple Perspectives,  $F(1, 25) = 9.88$ ,  $MSE = 0.15$ ,  $p < 0.05$ . For instance, teachers may have agreed strongly with statements such as "Scientific knowledge is developed by a community of researchers" or "I monitor my performance on a task," but had lower rating for statements such as, "Challenge stimulates me" or "I create several models of an engineering problem to see which one I like best."

Table 5  
Fisher Survey: four dimensions of adaptive expertise means and standard deviations (N=26, scale=1–5).

Design Survey	Time	
	Pretest	Posttest
Multiple Perspectives		
<i>M</i>	3.80	3.86
<i>SD</i>	0.44	0.39
Metacognitive Self-Assessment		
<i>M</i>	4.06	4.11
<i>SD</i>	0.36	0.42
Goals and Beliefs		
<i>M</i>	3.76	3.81
<i>SD</i>	0.41	0.40
Epistemology		
<i>M</i>	3.98	3.99
<i>SD</i>	0.36	0.42

## Discussion and Conclusion

Our first research question addressed whether participating in the ESIT program could impact teachers' engineering innovation and efficiency when they were presented with content-specific problems to solve. The three content test results demonstrate that the DBI used in the ESIT program significantly increased the teachers' efficiency score. The results for teachers' engineering innovation were mixed. It increased significantly over the Robotics Challenge, but not over the other two units. However, the fact that the innovation score for the Reverse Engineering Challenge was high for both pre- and posttests suggests that there may have been a ceiling effect where there was not much room for the scores to improve despite the DBI curriculum. From these results, it appears that it is possible for DBI to increase teachers' engineering efficiency and innovation, but some challenges (particularly Vehicle Design) may need revision to focus more on the innovative aspects of the problem.

Our second research question concerns whether DBI increases teachers' adaptive beliefs about learning engineering content and the engineering design process. The Design Survey results indicate a significant increase in the teachers' adaptive beliefs about engineering design. The teachers improved significantly on both innovation and efficiency, with innovation averages being significantly higher than efficiency averages. As design was the core principle of the ESIT program, the increases on both innovation and efficiency were encouraging.

However, the Fisher Survey results showed that teachers' beliefs about how engineering is learned remained unchanged; the teachers' beliefs about learning in general did not become more adaptive. Although the teachers' scores increased slightly for each measure (Multiple Perspectives, Metacognitive Self-Assessment, Goals and Beliefs, and Epistemology), those scores were already high at the beginning of the ESIT program. This result is interesting when compared with the

Design Survey results. Teachers did not increase the adaptiveness of their beliefs about learning in general, but they did increase their innovative approach to design in engineering. This suggests that the design focus of the ESIT program may be a key to increasing teachers' innovation.

There are important limitations of this study. The sample population is relatively small. Owing to study constraints, we were also unable to determine the reliability of the unit tests and the parts of the Design survey that we used. In addition, because we were unable to have a control group, we cannot compare the ESIT to other professional development programs. It is also possible that there are self-selection effects and that our participants may not be representative of the entire population of teachers who may be interested in learning to teach design engineering. As the number of professional learning opportunities for teachers in engineering grow, we hope to be able to conduct such a study.

The ESIT program was born out of the necessity to train teachers to fill the expected demand for high school engineering classes. It is impossible to duplicate the experience of a full college major or work experience in engineering in the required training time. This problem is further complicated by the fact that the teachers will need to work across multiple engineering domains. The ESIT program believes that instead of standard rigid routine content instruction, the teachers are better served by giving them experiences using basic design engineering knowledge fluidly and flexibly. Thus, it takes an adaptive expertise approach to the training. This study has provided some insight on elements of the ESIT that improved teachers' adaptive expertise. Our next step will be to investigate the data we have collected from these teachers' students. This will provide more information on both how to design the ESIT experience, and on how changes in teachers' adaptive expertise transfer to their teaching practice and their students' growth in adaptive expertise.

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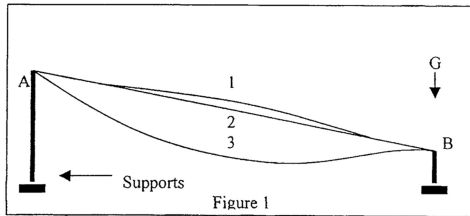
**Appendix A**

**Instrument A1. Vehicle design pre/posttest with questions labelled as Innovation or Efficiency**

Vehicle Design Challenge

Pre Test:

Given the following diagram of three tracks (tracks 1, 2, 3) from point A to point B. If there are identical vehicles starting at point A at the same time:



Answer the following:

- a) Which car (1, 2, or 3) arrives first? (Efficiency)
- b) What are their relative speeds at point B (which car - 1, 2, or 3 has the highest velocity)? (Efficiency)
- c) What forces are acting on the vehicles? (Efficiency)
- d) Which of these forces are negligible and can be ignored and why? (Innovation)

**Instrument A2. Reverse engineering pre/posttest with questions labeled as Innovation or Efficiency**

**Introduction to Engineering and Design**

Summer 2010

**Pre-test Week 2**

1. What are the stages of the engineering design process? (Innovation)
2. Describe the differences between *Reverse Engineering* and *Forward Design*. Explain why these differences make sense. (Efficiency)
3. Think of a situation in which weight is an important aspect of a product that is being designed.
  - a. Identify an engineering situation or product in which weight might be a constraint. (Innovation)
  - b. Identify an engineering situation or product in which weight might be a performance metric. (Innovation)
  - c. Briefly explain how you decide when an aspect of a product would be a constraint and when it would be a performance metric. (Innovation)
4. What is the purpose of functional modeling in engineering design? (Innovation)
5. Suppose a flashlight operates with a 3 V battery pack and draws 300 mA of current while producing 0.1 W of output light power.
  - a. How much power does the flashlight use? (Efficiency)
  - b. What is the efficiency of the flashlight? (Efficiency)

**Instrument A3. Robotics pre/posttest with questions labeled as Innovation or Efficiency**

**Introduction to Engineering and Design**

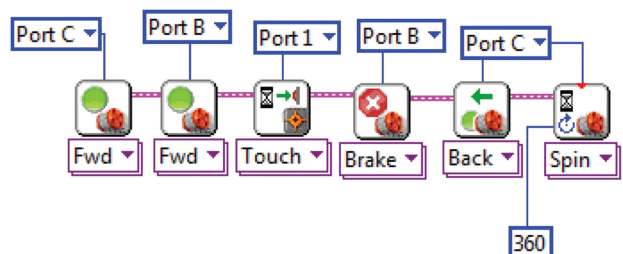
Summer 2010

**Pre-test Week 3**

1. What characteristics distinguish automated or controlled systems? (Efficiency)
2. What is the difference between open-loop control and closed-loop control? Give an example of each. (Efficiency)
3. Explain why a “wait for” programming construct (one that waits for a sensor to trigger) cannot be used when monitoring more than one sensor? (Innovation)
4. A small robot has motors to drive each rear wheel independently. The vehicle executes turns by driving one wheel forward and the opposite wheel backward. The motors are connected to gear train with a speed ratio of 1 to 3 (1 output rotation for 3 input rotations). The robot has 5.75 cm diameter tires and a wheel base (distance between wheel centers) of 16.5 cm. How many rotations of each motor are required to execute a 90° turn? (Efficiency)
5. Suppose the robot described above has a touch sensor and an LEGO MINDSTORMS NXT controller. How will the robot behave if the program below is loaded and run? (Efficiency)



6. Suppose the program below is loaded and run on the robot described above. How will the robot behave? (Efficiency)



This is a LabVIEW version of the same program.

Table A1  
List of Innovation and Efficiency questions in unit pre/posttests.

Test	Question	Innovation/Efficiency
Vehicle Design	A	Efficiency
	B	Efficiency
	C	Efficiency
	D	Innovation
Reverse Engineering	1	Innovation
	2	Efficiency
	3a	Innovation
	3b	Innovation
	3c	Innovation
	4	Innovation
	5a	Efficiency
Robotics	5b	Efficiency
	1	Efficiency
	2	Efficiency
	3	Innovation
	4	Efficiency
	5	Efficiency
	6	Efficiency

## Appendix B

*Design Survey with items labeled as Innovation, Efficiency, or N/A*

Below are a number of statements people have made about design. We expect that different statements will appeal to different people. In the table below, please indicate the extent to which you agree with the statement provided (i.e., speaks to you, resonates with you, you agree with it, etc.)

- Good designers get it right the first time. (*Efficiency*)
- Good designers have intrinsic design ability. (*Efficiency*)
- In design, a primary consideration through the process is addressing the question “Who will be using the product?” (*N/A*)
- Visual representations are primarily used to communicate the final design to a teammate or the client. (*Efficiency*)
- Engineering design is the process of devising a system, component or process to meet a desired need. (*Innovation*)
- Design in a major sense is the essence of engineering; Design, above all else, distinguishes engineering from science. (*Innovation*)
- Design begins with the identification of a need and ends with a product or system in the hands of a user. (*N/A*)
- Design is primarily concerned with synthesis rather than the analysis, which is central to engineering science. (*N/A*)
- ... design is a communicative act directed towards the planning and shaping of human experience. The task of the designer is to conceive, plan, and construct artifacts that are appropriate to human situations, drawing knowledge and ideas from all the arts and sciences. (*Innovation*)
- Design is as much a matter of finding problems as it is of solving them. (*Innovation*)
- In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem. (*Innovation*)
- Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers. (*Innovation*)
- Designing as a conversation with the materials of a situation. (*N/A*)
- Design defines engineering. It’s an engineer’s job to create new things to improve society. (*Innovation*)
- Design is not description of what is, it is the exploration of what might be. (*Innovation*)
- Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem. (*Innovation*)
- In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a ‘surprise’ that drives the originality streak in a design project. (*Innovation*)
- Design is a goal-oriented, constrained, decision-making activity. (*Efficiency*)
- Designers operate within a context which depends on the designer’s perception of the context. (*Innovation*)
- Creativity is integral to design, and in every design project creativity can be found. (*Innovation*)
- Engineering design impacts every aspect of society. (*Innovation*)
- A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency. (*N/A*)
- Design is “world” creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools. (*Innovation*)
- Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design. (*Innovation*)
- Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design. (*Innovation*)
- Information is central to designing. (*N/A*)
- Design is iteration. (*Innovation*)

Of the 27 statements above, which statement do you agree with the MOST?

Please type in the number of the statement (1–27). (*Not used in the analysis*)

Of the 27 statements above, which statement do you agree with the LEAST?

Please type in the number of the statement (1–27). (*Not used in the analysis*)

Table B1  
List of Innovation and Efficiency items in the Design Survey.

Question #	Innovative, Efficient, or N/A
1	Efficient
2	Efficient
3	N/A
4	Efficient
5	Innovative
6	Innovative
7	N/A
8	N/A
9	Innovative
10	Innovative
11	Innovative
12	Innovative
13	N/A
14	Innovative
15	Innovative
16	Innovative
17	Innovative
18	Efficient
19	Innovative
20	Innovative
21	Innovative
22	N/A
23	Innovative
24	Innovative
25	Innovative
26	N/A
27	Innovative

## Appendix C

Fisher Survey of adaptive beliefs labeled by subscale (Multiple Perspectives, Metacognitive Self-Assessment, Goals & Beliefs, Epistemology).

Please answer the questions using the following rating scale:

1 (strongly disagree), 2 (disagree) 3 (neutral), 4 (agree), 5 (strongly agree)

1. I create several models of an engineering problem to see which one I like best. (*Multiple Perspectives*)
2. I often try to monitor my understanding of the problem. (*Metacognitive Self-Assessment*)
3. Most knowledge that exists in the world today will not change. (*Epistemology*)
4. I rarely consider other ideas after I have found the best answer. (*Multiple Perspectives*)
5. As I learn, I question my understanding of the new information. (*Metacognitive Self-Assessment*)
6. Facts that are taught to me in class must be true. (*Epistemology*)
7. When I consider a problem, I like to see how many different ways I can look at it. (*Multiple Perspectives*)
8. I feel uncomfortable when I cannot solve difficult problems. (*Goals & Beliefs*)
9. I create several models of an engineering problem to see which one I like best. (*Multiple Perspectives*)
10. Experts in engineering are born with a natural talent for their field. (*Goals & Beliefs*)

11. Usually there is one correct method in which to represent a problem. (*Multiple Perspectives*)
12. When I struggle, I wonder if I have the intelligence to succeed in engineering. (*Goals & Beliefs*)
13. There is one best way to approach a problem. (*Multiple Perspectives*)
14. Although I hate to admit it, I would rather do well in a class than learn a lot. (*Goals & Beliefs*)
15. Knowledge that exists today may be replaced with a new understanding tomorrow. (*Epistemology*)
16. I am open to changing my mind when confronted with an alternative viewpoint. (*Multiple Perspectives*)
17. I seldom evaluate my performance on a task. (*Metacognitive Self-Assessment*)
18. Existing knowledge in the world seldom changes. (*Epistemology*)
19. I tend to focus on a particular model in which to solve a problem. (*Multiple Perspectives*)
20. One can increase their level of expertise in any area if they are willing to try. (*Goals & Beliefs*)
21. Poorly completing a project is not a sign of a lack of intelligence. (*Goals & Beliefs*)
22. I have difficulty in determining how well I understand a topic. (*Metacognitive Self-Assessment*)
23. I find additional ideas burdensome after I have found a way to solve the problem. (*Multiple Perspectives*)
24. Scientists are always revising their view of the world around them. (*Epistemology*)
25. As a student, I cannot evaluate my own understanding of new material. (*Metacognitive Self-Assessment*)
26. Challenge stimulates me. (*Goals & Beliefs*)
27. I solve all related problems in the same manner. (*Multiple Perspectives*)
28. Scientific theory slowly develops as ideas are analyzed and debated. (*Epistemology*)
29. I feel uncomfortable when unsure if I am doing a problem the right way. (*Goals & Beliefs*)
30. For a new situation, I consider a variety of approaches until one emerges superior. (*Multiple Perspectives*)
31. Experts are born, not made. (*Goals & Beliefs*)
32. I rarely monitor my own understanding while learning something new. (*Metacognitive Self-Assessment*)
33. Scientific knowledge is discovered by individuals. (*Epistemology*)
34. Even if frustrated when working on a difficult problem, I can push on. (*Goals & Beliefs*)
35. When I know the material, I can recognize areas where my understanding is incomplete. (*Metacognitive Self-Assessment*)
36. Most knowledge that exists in the world today will not change. (*Epistemology*)
37. To become an expert in engineering, you must have an innate talent for engineering. (*Goals & Beliefs*)
38. Scientific knowledge is developed by a community of researchers. (*Epistemology*)

39. I am afraid to try tasks that I do not think I will do well. (*Goals & Beliefs*)
40. I monitor my performance on a task. (*Metacognitive Self-Assessment*)
41. Progress in science is due mainly to the work of sole individuals. (*Epistemology*)
42. Expertise can be developed through hard work. (*Goals & Beliefs*)
43. As I work, I ask myself how I am doing and seek out appropriate feedback. (*Metacognitive Self-Assessment*)
44. When I solve a new problem, I always try to use the same approach. (*Multiple Perspectives*)

Table C1

List of Fisher Survey items by subscale: Perspectives, Metacognitive Self-Assessment, Goals & Beliefs, and Epistemology.

Question	Aspect of Adaptive Expertise	Question	Aspect of Adaptive Expertise
1	Multiple Perspectives	23	Multiple Perspectives
2	Metacognitive Self-Assessment	24	Epistemology
3	Epistemology	25	Metacognitive Self-Assessment
4	Multiple Perspectives	26	Goals & Beliefs
5	Metacognitive Self-Assessment	27	Multiple Perspectives
6	Epistemology	28	Epistemology
7	Multiple Perspectives	29	Goals & Beliefs
8	Goals & Beliefs	30	Multiple Perspectives
9	Multiple Perspectives	31	Goals & Beliefs
10	Goals & Beliefs	32	Metacognitive Self-Assessment
11	Multiple Perspectives	33	Epistemology
12	Goals & Beliefs	34	Goals & Beliefs
13	Multiple Perspectives	35	Metacognitive Self-Assessment
14	Goals & Beliefs	36	Epistemology
15	Epistemology	37	Goals & Beliefs
16	Multiple Perspectives	38	Epistemology
17	Metacognitive Self-Assessment	39	Goals & Beliefs
18	Epistemology	40	Metacognitive Self-Assessment
19	Multiple Perspectives	41	Epistemology
20	Goals & Beliefs	42	Goals & Beliefs
21	Goals & Beliefs	43	Metacognitive Self-Assessment
22	Metacognitive Self-Assessment	44	Multiple Perspectives