Using Design-Based Instruction to Increase Engineering Adaptive Expertise in Teachers

Abstract

With the growing popularity of high school engineering design courses, teachers with varying engineering backgrounds, multiple course options, and the open-ended nature of design, engineering design teachers need to be trained towards adaptive expertise (AE). Adaptive experts are both efficient and innovative. Working with 33 in-service teachers, we investigated whether design-based instruction (DBI) can develop AE in a 6-week summer professional development course. We measured teachers' beliefs about engineering before and after the course, as well as their innovation and efficiency before and after each course challenge unit. From the results, we conclude that DBI has improved the teachers' AE.

Introduction

With the rapid growth of engineering courses in high schools, there is a shortage of trained teachers. Texas's goal of having at least one engineering teacher in each high school will require nearly 2000 teachers in that state alone. Additionally, there is an overabundance of content areas (mechanical, electrical, etc.) to cover, teachers have varying levels of engineering experience, and design is open-ended by nature. As such, it is necessary to train teachers for adaptive expertise (AE). Adaptive experts are able to apply core knowledge appropriately and expeditiously (*efficient*), but also perform well in novel and fluid situations (*innovative*).

Previous work (Martin, Petrosino, Rivale, & Diller, 2006) has shown that challenge-based instruction (CBI) can develop AE in engineering problem solving. The current work investigates whether design-based instruction (DBI) develops AE in a group of 33 in-service high school teachers in a 6-week professional development.

Our research questions are:

1. Does DBI increase the teachers' engineering innovation and efficiency?
2. Does DBI increase their adaptive beliefs about engineering and learning?

Background

Expertise

Hatano and colleagues (Hatano & Inagaki, 1986; Hatano & Oura, 2003; Inagaki & Miyake, 2007) categorized expertise into two types. *Routine experts* are highly skilled in their knowledge domain and can solve familiar problems efficiently. However, faced with a novel problem, they make mistakes in applying principles, using procedures, or interpreting results (Bransford, Brown, & Cocking, 2000). *Adaptive experts* (Hatano & Inagaki, 1986) have the same core technical abilities as routine experts, but are better able to develop solutions to novel challenges. Unlike routine experts, adaptive experts tend to seek out new situations, think of their skill set as dynamic, can assess their own knowledge, and consider multiple perspectives (Bransford et al., 2000; Wineburg, 1998).

Innovative applications of principles and resources are at the core of engineering design. Because it is fundamentally an adaptive field, engineering design teachers need to be adaptive to handle the changing demands of the field and teach those skills to their students.

Teaching for Adaptive Expertise

Several methods have been created to develop adaptive expertise in students. Itakura's Hypothesis-Experiment-Instruction method (Hatano, 1988) is based on class discussions of novel problems. The Fostering Communities of Learners (FCL) program (Brown, 1997) uses a modified jigsaw to assemble individual students' research to solve a larger class project.

In challenge-based instruction (CBI) student teams solve a problem using a solution process that often involves brainstorming, researching ideas, and considering other perspectives. Schwartz and Martin (2004) showed that 9^{th} graders who use CBI to create a method to calculate standardized scores learned the content as well as traditionally taught students, but were better at solving novel problems.

Since experts agree that engineering in high school should be based on design (Katehi, Pearson, & Feder, 2009), the elements of CBI were adapted to create design-based instruction (DBI). Based on actual engineering design processes, Figure 1 shows the DBI design cycle that we used in our program. Like CBI, DBI is oriented around extended projects, called design challenges, that are open-ended and integrate design methodology with applications of STEM content. At any step, the design may need to be reevaluated and the students fall back to an earlier stage in the process, just like in a professional engineering design projects.

Methods

Participants

In the summer of 2010, 33 in-service high school teachers participated in a 6-week summer institute as part of the UTeach*Engineering* project. Forty-four percent were female, and seventy-two percent self-reported as Caucasian. The average amount of teaching experience was over 7 years, and 28% have Master's degrees. Previous experience with DBI is unknown.

Instructional Intervention

In 2006, the Texas legislature mandated that all high school students complete four years of science instead of three, and could enroll in an engineering course to fulfill the requirement. However, the knowledge and skills needed to teach design-based engineering are different than other science classes. The UTeach*Engineering* program was created to fill the need to train teachers to teach design-based engineering.

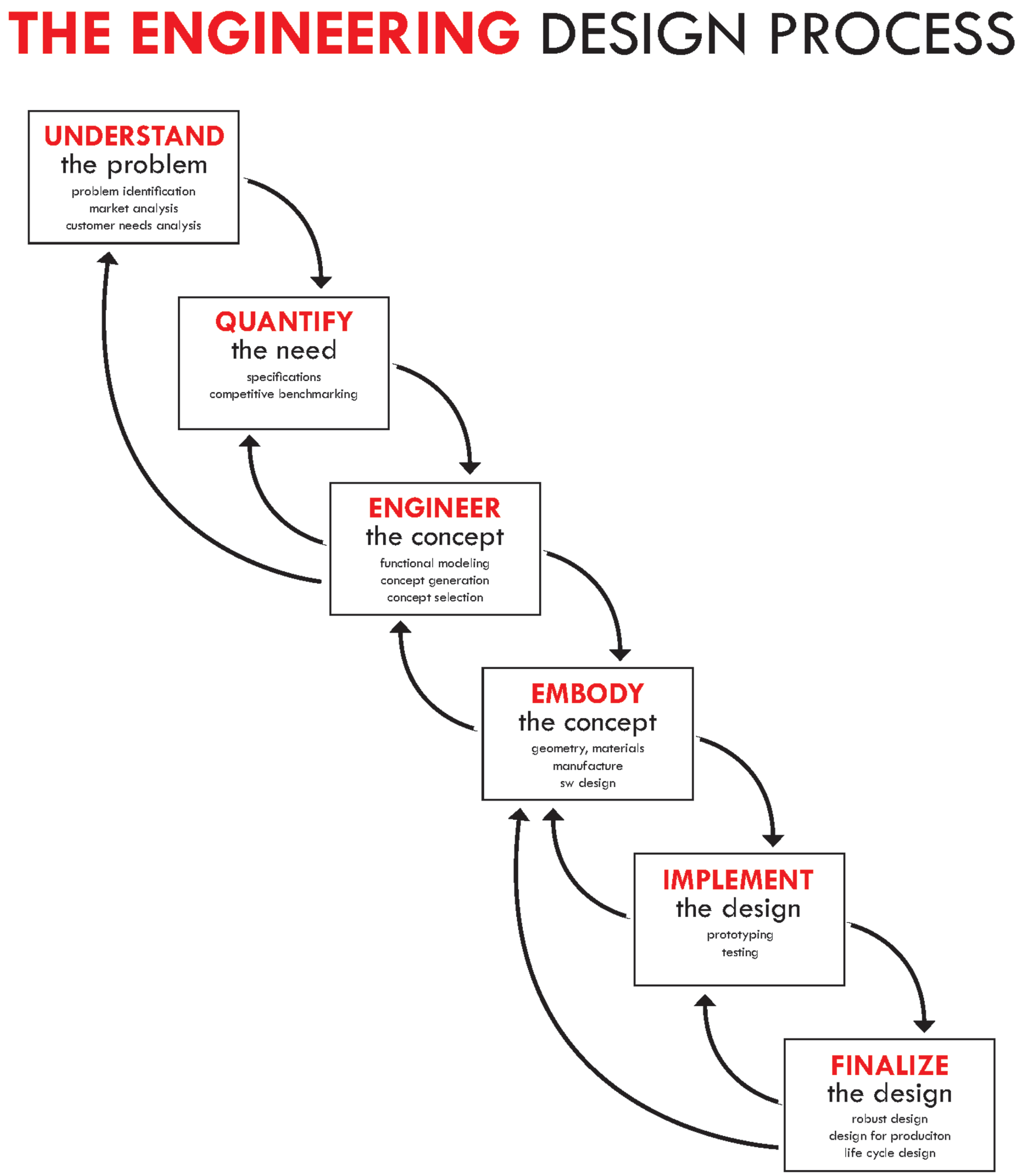

Figure 1. The Design Based Instruction (DBI) cycle

This paper focuses on the *Fundamentals in Engineering and Design* professional development course, which is completed by all UTeach*Engineering* teachers. It is a 6-week summer class that meets for four hours a day, covers the essential parts of the emerging Texas standardized curriculum, and prepares teachers for the state engineering teacher certification exam. The course introduces teachers to the scope of engineering, the basics of engineering science, and engineering design. There are four major units, each with a design challenge, which the teachers complete in small teams.

Vehicle Design Challenge.

Teacher teams build a superstructure on top of a dynamics cart that attempts to maximize cargo space while minimizing drag. The teams use a wind tunnel to characterize the drag coefficient of their design.

Reverse Engineering and Product Redesign.

This unit focuses on product design and specification of requirements. Using a hair dryer as an example product, teachers perform a needs analysis and create performance metrics. They predict the inner workings of a hair dryer, and then disassemble an actual device to compare against their predictions. After characterizing the performance of the dryer, they make suggestions for design improvements.

Robotics.

Using LEGO MINDSTORMS™ kits, teachers create robots to perform a variety of tasks. The lessons progress from basic physics and mechanical engineering (e.g. torque, gear ratios), to controlling sensors and motors, and to programming the microcontroller with LABVIEW™.

Final Design Project.

The final third of the class is reserved for a capstone project in which teachers work in small groups on a topic of their choosing. They consult with the professors about their ideas, materials needed, and deliverables. At the end of the course, teams present their projects to the class.

Measures

Engineering Content Knowledge

Each content test (Vehicle Design, Reverse Engineering, Robotics) corresponds to a weeklong instructional unit and measures growth in AE. Some of the questions require efficiency (e.g. comprehension and routine task completion) while others require innovation (e.g. imagining situations or describing design processes). Validation was provided by content experts. Pretests and posttests were given on the first and last days of each unit, respectively. The tests were 4 to 5 questions each. Two researchers scored the questions from 0-3 points, and inter-grader reliability was 82%. Each test was analyzed using a 2 x 2 repeated measures ANOVA with two within-subjects factors: time (pretest, posttest) and measure (innovation, efficiency). Our criterion for significance is $p < .05$.

Engineering Design Beliefs: Design Survey

The *Design Survey* is a subsection of a larger assessment created by Mosborg et al. (2005). The section consists of 27 Likert scale questions about engineering design, such as “Good designers get it right the first time.” No reliability information is available. We administered the Design Survey online at the beginning of the teachers’ final design project and during the final week of class. We divided the questions into those that indicated innovative attitudes, and those indicating efficiency attitudes. Questions that did not indicate either were excluded. We analyzed using a 2 x 2 repeated measures ANOVA with two within subjects factors: time (pretest, posttest) and measure (innovation, efficiency).

AE Foundational Beliefs: Fisher Survey

The *Fisher Survey* (Fisher & Peterson, 2001) is a 42 question self-reported Likert scale survey that measures 4 constructs (Multiple perspectives, Metacognitive self-assessment, Goals and beliefs, and Epistemology) that are believed to form the foundation of AE. Multiple perspectives involves willingness to use different approaches and representations when problem solving. Metacognitive self-assessment is related to the ability to monitor one's own understanding. Goals and beliefs relate to expertise and learning goals. Epistemology is concerned with the subject's belief about the creation of knowledge.

The Cronbach α reliability of the subscales range from 0.66 to 0.80 for the different test groups, with an overall measure between 0.85 and 0.89. All subjects took online pretests and posttests on the first day and final week of class, respectively.

We used a 2 x 4 repeated measures ANOVA with two within subjects factors: time (pretest, posttest) and dimension (Metacognitive self-assessment, Epistemology, Multiple perspectives, and Goals and beliefs).

Results

Engineering Content Tests

Vehicle Design.

Main effects of time and measure were not significant, $F\ (1, 28) = 2.91$, $MSE = 1.35$ and $F\ (1, 28) = 1.30$, $MSE = 1.30$, respectively. However, the teachers showed improvement on the Vehicle Design content test on innovation and they improved significantly on efficiency, $F\ (1, 28) = 7.04$, $MSE = .26$.

Reverse Engineering.

There were main effects of both time, $F\ (1, 28) = 9.11$, $MSE = .31$, and measure, $F\ (1, 28) = 5.79$, $MSE = .48$. The main effects are dependent upon the other, as is indicated by the significant interaction, $F\ (1, 28) = 6.01$, $MSE = .24$. Teachers' innovation scores were significantly higher than their efficiency scores at the pretest. From pretest to posttest, efficiency scores improved significantly. Innovation scores improved, but not significantly.

Robotics.

Teachers improved significantly on both innovation and efficiency, as is seen with the main effect of time, $F\ (1, 32) = 28.14$, $MSE = .80$. Efficiency averages were higher than innovation averages, but there was not a significant main effect of measure, $F\ (1, 32) = .15$, $MSE = .70$. There was not a significant interaction between time and measure, $F\ (1, 32) = 3.69$, $MSE = .49$.

Design Survey

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, $F(1, 29) = 6.95$, $MSE = .14$, $p < .05$. There was also a significant main effect of measure, $F(1, 29) = 130.97$, $MSE = .31$, $p < .05$, with innovation averages being significantly higher than efficiency averages.

Fisher Survey

Teachers held fairly adaptive beliefs about learning science and engineering both before and after the course. Teachers' scores on the Fisher Survey did not change significantly, $F(1, 25) = 1.49$, $MSE = .19$, $p > .05$. However, teachers rated Epistemology and Metacognitive self-assessment significantly higher than Goals and beliefs and Multiple perspectives, $F(1, 25) = 9.88$, $MSE = .15$, $p < .05$.

Conclusions

After the summer program, each of the unit tests indicates that teachers improved in both efficiency and innovation. From the Design Survey, we examined the responses to questions that relate to beliefs about efficiency and innovation, and teachers demonstrated significant increases in both measures. In each of the Fisher Survey categories, the teachers' views changed to be more aligned with adaptive experts, but not significantly.

The results of this study are subject to several limitations. Our sample size is insufficient to establish accepted norms of statistical significance and there is no control group against which we can measure. Thus, we must temper our conclusions. Overall, DBI showed uniformly positive benefits for increasing innovation and efficiency. The effect sizes on the Fisher survey were small, but this may be due to the length of the treatment. A semester-long or full year program may produce a greater effect. In addition to continuing to study effects on teachers, we are currently researching ripple effects of this program in participating teachers' classrooms to look for student development of AE.

This work adds credence to the theory that particular teaching methods can increase adaptivity in students. Furthermore, using DBI, significant measurable increases in engineering AE are possible in a short period of time.

References

Bransford, J. D., Brown, A. L., & Cocking, R. (2000). *How people learn: Brain, mind, experience, and school*. Washington DC: National Academy Press.

Brown, A. L. (1997). Transforming schools into communities of thinking and learning about serious matters. *American Psychologist*, *52*(4), 399-413.

Fisher, F. T., & Peterson, P. L. (2001). A Tool to Measure Adaptive Expertise in Biomedical Engineering Students. *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition*. Presented at the Annual Conference of the American Society for Engineering Education, Albuquerque, NM.

Hatano, G. (1988). Social and motivational bases for mathematical understanding. *New Directions for Child and Adolescent Development*, *1988*(41), 55-70.

Hatano, G., & Inagaki, K. (1986). Two courses of expertise. In H. Stevenson, J. Azuma, & K. Hakuta (Eds.), *Child development and education in Japan* (pp. 262-272). New York, NY: W. H. Freeman & Co.

Hatano, G., & Oura, Y. (2003). Commentary: Reconceptualizing School Learning Using Insight from Expertise Research. *Educational Researcher*, *32*(8), 26-29.

Inagaki, K., & Miyake, N. (2007). Perspectives on the Research History of Giyoo Hatano. *Human Development*, *50*(1), 7-15. doi:Article

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington DC: The National Academies Press.

Martin, T., Petrosino, A., Rivale, S., & Diller, K. (2006). The development of adaptive expertise in biotransport. *New Directions in Teaching and Learning*, (108), 35-47.

Mosborg, S., Adams, R., Kim, R., Atman, C. J., Turns, J., & Cardella, M. (2005). Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals. *Proceedings of the 2005 American Society for*

Engineering Education Annual Conference & Exposition. Presented at the Annual Conference of the American Society for Engineering Education, Portland, OR.

Schwartz, D. L., & Martin, T. (2004). Inventing to prepare for future learning: The hidden efficiency of encouraging original student production in statistics instruction. *Cognition and Instruction*, *22*(2), 129-184.

Wineburg, S. (1998). Reading Abraham Lincoln: An expert/expert study in the interpretation of historical texts. *Cognitive Science*, *22*(3), 319-346.