AC 2011-2024: USING DESIGN-CENTERED CHALLENGE BASED INSTRUCTION TO TEACH ADAPTIVE EXPERTISE IN HIGH SCHOOL ENGINEERING

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Using Design-Centered Challenge-Based Instruction to Teach Adaptive Expertise in High School Engineering

Abstract

Popularization of high school engineering with multiple course options, varying teacher content expertise, and open-ended design-based courses requires maximally adaptive teachers. As researchers helping prepare these teachers, we conceptualize the competencies needed as Adaptive Expertise (AE), a balance between innovation and efficiency. Prior research shows that challenge-based instruction (CBI) courses increase engineering undergraduates' innovation and efficiency, developing AE, hence we used a cycle adapted for the design-based engineering course in our 6-week summer institute involving thirty-three experienced mathematics and science teachers. Teachers' adaptive beliefs about engineering and learning were measured before and after the institute. Pre- and posttests likewise measured teachers' innovation and efficiency relative to particular challenge units. From the results we conclude that design-based instruction (DBI) can improve teachers' AE in the space of one course.

Introduction

Engineering is exploding in popularity as a high school discipline, creating a demand to train both new and in-service teachers to teach engineering. In Texas for example, the goal is to have one teacher in every high school prepared to teach engineering by 2011. In just one state, this goal will require nearly 2000 teachers equipped to teach engineering.

So, what is engineering for high school? Mechanical? Chemical? Electrical? Curricula being developed to follow state standards primarily focus on engineering design. Therefore, the course could draw from several content areas.

This intersection of content options, varying teacher content expertise, and the open-ended nature of design-based courses creates a need for maximally adaptive teachers. As researchers involved in the preparation of these teachers, we conceptualize the competencies they need as Adaptive Expertise (AE). Adaptive experts are *innovative*: they adapt to perform well in novel and fluid situations. They are also *efficient*: they apply core knowledge appropriately and expeditiously.

Common engineering educational methods succeed at developing either efficiency (e.g., traditional lecture-based instruction) or innovation (e.g., problem-based instruction, or PBI). Challenge-based instruction (CBI) is centered around challenge problems, much like PBI. However, there are explicit components of the instructional cycle that present information directly, more like traditional lecture-based instruction.

Prior research[1] demonstrates that undergraduate engineering students in CBI courses improve on both innovation and efficiency, showing growth in AE. However, the instructional cycle in these studies was primarily aimed at teaching in problem-solving contexts. Therefore, we developed and conducted our research using a cycle adapted for the design-based engineering course.

We have shown CBI develops AE in engineering problem solving. The current research investigates whether and how design-centered CBI (or Design-Based Instruction, DBI) develops AE.

Thirty-three experienced mathematics and science teachers participated in a 6-week summer institute made up of 4 DBI units centered around the following engineering design challenges:

1. Vehicle Design Challenge: Design and build a superstructure on a moving platform maximizing cargo volume while minimizing drag.
2. Reverse Engineering Challenge: Perform a customer needs analysis for a household object, such as a hair dryer, and predict the internal mechanisms of the machine.
3. Robotics Design Challenge: Design and build a robot to detect objects and transport them to a goal area.
4. Final Design Challenge: Develop and collaborate on a design project in groups (similar to a capstone design experience).

Using a within-subjects pre-post design, we tested the following hypotheses:

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

Expertise

While research shows that content specificity is important to expertise,[2] differences between experts' and novices' can be generalized to many domains.[3, 4, 5, 6] First, experts perceive problems and pay attention to different aspects than novices. Studying x-ray diagnoses, Lesgold et al.[7] and Raufaste, Eyrolle, and Marine[8] found that experts focused on different elements in the x-rays than novices during diagnosis.

Second, experts have a more global perspective than novices. After being shown randomly placed chess pieces on a board, chess masters and novices performed equally well on memorizing and reproducing the position of the pieces. However, when a board position from a real game was used instead of random placement, the chess masters were able to duplicate the board significantly more accurately than the novices, suggesting that the experts perceived and remembered meaningful patterns while novices were memorizing individual configurations.[9, 10]

Third, experts classify and solve problems based on deeper principles than novices. Novices tend to focus on surface features, such as the wording of the problem or the objects involved (e.g. block on an inclined plane), whereas experts tend to group problems by the basic governing principles used in the solution, such as which of Newton's Laws should be applied or whether the conservation of energy is relevant. Chi, Feltovich, and Glaser[11] noted that physics experts examine problems more deeply before attempting a solution. Whereas novices search first for formulas to apply, experts attempt to uncover additional applications of basic principles and then develop a general solution plan. Several researchers[5, 12, 13, 14] have referred to this difference as novices reasoning backwards from the solution goal to the problem specifications, while experts reason forwards from the whole problem to generate a solution.

Routine and adaptive expertise

Other research has demonstrated how experts can differ on their level of flexibility. Hatano and colleagues[15, 16, 17] studied expert abacus users who could mentally add ten multi-digit numbers with only 2 seconds between each. While these experts were highly proficient at the task, the breadth of their expertise was narrow and they did not seek to apply their skills to new problems or expand their domain. Hatano and colleagues referred to this group as "routine experts." Routine experts are highly skilled in their domain and efficiently solve familiar problems, but make mistakes in applying technical principles, using procedures, or interpretation results when faced with a novel challenge.[4]

In contrast, "adaptive experts"[15] share the same core technical abilities as routine experts, but are more flexible in developing solutions for novel problems. According to Bransford, Brown & Cocking[4] and Wineberg[18], adaptive experts tend to seek out new situations, can gauge their own knowledge set, consider their skill set as dynamic, and consider multiple different perspectives when solving problems.

The need for teaching AE in high school engineering teachers

Engineering is an adaptive field, not an exact science. Engineers are constantly learning and building their skill set, while using their creativity and ingenuity to adapt to new technologies and available resources. Therefore, engineering teachers must also learn to be adaptive experts. Curriculum content will be continuously updating, requiring ongoing increases in their knowledge base and efficiency. An engineering classroom is a dynamic environment, thus engineering teachers need to be innovative, able to creatively adapt their skill sets to new situations. We must train our engineering teachers to be adaptive experts to handle the changing demands of the discipline and effectively teach these skills to their students.

Approaches to teaching engineering

<u>Lecture-based instruction</u>

The various methods of teaching engineering each have particular advantages and disadvantages. The traditional approach is through direct transmission or lecture. When executed well, teachers can easily keep track of what information was disseminated and students have an inventory of information that need to know. Students tend to perform well on tests that follow the content and context of the lectures and supporting materials.[4, 19]

However, there are also drawbacks to traditional instruction. Since the learning environment of the lecture is removed from real-world situations, students can have difficulty transferring their knowledge and applying them to the workplace or graduate school.[4, 20] In addition, students can have difficulty with long-term retention of information.[21, 22]

<u>Inquiry-based instruction</u>

An alternative to lecture is to present students with authentic problems to solve, particularly ones where there are multiple acceptable answers. Various studies[23, 24] found that this approach develops strong connections between class learning and real-world applications, increases student motivation, and leads to positive attitudes towards learning. In addition, when it is well executed, there are strong gains in content knowledge.[23, 24]

While there are many variations on this method, such as problem-based, project-based, case-based, discovery learning, and authentic inquiry[24, 25, 26, 27, 28, 29], we will collectively refer to them as inquiry-based instruction. However, to reap these benefits, both teachers and students have to be trained in inquiry-based methods. Compared to other methods, an ill structured inquiry-based unit can results in lower student learning than a well-executed lecture.[24, 26, 27]

Teaching for adaptive expertise

Ideally, students should learn to solve problems efficiently and innovatively, like adaptive experts.[19, 30] They should answer typical problems quickly and accurately like routine experts, but have the flexibility to solve novel problems. The literature suggests that the best method to teach adaptive expertise (AE) in a complex domain, such as engineering, is to "blend" the inquiry and lecture formats, so that students can explore problems and invent solutions, but also have some direct teaching and guidance. This method tries to attain long-term knowledge retention and problem solving tactics, along with experience in solving unfamiliar problems.

Working with 9th grade students, Schwartz and Martin[30] taught one group a graphical method to calculate standardized scores, and let another group invent their own method to compute them. Later, when given a content test, both groups performed equally well. However, when they were presented with a question that required the students to apply standardized scores, but did not explicitly tell them to use standardized scores, the students who invented their own method outperformed the students who were directly taught.

Challenge-based instruction (CBI)

To design a challenge-based instructional approach we used the STAR.Legacy Cycle (SL Cycle). Figure 1 is based on Schwartz et al.[31] and shows the main steps of the SL Cycle.

Figure 1. The STAR.Legacy (SL) Cycle

In the first step, students start at The Challenge and are presented with a problem that is complex, but realistic. From there, they proceed to the Generate Ideas step where they create ideas (often in small teams) based on their prior knowledge and write down what information they will need to learn. During this step, they can ask questions and consult with the teacher. From there, the teams go to Multiple Perspectives and try to look at the problem and its components from different angles. The teacher may present small lectures to help the students during this phase, sometimes based on the questions raised during the previous step. The teams make improvements to their ideas during Research and Revise. Guided assignments are often useful at this stage. When they are done, they conduct a formative assessment with the teacher or with other teams in the Test Your Mettle stage. In the final step, the students present their solution publicly in Go Public.

In the SL Cycle, knowledge is learned mainly in the Multiple Perspectives, Research and Revise, and Test Your Mettle steps when students discover information or when the teacher presents it. When going through the cycle, feedback can be provided through formative assessment and chances to revise and improve their ideas. These opportunities help teacher and students improve and adjust their learning.[32, 33, 34]

In the Generate Ideas (GI) stage, students try to create solutions to a novel and challenging problem. It provides practice with the cognitive and affective sides of creative problem solving and is the primary step where innovation is developed.[35]

Since students reflect on what they know and determine what they need to learn, the GI stage exercises metacognition.[36] When working in teams, the students share ideas and develop different perspectives on the problem.[37] If students attempt to understand and solve the problem before they receive instruction, it can help their learning[30] and increase the probability that they will create guiding questions.[38]

Frequently, college engineering students are unaccustomed to solving unfamiliar problems and feel threatened.[1] The GI stage allows students to practice, develop tactics, and acclimate to facing new challenges.

Design-based instruction (DBI)

Experts agree that high school engineering should be centered on design.[39] To this end, we adapted elements of CBI to create a new framework for classroom Design Based Instruction (DBI). Figure 2 shows the steps in the DBI cycle that we used. Like its predecessor, DBI structures curriculum around extended projects that may not include fixed paths to success. Called design challenges, these projects integrate engineering design methodology with a wide variety of applied STEM content. Design challenges utilize an adapted version of CBI's SL Cycle to shepherd students through the design process. As in the SL Cycle, the challenge statement presented to the students in the Understand the Problem step provides a particular engineering problem to be addressed and the constraints (such as cost, safety, and feasibility) for the solution. In Quantify the Need, the students use their comprehension of the problem to formalize a design specification. Generating ideas as well as getting multiple perspectives occurs in the Engineer the Concept phase. During the Embody the Concept and Implement the Design steps, the students create prototypes, test their creation, and make improvements to it. After the students are satisfied that their resulting design will meet the stated specifications, they Finalize the Design, complete their construction, and get ready to present their work to the teacher and class. As shown in Figure 2, at each step it is possible that a requirement, idea, or design will need to be reevaluated and to fall back to an earlier step just like in a professional engineering project.

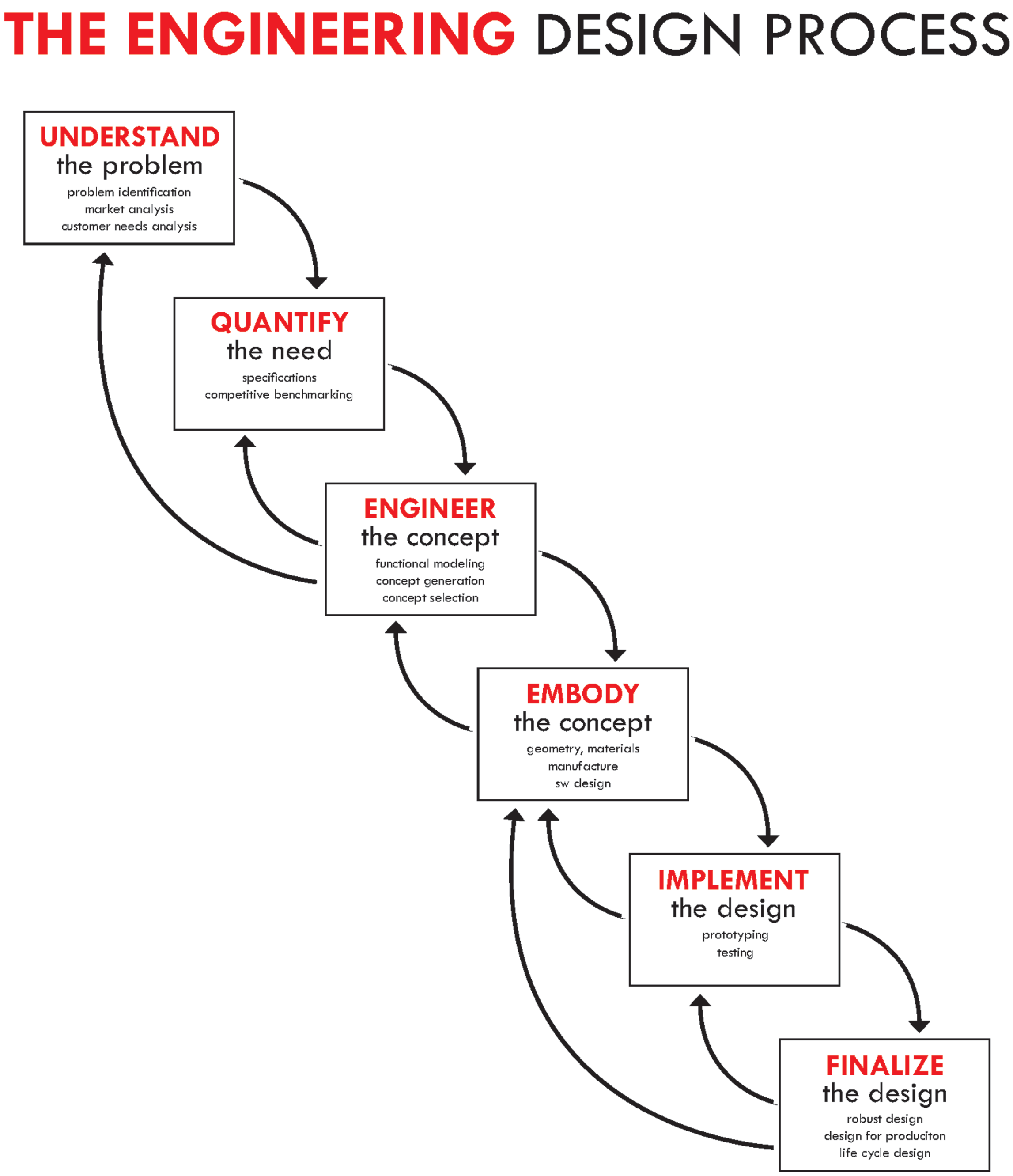

Figure 2. The Design Based Instruction (DBI) cycle

Methods

Participants

In-service high school teachers participated in the second cohort of the UTeach Engineering ESIT (summer 2010). Of the 33 participating teachers, 56% were male and 44% were female. Seventy-two percent of the teachers self-reported as Caucasian. The average amount of teaching experience was over 7 years, and 28% of the teachers have Master's degrees. Fifteen of these teachers are seeking a graduate degree (MASEE) and 18 are summer institute only (ESIT) students (both groups take the full Engineering summer institute class together).

Instructional intervention

The UTeach Engineering program was conceived as a way to train current and future teachers to teach a design-based high school engineering course. In 2006, the Texas state legislature mandated that all high school students complete four years of science instead of three. One of the courses approved to fulfill the requirement is an engineering class. While science and math teachers may be recruited to teach engineering, there are significant differences between teaching the sciences and teaching a design-based class. To offer engineering in every high school in the state, up to two thousand trained engineering teachers will be needed to fulfill the demand.

To properly prepare in-service teachers to handle a design engineering class, the UTeach Engineering program is implementing two development tracks for in-service teachers.

1. UTeach Master of Arts in Science and Engineering Education (MASEE) – this track parallels the existing UTeach Master of Arts in Science and Mathematics Education at the University of Texas and is intended for in-service teachers.
2. Engineering Summer Institute for Teachers (ESIT) – this pathway is a six week course for in-service teachers who wish to teach high school engineering, but not in a graduate degree.

The focus of study of this paper is the design-challenge based *Fundamentals in Engineering and Design* course (all MASEE and ESIT teachers take this course). It introduces in-service teachers with limited training in engineering to the scope of engineering, basic foundations of engineering science, and engineering design. The course is designed to cover essential elements as defined by the State of Texas in the emerging Texas Essential Knowledge and Skills (TEKS) for engineering, and help prepare enrollees to pass the state engineering teacher certification exam.

Engineering fundamentals and design principles are addressed through a series of design challenges. The course culminates with a final design challenge of the teacher's choosing. The students learn specific engineering content as they solve engineering problems in multiple contexts and are taught by university engineering faculty.

The course consists of four major modules. In each of them, teachers work together in a small team.

A. Vehicle Design Challenge
Given a dynamics cart, the teacher teams must build a superstructure on top of it that attempts to maximize cargo space and speed (i.e. minimize drag). Their projects are tested rolling down an elevated test track with a head wind, both of which are not revealed to the teachers until shortly before project completion. To predict the track time of their design, the teachers characterize the drag coefficients across a range of head wind speeds. Probe ware is used to measure temperature, wind speed, and drag, and interpolated values are fed into tables with projected areas to estimate

air density. Wind tunnel tests are used as a visualization tool and design modifications are encouraged.

B. Reverse Engineering and Product Redesign
This module focuses on the requirements and design of products. For example, the 2010 ESIT used a hair dryer. The teachers interviewed possible customers and gathered information for a needs analysis. They prioritized the needs and assigned them to quantifiable performance metrics. Next, they were given an actual hair dryer, asked to predict the inner working of the dryer, and sketch their predictions. The teams disassembled the dryer and compared their predictions with the actual mechanism. Then the actual system was diagrammed and the dryer reassembled. The teachers measured or calculated the dryer's air speed, volumetric and mass flow rates, temperature, current draw, power, and efficiency. Finally, they compared the dryer's noise and time to dry to their needs analysis and produced ideas to redesign the product.

C. Robotics
The goal of the robotics unit is to use LEGO MINDSTORMS kits to create robots to perform specific tasks. The beginning tasks teach basic physics and mechanical engineering concepts, such as torque and gear ratios. To control the motors and read the various sensors (ultrasonic, color, touch), the teams then learn to program the microcontroller using the LABVIEW graphical programming language. In addition, the projects convey concepts about control and automation, such as the difference between open and closed-loop systems.

D. Final Project
The last two weeks of the six week course is reserved for the final project, where the teachers can choose to invent a new product or improve an existing device. Working individually or in groups, they consult with the professors about their ideas, the materials needed, and the deliverables. At the end of the project, they do a presentation of their ideas and products, and demonstrate their designs to the class.

Measures and results

Engineering design knowledge

The three content tests (Vehicle Design, Robotics Design, and Reverse Engineering Design) each correspond to a weeklong instructional unit in the summer class. For more detailed descriptions of the instructional units, refer to the Instructional intervention section. Each of the content tests is a short four to five question test. The tests were created by the faculty member teaching the unit.

Some questions are aimed at efficiency and others require innovation. In order to assess the participants' growth in AE, the content test questions that measure efficiency ask the participant to perform routine problem solving and comprehension tasks, such as calculation, describing differences, and listing forces. The innovation questions typically ask the participant to think on a more abstract and broader level. Examples include imagining situations, explaining how or why something happens, describing the design process, and using judgment. For more information regarding the content questions, refer to Appendix A, Instruments A1, A2, and A3 and Table A1.

For each of these units, the pretest was given on the first day of the unit, and the posttest was given on the last day. Each question was graded on a scale of 0, 1, 2 or 3 points, representing no credit, partial credit (major omissions), partial credit (minor omissions), and full credit. Two researchers graded the tests. To establish inter-grader reliability, 10% of each group of tests was given to both graders and consistency was found to be 82%.

Teachers' AE developed in both content and design over the course of the ESIT. We conducted analyses on each test's scores using a 2 x 2 repeated measures ANOVA with two within-subjects factors: time (pretest, posttest) and measure (innovation, efficiency). All significant results are at the $p < .05$ level.

Vehicle design challenge

The main effects of time, $F(1, 28) = 2.91$, $MSE = 1.35$, $p > .05$ and measure, $F(1, 28) = 1.30$, $MSE = 1.30$ were not significant. However, the teachers showed improvement on the Vehicle Design content test on innovation and they improved significantly on efficiency, $F(1, 28) = 7.04$, $MSE = .26$. Vehicle Design results may be found in Figure 3.

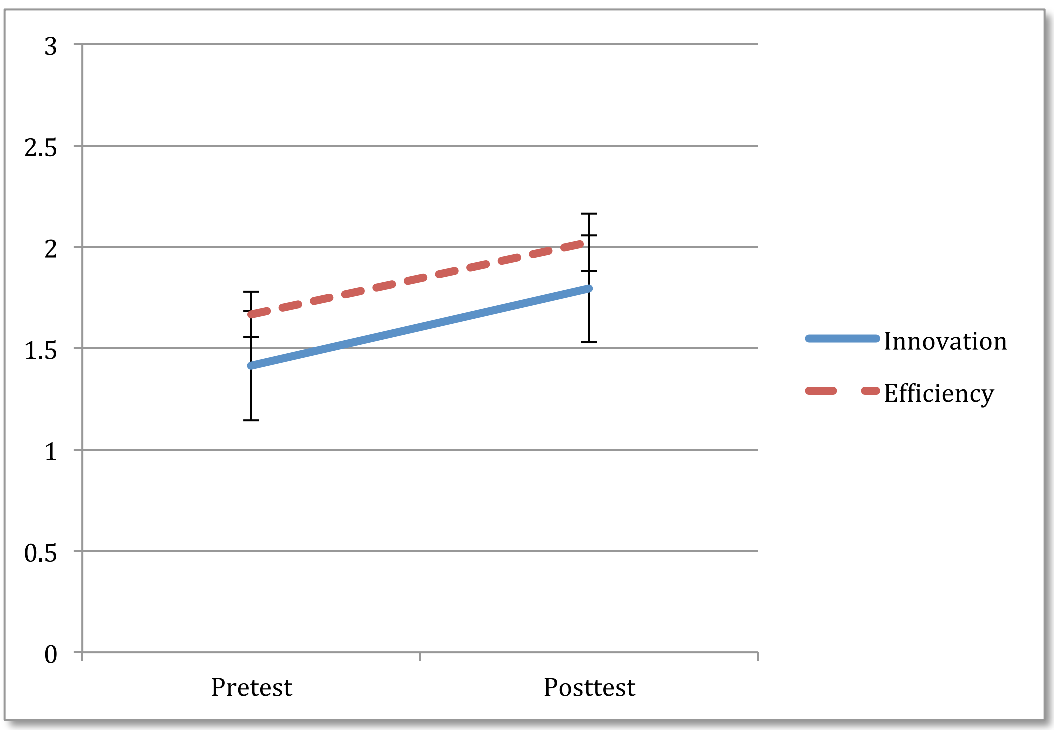

Figure 3. Engineering Design Knowledge: Vehicle Design Results

Reverse engineering design challenge

On the Reverse Engineering Design content test, teachers improved significantly on innovation and efficiency, $F(1, 28) = 9.11$, $MSE = .31$. There was also a significant main effect of measure,

F (1, 28) = 5.79, *MSE* = .48, with innovation averages significantly higher than efficiency averages. Both main effects are dependent upon the other, as is indicated by the significant interaction between time and measure, F (1, 28) = 6.01, *MSE* = .24, with the efficiency measure approaching the innovation measure by the posttest. See Figure 4 for results on the Reverse Engineering Design content tests.

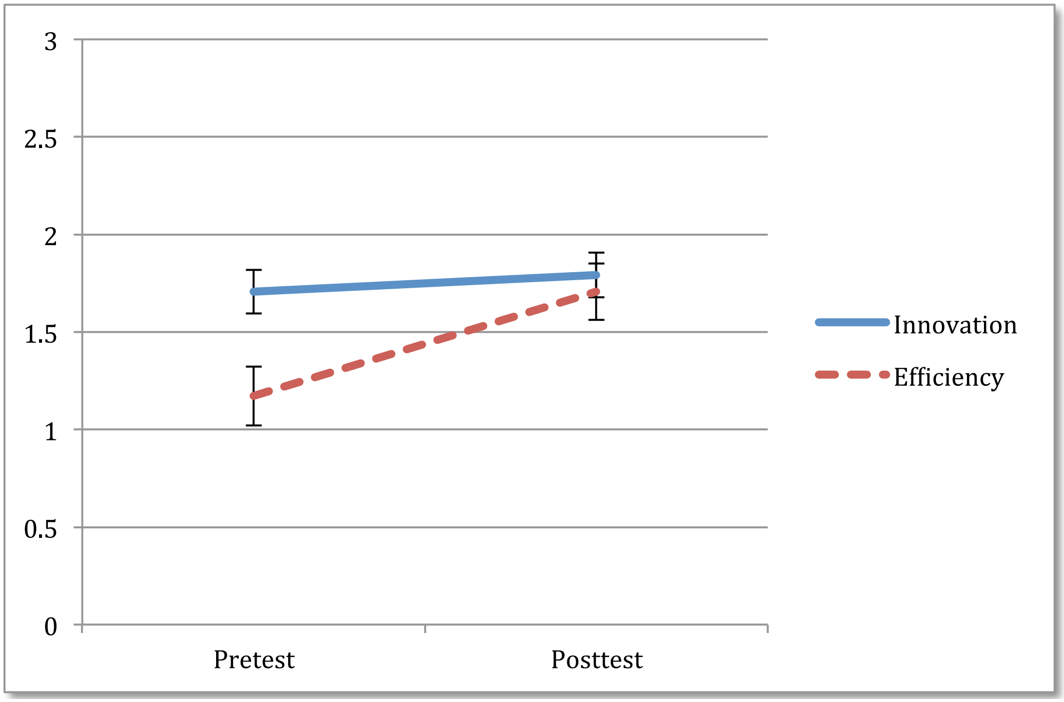

Figure 4. Engineering Design Knowledge: Reverse Engineering Design Results

Robotics design challenge

On the Robotics Design content test, 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 are higher than the 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. Robotics Design content test results appear in Figure 5.

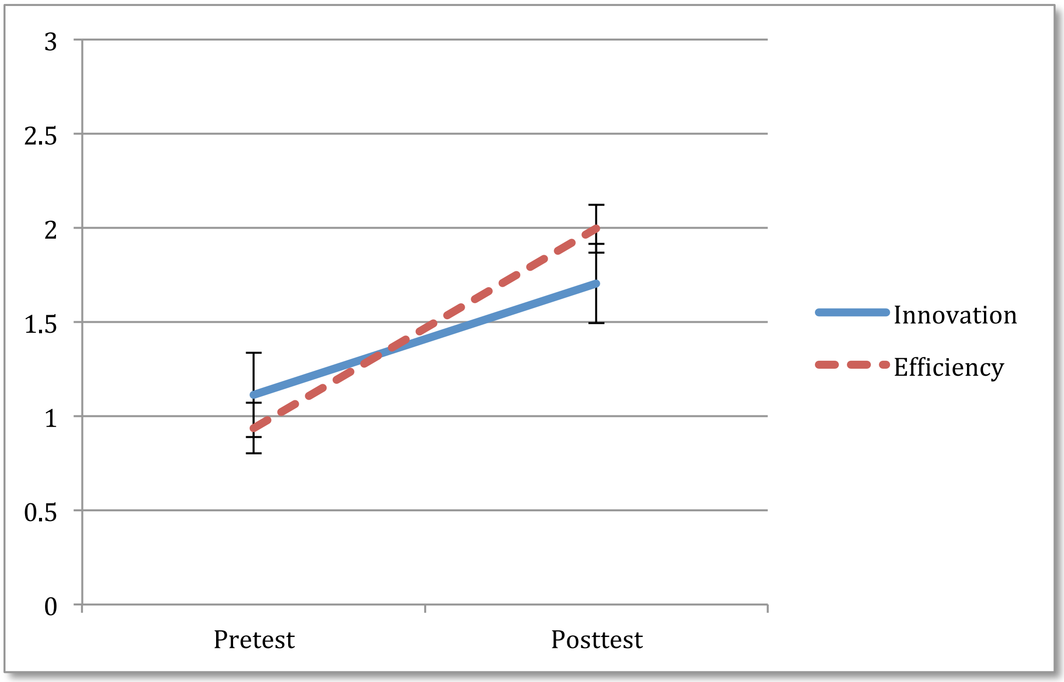

Figure 5. Engineering Design Knowledge: Robotics Design Results

Design Survey

The *Design Survey* that we used was created by Mosborg, Cardella, Saleem, Atman, Adams, and Turns[40] and was a subsection of a larger assessment of engineering design expertise. It consists of 27 statements and beliefs about engineering design. Subjects rate their level of agreement with the statement on a Likert scale. A typical item is "Good designers get it right the first time." Mosborg et al.[40] administered the survey to 19 advanced practicing engineers and tallied the results. At the beginning stage of the teachers' final design project, the Design Survey pretest was given online. The Design Survey posttests were administered online during the final week of class.

Each question in the Design Survey was marked as either associated with innovation, efficiency, or not applicable. A question was marked "N/A" if the subject of the question is not relevant to attitudes that could be associated with innovation or efficiency. These questions were not included in the innovation/efficiency data analysis. Questions that were denoted as "innovative" tend to be concerned with broader and holistic views of design and creativity. "Efficiency" questions convey a sense of rigidity to the design process and emphasize task completion. For a complete list of items and their respective coding, see Instrument A4 and Table A2 in Appendix A.

We analyzed the Design Survey scores using a 2 x 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 significantly improved 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. Refer to Figure 6 for Design Survey results.

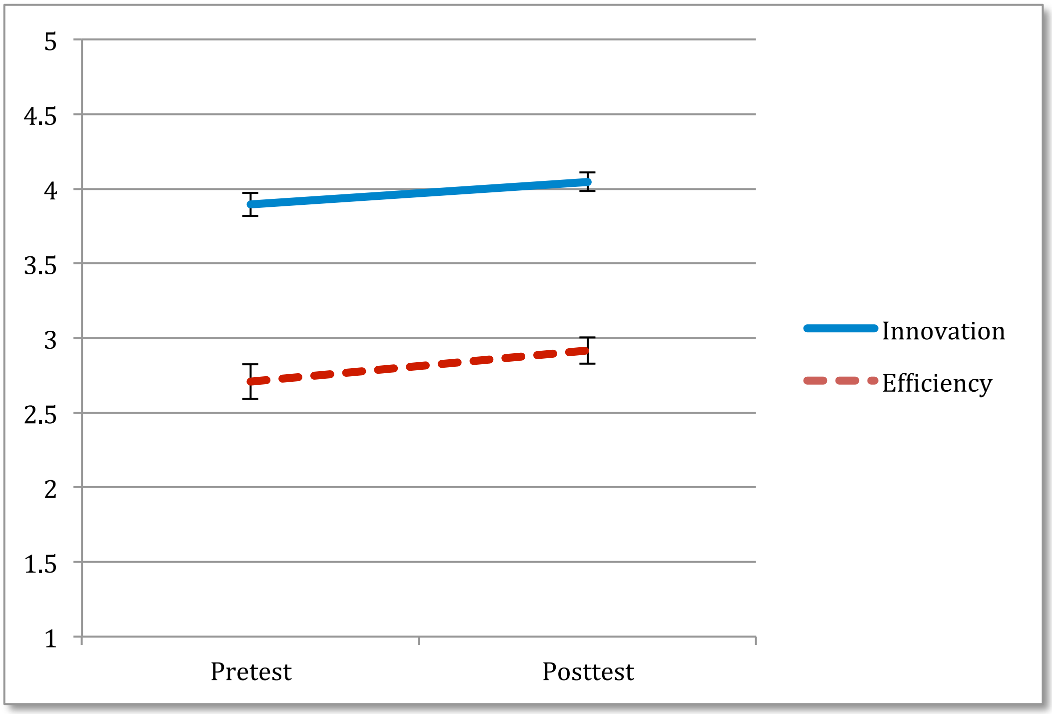

Figure 6. Engineering Design Knowledge: Design Survey Results

Adaptive beliefs

The *Fisher Survey*[41] measures constructs that are believed to form the foundation of AE. Each of the four subscales (Multiple perspectives, Metacognitive self-assessment, Goals and beliefs, and Epistemology) in the 42 self-reported Likert scale survey measures one of the four traits. The instrument was tested on groups of engineering freshmen, biomedical engineering students, and engineering faculty. The Cronbach α reliability of the subscales range from 0.66 to 0.80 for the different test groups, with an overall AE Cronbach α between 0.85 and 0.89. All subjects took the Fisher Survey online as a pretest on the first day of the UTeachEngineering Institute. During the final week of class, the Fisher Survey posttests were administered online.

Multiple perspectives refers to the subject's willingness to use different approaches and representations when solving a problem. Metacognitive self-assessment involves the subject's ability to monitor and evaluate his/her own understanding. Goals and beliefs questions examine the subject's beliefs about expertise and their learning goals. Epistemology questions investigate the subject's belief about knowledge and how it is created. Following are sample items from each of the four constructs:

1. Multiple perspectives – I solve all related problems in the same manner.
2. Metacognitive self-assessment – I monitor my performance on a task.
3. Goals and beliefs – I am afraid to try tasks that I do not think I will do well.
4. Epistemology – Most knowledge that exists in the world today will not change.

All items and their respective designations may be found in Appendix B, Instrument B1 and Table B1.

Teachers held fairly adaptive beliefs about learning science and engineering both before and after the ESIT (See Figure 7). We conducted 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). 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, $F\ (1, 25) = 9.88$, $MSE = .15$, $p < .05$.

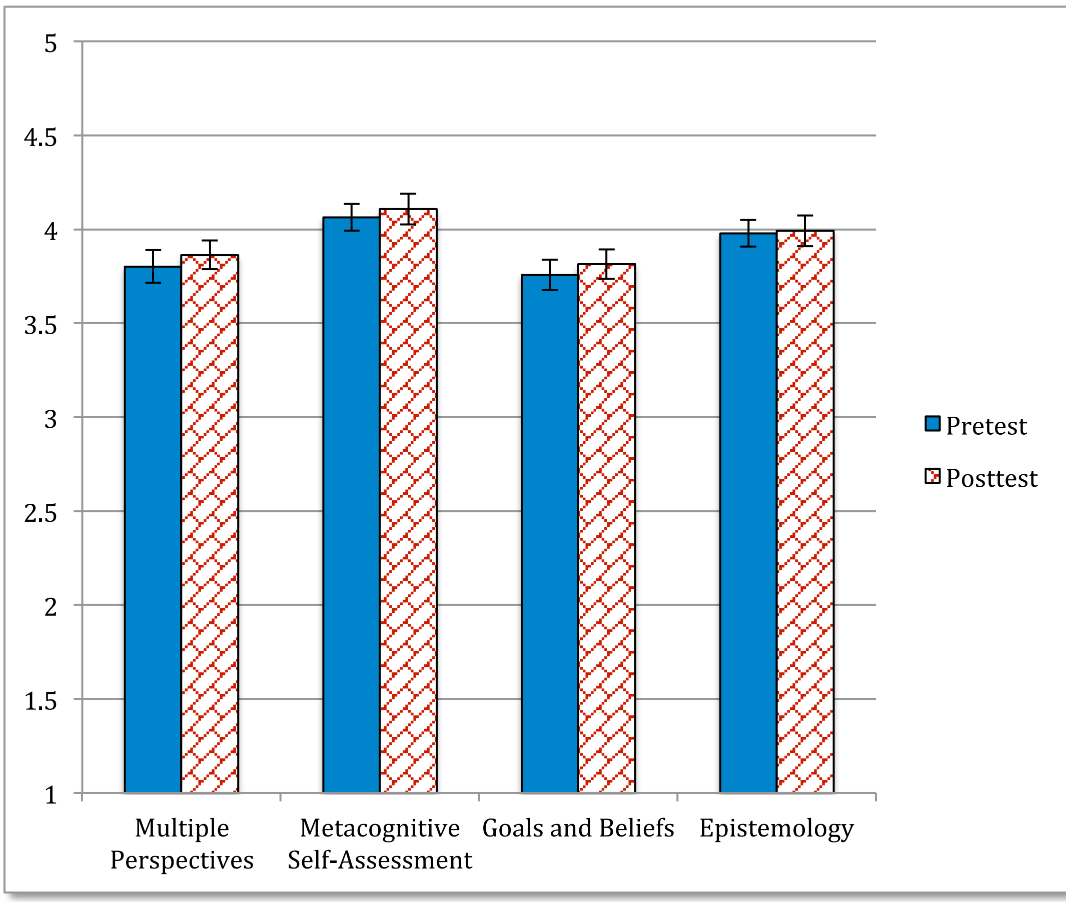

Figure 7. Adaptive Beliefs: Fisher Survey Results

Conclusions

Our two research questions are whether DBI increased engineering innovation and efficiency in our participant teachers and whether it increased their adaptive beliefs about engineering and learning.

After undergoing the ESIT summer program, each of the unit tests (vehicle design, reverse engineering, and robotics) indicates that the teachers improved in both efficiency and innovation. Efficiency is a measure of their knowledge of facts about the subject and ability to solve typical problems, while innovation is measure of the flexibility or adaptability of their problem solving.

From the Design Survey, we examined the responses to questions that relate to beliefs about efficiency and innovation. Both beliefs about efficiency and innovation increased, but not a statistically significant amount.

The Fisher Survey measures a person's beliefs in four areas that relate to adaptive expertise. In each of the categories (Multiple perspectives, Metacognitive self-assessment, Goals & Beliefs, and Epistemology), the teachers' views changed to be more aligned with adaptive experts. However, none of the changes were large enough to be significant.

Unfortunately, the results of this study are subject to several limitations. The size of our sample population is not sufficient to establish accepted norms of statistical significance. Second, there is no control group against which we can measure. Thus, we must temper our conclusions with these issues in mind.

Overall, DBI showed uniformly positive benefits for increasing innovation and efficiency in teachers participating in our program. While the sizes of the effects were small on the Design and Fisher surveys, it is important to note that the length of treatment was short. A semester-long or full year program may produce a greater effect.

We are currently analyzing data gathered from classroom observations of the teachers taken before and after the 2010 UTeach Engineering summer program. In addition to the summer institute, we have also participated in creating a high school level engineering course. The class was piloted during the 2010-2011 academic year and we are collecting data from multiple instruments given to the teachers and students. Other possible avenues of further study include following up with the teachers over several years to find out if their teaching continues to develop.

Acknowledgments

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Appendix A

Instrument A1. *Innovation and efficiency items for engineering design knowledge test: Vehicle Design Challenge*

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:

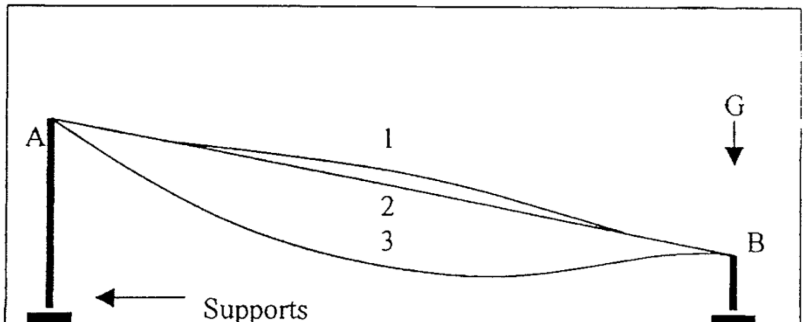

Figure 1

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. *Innovation and efficiency items for engineering design knowledge test: Reverse Engineering Design Challenge*

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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. *Innovation and efficiency items for engineering design knowledge test: Robotics Design Challenge*

UTeachEngineering

Preparing Secondary School Teachers to Deliver Design-Based Engineering Courses

Introduction to Engineering and Design
Summer 2010
Pre-test Week 3

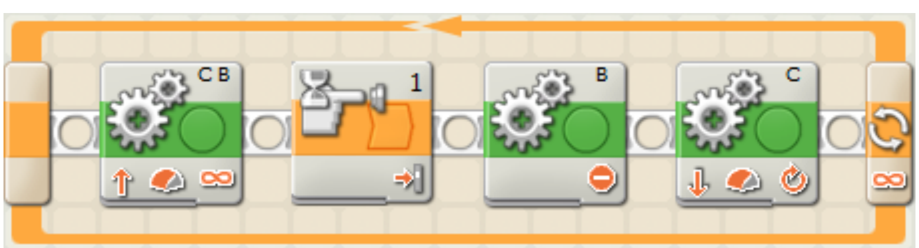
1. What characteristics distinguish automated or controlled systems? *(Efficiency)*

2. What is the difference between open-loop control and closed-loop control? Give an example of each. *(Efficiency)*

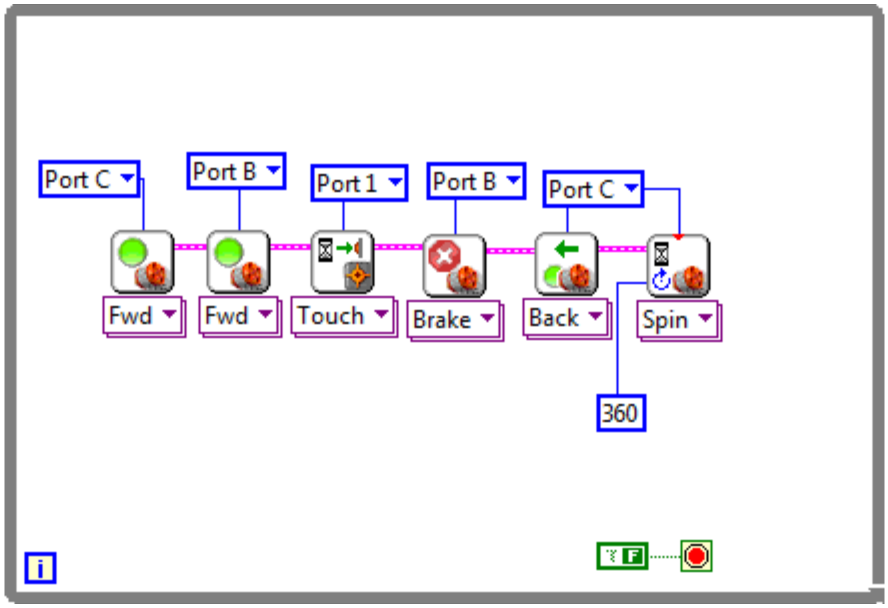
3. Explain why a "`wait for`" programming construct (one that waits for a sensor to trigger) cannot be used when monitoring more than one sensor? *(Innovation)*

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. *Innovation and efficiency item numbers for engineering design knowledge tests: Vehicle Design Challenge, Reverse Engineering Design Challenge, and Robotics Design Challenge*

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
	5b	Efficiency
Robotics	1	Efficiency
	2	Efficiency
	3	Innovation
	4	Efficiency
	5	Efficiency
	6	Efficiency

Instrument A4. *Innovation and efficiency items for engineering design knowledge test: Design Survey*

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.)

1. Good designers get it right the first time. *(Efficiency)*
2. Good designers have intrinsic design ability. *(Efficiency)*
3. In design, a primary consideration through the process is addressing the question “Who will be using the product?” *(N/A)*
4. Visual representations are primarily used to communicate the final design to a teammate or the client. *(Efficiency)*
5. Engineering design is the process of devising a system, component or process to meet a desired need. *(Innovation)*
6. Design in a major sense is the essence of engineering; Design, above all else, distinguishes engineering from science. *(Innovation)*
7. Design begins with the identification of a need and ends with a product or system in the hands of a user. *(N/A)*
8. Design is primarily concerned with synthesis rather than the analysis, which is central to engineering science. *(N/A)*
9. … 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)*
10. Design is as much a matter of finding problems as it is of solving them. *(Innovation)*
11. 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)*
12. Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers. *(Innovation)*
13. Designing as a conversation with the materials of a situation. *(N/A)*
14. Design defines engineering. It’s an engineer’s job to create new things to improve society. *(Innovation)*
15. Design is not description of what is, it is the exploration of what might be. *(Innovation)*
16. Design is often solution –led, in that early on the designer proposes solutions in order o better understand the problem. *(Innovation)*
17. 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)*
18. Design is a goal-oriented, constrained, decision-making activity. *(Efficiency)*

19. Designers operate within a context which depends on the designer's perception of the context. *(Innovation)*
20. Creativity is integral to design, and in every design project creativity can be found. *(Innovation)*
21. Engineering design impacts every aspect of society. *(Innovation)*
22. 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)*
23. 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)*
24. Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design. *(Innovation)*
25. 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)*
26. Information is central to designing. *(N/A)*
27. 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 A2. *Innovation and efficiency item numbers for engineering design knowledge test: 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 B

Instrument B1. *Multiple Perspectives, Metacognitive Self-Assessment, Goals & Beliefs, and Epistemology items for adaptive beliefs survey: Fisher Survey*

Please answer the questions using the following rating scale:
1 (strongly disagree), 2 (disagree) 3 (neurtral), 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 B1. *Multiple Perspectives, Metacognitive Self-Assessment, Goals & Beliefs, and Epistemology item numbers for adaptive beliefs survey: Fisher Survey*

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

42	Goals & Beliefs
43	Metacognitive Self-Assessment
44	Multiple Perspectives