

AC 2010-2091: TRANSFER OF ADAPTIVE EXPERTISE TO TRANSFORM ENGINEERING EDUCATION

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Taylor Martin received a B. A. in Linguistics and an initial teaching certification from Dartmouth College in 1992, an M.S. in Psychology from Vanderbilt University in 2000, and a Ph.D. in Education from Stanford University in 2003. She joined the faculty at the University of Texas at Austin in 2003. Her primary research interest is how people learn content in complex domains from active participation, both physical and social. She is cooperating with local elementary schools to improve assessment tools for young children's mathematics and to examine how hands-on activities impact mathematics learning and investigating the development of adaptive expertise through cooperation with the VaNTH Engineering Research Center in Bioengineering Educational Technologies.

Research interests include the role of active learning strategies (e.g., hands-on activities and invention) in development of mathematics concepts, dynamic development of concrete & symbolic understanding of mathematics concepts, design & implementation of curricula and technologies that promote good math learning, and examining effectiveness of curricula and technologies in classrooms using experimental & observational methods.

Tom Benton, University of Texas, Austin

Tom Benton received a B.S. in Mechanical Engineering from the University of Texas in 1999 and is currently a Masters student in the University's Educational Technology program. He is primarily interested in the development and study of systems that support collaboration between designers while scaffolding elements of the design process.

William McKenna, University of Texas, Austin

Bill comes to education by way of acoustical engineering. He received his masters of mathematics from the University of North Texas about ten years ago, and after a brief but potentially promising career in acoustical test enclosures, he is now working towards a doctorate in Science and Mathematics Education. Helping to make the world a quieter place is a fine and noble thing, but it simply does not compare to educating people. These days Bill finds himself thinking about a number of topics including architecture (of schools, museums, learning spaces), museum exhibit design and visitor interaction, on-line learning tools, project-based instruction, teacher training, cultural formation and interaction within learning spaces, postmodern thought, learning and teaching by design, and emotional intelligence.

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With degrees in electrical engineering and in computer science, Pat worked in computer chip design before changing careers to teach high school. He is currently a graduate student in STEM Education at the University of Texas at Austin and his research interests include measuring the educational benefits of middle school and high school robotics programs.

Response Memo for AC 2010-2091: TRANSFER OF ADAPTIVE EXPERTISE TO TRANSFORM ENGINEERING EDUCATION

Thank you for the thorough review and excellent comments. They made clear areas that definitely needed improvement. We hope we have addressed each one in the paper. Below, we detail our response to each comment.

Your paper titled AC 2010-2091: TRANSFER OF ADAPTIVE EXPERTISE TO TRANSFORM ENGINEERING EDUCATION has been accepted pending changes. Please submit your revised paper before the deadline date. Please refer to your Author's Kit for the "Revised Paper Submission Deadline" date.

Reviewer Comments

1 _____

While the topic of this paper is worthwhile, and the researchers appear to be earnest in conducting a well designed and carefully executed study, I believe the claims made in the paper, especially at this very preliminary stage of study, to be too much of a stretch. The paper is replete with examples of this. I think the authors should perhaps considering paring back such claims, and provide the readers with disclaimers about the study's limitations up front.

*We agree completely. We have added a description of limitations in the introduction, and attempted to couch the claims in language more appropriate to the preliminary state of the conclusions we can draw.

For example, in the Introduction section, the authors state that the goal of the study is to answer the question "Do CBI learning experiences place learners on a trajectory towards demonstrating adaptive expertise in the workplace, years after they have left the classroom?" However, the truth is that while this may be the overarching goal of the study, this paper goes nowhere near answering this question, certainly not any more than a study that simply looks at teacher practices pre- and post- a simple engineering workshop for teachers.

*We changed this language to what we hope is more appropriate. Thank you for pointing this out. Particularly, we removed the "years" comment, as you are correct, this is just a six-week experience.

Most of the other claims that are too far-reaching are in the results section. For example, in discussing Fig. 3, the authors claim that "Posttest results for the ATI

showed a significant shift towards inquiry practices in both types of classes. While the use of inquiry practices remains more frequent in engineering classes, note the definitive shift away from equal usage for science classes." It doesn't appear that Fig. 3 supports this definitively, at least not without statistical analyses.

* Absolutely. "Significantly" is inappropriate here.

In discussing Fig. 4, the authors claim that the engineering courses were more "student centered," which the UTOP data seems to support. However, it is not clear why being student centered is in line with the goals of this project, which is to promote adaptive expertise. Is there a definitive connection between these two, or is it just that student-centered learning is good IN GENERAL for all students, and is therefore inferred to be good for developing adaptive expertise.

*This definitely needed more clarification. We revised the language and added the following "Beyond being good teaching practice in general, student-centeredness invites deviation from established instructional routines; successfully managing this changing landscape demands innovative and efficient instruction, the mark of AE in teaching."

Also, while it is clear that the engineering classes were more student centered, is the reason for this because this is the way that the teachers were introduced to teaching engineering (through the workshop), while they simply reverted to their usual ways of teaching science and math? That is, if the teachers were retrained to teach science and math in a more student-centered way, would the results in Fig. 4 be different? I guess I'm just saying that the results shown in Fig. 4 is completely expected, given the training the teachers had (and didn't have).

*This is an underexplored area of our work. At this point, we need more data to answer some of these questions.

Regarding Fig. 6, how does the learning environment relate to adaptive expertise, or to innovation or efficiency? The connection was not clear to me.

* Please see student-centeredness comment above.

Finally, I think the authors should discuss the validity and reliability of all of the surveys and measurement instruments used, if they are available. If they are not, then disclaimers should be provided to the readers.

*This is a clear omission. We will address this for each instrument here and in the paper. The UTOP is commonly used but for many different purposes. Therefore, we now describe how we achieved inter-rater reliability for our observations.

The NOE was a self-created measure (using items from many different similar instruments and some of our own). It is largely exploratory.

The Engineering Design Test was developed by one of the course instructors to fit the material addressed in the ESIT.

The ATI and CLES have been used extensively and we will include the reliability figures in the final version of the paper. We apologize that have not been able to track them down yet.

Given my concerns described above, I clearly had many problems with several of the claims made in the Conclusions. I truly believe that the authors should carefully reconsider these claims and consider a rewriting of them. The paper could also use a thorough editing for several grammatical and spelling errors.

Introduction

The American engineering student faces an exciting and unpredictable future. Dwindling natural and economic resources, rapidly evolving technologies, and a well educated, globally distributed global workforce represent significant challenges to the status quo of U.S. engineering and engineering education. Meeting these challenges requires a *transformation* of how engineering is taught. Strong domain knowledge and technical expertise no longer make a well-rounded engineer; the rapid pace of change in science and engineering also requires high levels of ingenuity and adaptivity. Learning scientists describe these dual capabilities as “adaptive expertise” (AE). Adaptive experts are *innovative*: they are able to creatively leverage their experience and perform well in novel and fluid situations. They are also *efficient*: they apply their core taxonomic knowledge appropriately and expeditiously. Common engineering educational methods succeed well at developing either efficiency (e.g., traditional lecture-based instruction) or innovation (e.g., problem-based instruction, or PBI).

Our prior research demonstrated that a semester of challenge-based instruction (CBI) develops both innovation and efficiency in students (Martin et al., 2006). However, the positive results shown for developing innovation and efficiency must transfer beyond the classroom to have lasting impact.

Do CBI learning experiences place learners on a trajectory towards demonstrating adaptive expertise in the workplace, after they have left the classroom? We are examining this question in the context of the UTeach Engineering National Science Foundation Math and Science Partnership (MSP) in-service teacher program. The MSP is a partnership between The University of Texas at Austin's School of Engineering, College of Education, and UTeach Natural Sciences program and the Austin Independent School District. These partners are collaborating to develop and deliver an innovative design-based curriculum for preparing secondary teachers of engineering.

The participants in this study were high school teachers in the first cohort of the UTeach Engineering Summer Institutes for Teachers (ESIT) program. The 23 participants had an average of six years classroom experience teaching mathematics or science. While some of the teachers were also teaching engineering or engineering-related courses, most were preparing for their first experience in an engineering classroom. The six-week ESIT consisted of a pair of integrated design challenge based courses: Fundamentals of Engineering Design and Problem Solving and the Project-Based Lesson Development.

Our primary research questions were 1) was the ESIT successful in improving teachers' innovation and efficiency and 2) does this change translate to teacher practice?

Our results are primarily descriptive due to low sample sizes and inconsistency in response rates on pre- and post measures. However, our results suggest that teachers efficiency and innovation in engineering improved during the ESIT. Teachers significantly improved on measures of basic engineering knowledge and pedagogy from pre- to posttest. We also found that teachers increased the student-centeredness of their

classrooms and the use of constructivist learning theory in informing their classroom practice. These changes are not simply symptomatic of more innovative and efficient educators; they also stand to fruitfully foster innovation and efficiency in students.

Background

Expertise

There are two general approaches to defining an expert in a domain. An expert can be identified based on external criteria, such as a performance in a ballet or chess game or internal criteria such as a test of physics or biology knowledge (Chi, 2006a; Chi, 2006b). A challenge with this approach is identifying appropriate measures. A second approach is to use time spent working in the domain. For example, doctors with 30 years experience should be more expert than medical students. This approach more readily allows comparison of novice and expert performance, the first step in coming to understand expert thinking and the development of expertise.

Experts in many fields demonstrate common characteristics in solving problems in their domain (e.g., Bereiter & Scardamalia, 1993; Bransford, Brown, & Cocking, 2000; Ericsson, & Charness, 1994; Glaser, 1992). First, they notice aspects of and perceive problems differently than novices do. For example, experts and novices notice different elements in x-rays when they use them for medical diagnosis (Lesgold et al., 1988; Raufaste, Eyrolle, & Marine, 1998). Particularly, experts tend to catch anomalous features in the x-rays that lead to diagnoses of rare conditions. Next, experts perceive problem situations contextually and globally. For example, after viewing a chessboard with pieces displayed in typical game patterns for five seconds, experts recalled nearly the entire board, while novices remembered only a few pieces (de Groot, 1978). However, expert-novice differences are nearly eliminated when the chess pieces are laid out randomly (Chase & Simon, 1973). These results demonstrate that experts perceive layouts as formations relatable to their experience, not as individual pieces.

Experts also approach problems by considering the whole problem prior to attempting specific solution methods (Chi, Feltovich, & Glaser, 1981). They classify problems based on deep features, such as general principles that govern the correct solution to the problem (e.g., Newton's Force Laws or general conservation principles). In contrast, novices tend to characterize problems based on surface features such as vocabulary, appearance, or the relation between objects in a problem (e.g., a block on inclined plane). When solving problems, experts use basic principles. For example, in a study on physics, experts first noted important features of the problem, including keywords like adiabatic, heterogeneous, or one-dimensional. Next, they derived a second-order interpretation of the general principles that were not explicitly stated in the problem from these first order features. Finally, they developed general solution plans. In contrast, novices noted only first-order features and usually began solving the problem by identifying equations to use. This difference has been discussed as reasoning backwards from the solution goal to the information in the problem (novices) versus reasoning forwards or developing a representation of the whole problem and using it to generate a problem solution (experts) (e.g., Ericsson & Charness, 1994; Ho, 2001; Larkin, McDermott, Simon, & Simon, 1980; Patel & Groen, 1991).

Expertise takes significant time to develop, usually around ten years (e.g., Anderson, 1982; Ericsson & Charness, 1994). Whether it is playing tennis, teaching, or academic writing, that development requires deliberate and frequent practice in a field and should include challenging opportunities that push practitioners towards new levels of understanding and performance (Raufaste et al., 1998).

Adaptive Expertise

Another characteristic of experts is that they differ in the level of flexibility they demonstrate when confronted with novel situations. Hatano characterized this difference by discussing routine versus adaptive experts. Hatano and colleagues described routine experts as possessing a high degree of procedural efficiency (Hatano & Inagaki, 1986; Hatano & Oura, 1983; Inagaki, & Miyake, 2007). They describe abacus masters who could mentally sum ten multidigit numbers with a mere two seconds between each. Through years of practice, the masters had developed an internal simulation of the abacus. They were clearly experts, yet at the same time, their understanding was narrow and inflexible. Their competence was restricted to a small set of arithmetic tasks, and they did not seek new contexts in which to apply or extend their skills. Routine experts are technically proficient in their established domains of knowledge and application. They apply their well-developed knowledge base appropriately and efficiently to solve core problems in the domain. However, when they face a novel problem they tend to misapply technical principles, analysis procedures, and outcome interpretations in attempting to reach a solution (Bransford, Brown & Cocking, 2000). In other words, routine experts fail to adapt their expertise to a new context. Adaptive experts share the core technical proficiency of routine experts. Moreover, they are capable of developing appropriate responses and solutions to novel challenges. They tend to review multiple perspectives when considering the solutions to new problems, seek out challenges in their work, successfully and frequently gauge their own current knowledge state, and view their knowledge base as dynamic (Bransford, Brown & Cocking, 2000; Wineberg, 1998).

Many good examples of the differences in novices, routine experts, and adaptive experts come from studies of medical diagnosis (e.g., Lesgold et al., 1988; Raufaste et al. 1998). Raufaste and colleagues studied the adaptiveness of radiologists at different levels of experience at interpreting x-rays. They chose participants to correspond to four ascending levels of expertise: novices (1st- and 2nd-year residents), intermediates (3rd- and 4th-year residents), basic experts (radiologists with 6 years of experience past residency) and super experts (radiologists with at least 13 years of experience past residency who also engaged in teaching and research). Participants interpreted x-rays that indicated 4 possible correct diagnoses but had several misleading clues. Results showed a non-monotonic, zigzag like pattern of development. Novices and basic experts listed the fewest correct diagnoses. Intermediates and super experts listed more correct diagnoses than either of the other groups, and super experts listed more than intermediates. While all four groups mentioned the most standard diagnosis more often than the other three diagnoses, this trend was most evident for the basic experts. All of them mentioned the most standard diagnosis, one basic expert mentioned two of the other diagnoses, and

none mentioned the last. The other groups were more spread out in the diagnoses they mentioned.

The authors interpret these results as indicating a qualitative difference between the experiences of basic and super experts (similar to routine and adaptive experts). The basic experts had learned to efficiently determine the most likely diagnosis, but missed or did not find it worth mentioning more subtle possibilities. However, super experts had different experiences from the basic experts. The basic and super experts had equal knowledge training (though the super experts had more years of experience) but the super experts were professors. They taught radiology, were often called upon to consult on unusual cases and conducted research in the area. These experiences seem likely to develop the aptitudes and abilities that routine experts lack – flexibility, metacognition, and pursuit of extended learning experiences and challenging situations. It is possible that the basic experts could develop into super experts given similar adaptive learning experiences.

Teaching Approaches in Engineering

Lecture-based Instruction

Instructors use many alternative approaches to teaching courses that present fundamental and often difficult engineering content material. The most common approach is a didactic lecture format, which has numerous demonstrated benefits. Students receive a clear exposition of the information they need to learn, teachers can be sure they have covered the content if they follow well-organized materials that are readily available, and students tend to learn content well as measured by performance on tests that replicate the content and context under which the material was presented (Bransford, Brown & Cocking, 2000; Schwartz & Bransford, 1998).

However, there are drawbacks to the lecture approach as well. Students may learn the material in a disconnected fashion that makes it difficult for them to apply their knowledge out of context, and their long-term retention is often poor (Anderson, 1982; Brown, & VanLehn, 1988). Further, students have difficulty in relating their accrued knowledge to problems in the “real world” – in the workplace or graduate school (Barron et al., 1998; Bransford, Brown & Cocking, 2000).

Inquiry-based Instruction

An alternate teaching approach is to apply one of several methods that can be grouped together as inquiry learning. Problem- and project-based learning, case-based learning, authentic inquiry, and discovery learning are all examples (e.g., Albanese, & Mitchell, 1993; Dochy et al., 2003; de Jong, 2006; Prince & Felder, 2006; Terezini, 1993; Williams, 1992). Features of these methods are that they engage students in authentic problems without single correct solutions, they allow extended student exploration, and theories, principles and formalisms are taught when the need to know them has been established (Hmelo-Silver, 2004; Prince & Felder, 2006). These approaches increase student motivation and awareness of the connections between their in-class experiences and their future work, lead to positive attitudes about learning for both students and

teachers, and, when structured well, lead to significant increases in knowledge (Hmelo-Silver, 2004; Prince & Felder, 2006).

However, like traditional lecture, inquiry methods can have drawbacks. Without extensive training, teachers often have trouble selecting problems that highlight the key principles in the discipline, opting rather for problems that merely seem engaging (Barron et al., 1998). Students consequently often miss important concepts they need to learn (Prince & Felder, 2006). Students may have trouble structuring their approach to these open-ended problems if they have not also learned the fundamental principles for the subject and how to apply them with an effective analysis strategy (de Jong, 2006). Thus, they may struggle with the processes such as hypothesis generation, defining appropriate systems for investigation, and confining the breadth of their investigation to answer the question asked. Finally, if these approaches are not structured well, students' knowledge gains are less than in lecture-based educational settings (Dochy et al., 2003; de Jong, 2006; Prince & Felder, 2006).

Teaching for Adaptive Expertise (AE)

Research on preparation for future learning has addressed the question of how to teach for both innovation and efficiency (Schwartz & Bransford, 1998; Schwartz & Martin, 2004). Inventing formalisms for situations about central tendency and variability helped 9th-grade students understand standard ways to deal with these concepts – computing and representing them (Schwartz & Martin, 2004). Students who invented methods of standardizing scores were compared to students who learned a graphical procedure for computing standardized scores. On a subsequent test, the two groups of students were equal in their performance on a resource item that showed them how to compute z-scores. However, the inventing students were more prepared to learn from that item. They applied what they learned better than the procedure students to a later transfer item on the test that required that procedure but did not tell students to use what they had learned earlier. There were also two groups that did not receive the resource item (one who had received procedural instruction and one who had invented). The procedural instruction students performed as badly as students who did not receive the z-score training problem on the transfer problem.

AE research suggests that a combination of opportunities to explore or to invent, combined with timely interventions of directed guidance could be the best combination for learning complex domains like engineering. In such an environment students are likely to obtain both long-term memory gains in core knowledge and problem solving heuristics and experience in dealing with the kinds of uncertain problems that people face in real job situations. In other words, this combination could develop adaptive expertise.

Challenge-based Instruction (CBI)

Structuring Learning Environments for AE

Designing a productive learning environment requires providing opportunities to build both the efficiency and innovation dimensions of AE. In 2000, the National Research Council published a report called “How People Learn” (Bransford, Brown & Cocking,

2000) synthesizing research on effective learning principles and practices. There are four design principles for learning environments presented in the report (HPL principles):

1. Learning environments should be knowledge centered; the core knowledge and skills of the domain should inform the design of the learning materials.
2. Learning environments should be learner centered or designed with students' current level of prior knowledge in mind.
3. Learning environments should be assessment centered. These assessments should include formative components that give students and teachers information about performance during the learning process in addition to the more traditional summative components that occur at the end of a topical unit.
4. Learning environments should be community centered; they should use realistic problems to prepare students to participate in the larger engineering community.

These principles are consistent with many inquiry-learning models, including problem- and case-based learning (e.g., Albanese, & Mitchell, 1993; Dochy et al., 2003; de Jong, 2006; Prince & Felder, 2006; Terezini, 1993; Williams, 1992).

Through the VaNTH ERC, we collaborated with biomedical engineers to design and implement a challenge-based method of instruction designed to develop both efficiency and innovation based on the HPL principles. We implemented these four principles using a Challenge-Based inquiry cycle called STAR.Legacy Cycle (SL Cycle) (See Figure 1, adapted from Schwartz et al., 1999).

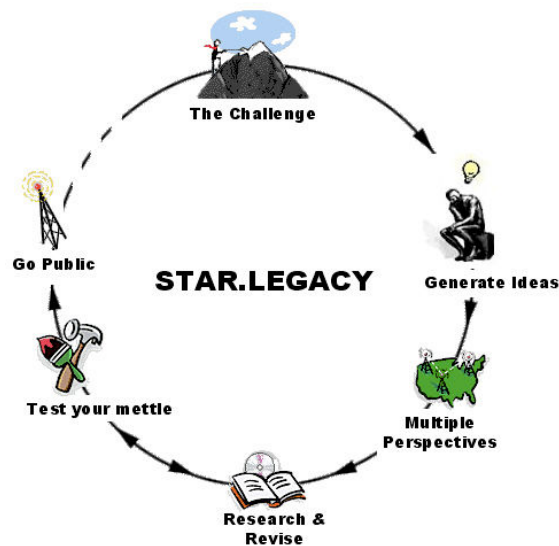


Figure 1 - The STAR.Legacy Cycle

In the SL Cycle, students first receive a realistic, complex problem (The Challenge). They then generate ideas about what they already know and what they will need to learn to solve the challenge (Generate Ideas). Students often work in small teams during the class period to carry out this exercise. The instructor is available for consultation during and after this step. Then the students discover different views on important aspects of the challenge and key components of the knowledge taxonomy, including lectures from the

instructor (Multiple Perspectives). The lecture may flow seamlessly from questions students pose during Generate Ideas. Next students revise their ideas, often via guided assignments outside of class (Research and Revise), and complete formative assessments with peers and/or the instructor (Test Your Mettle). Finally, students publicly present their solutions to the challenge (Go Public).

The SL Cycle helps instructors ensure that they have incorporated the HPL principles into their learning materials to improve both the knowledge and innovation dimensions of AE. The Multiple Perspectives, Research and Revise, and Test Your Mettle phases primarily develop the knowledge component. In each of these phases, students discover or receive important information for solving the challenge. The cyclical approach to addressing knowledge components used in these phases is beneficial because people learn more when they have a chance to revise (Vye et al., 1998). In addition, in these phases students receive formative feedback, which helps teachers and students adjust their actions to improve learning (Roselli & Brophy, 2006; Sadler, 1989).

Students develop their innovative skills primarily in the Generate Ideas (GI) phase (Martin, Pierson, Rivale, Vye, Bransford, & Diller, 2007). Here, they attempt to address the novel and difficult challenge problem on their own prior to consulting resources that provide knowledge they need to solve the problem. This gives them practice with both the cognitive and affective aspects of confronting an unknown problem and helps them develop several of the characteristics of AE.

On the cognitive side, GI develops several of the innovative characteristics of adaptive experts. First, it develops metacognition, or the ability to be aware of your own state of knowledge, because students consider and discuss what they know and need to discover (Walker, Brophy, Hodge & Bransford, 2007). Second, GI develops multiple perspectives because students work in groups and share ideas that they generated (Lin, Schwartz, & Hatano, 2005). Third, GI helps students structure their work on the challenge problem. Grappling with problems independently prior to receiving resources and direct instruction improves students' subsequent learning (Schwartz & Martin, 2004) In addition, it increases the likelihood they will generate questions that guide their inquiry productively (Schwartz, Bransford, & Sears, 2005).

On the affective side, GI develops comfort with facing an unfamiliar problem that takes time to solve. Many students in traditional engineering programs have not faced this type of problem and report feeling somewhat threatened by them early on (Martin et al., 2006). However, as they practice generating ideas over time, they develop confidence in their ability to approach the problem.

Design Based Instruction

Experts agree that high school engineering should be centered around design (Katehi et al., 2009). Therefore, we adapted the SL Cycle of CBI to support Design Based Instruction (DBI) by creating a cycle that was suited for addressing design challenges rather than problem solving challenges (See Figure 2).

Teachers will generally enter the DBI cycle with some idea in mind of a classroom activity they would like to further develop, or with certain content areas that need to be addressed. In Content Areas and Constraints the teacher outlines the STEM content areas potentially bound up within a lesson in addition to the constraints (material resources, space, time, etc) that must be kept in mind. This section mirrors The Challenge statement in the SL cycle as well as the beginning phase of Generate Ideas. In the Generate Approaches section, the instructors brainstorm real-world engineering problems involving the STEM content determined previously. They also consider societal needs in which this content might play a role, as well as methods for effectively assessing understanding of the content. This section continues to mirror the SL cycle's Generate Ideas section, as well as Gather Multiple Perspectives in its looking to society and the world at large. Generate Ideas continues with Generate Activity Ideas; here the instructors focus sharply, moving from the broad vantage point of a design challenge covering many class periods to the actual activities that may occur in the classroom over the course of the challenge. They will also be studying the topic at hand more specifically as they develop activities, touching on the Research and Revise phase from the SL cycle. Finally, in Choose an Approach, instructors finalize the broad direction of their design challenge based on opportunities for content coverage, interesting activity ideas, and constraints affecting various alternatives. In Create a Prototype, instructors produce an actual lesson plan describing the challenge at a class period level of detail. Evaluate the Prototype is simply teaching a lesson, while taking careful note of its strong and weak points. These steps act as Test Your Mettle and Go Public from the SL cycle, with Research and Revise bringing us back to The Challenge once again.



Figure 2 - Design Challenge Based Instructional Cycle used in the ESIT

The UTeach Engineering Program

The UTeach Engineering Project, while setting the stage for addressing preparation of secondary engineering teachers at a national level, is particularly urgent in Texas because of a 2006 legislative decision requiring all high school students, beginning with those

who entered ninth grade in 2007, to complete four years of science to graduate under the state's default degree plan. This fourth year of science, which must be laboratory-based, may be selected from existing courses in anatomy/physiology, astronomy, advanced biology, chemistry and physics, environmental systems and research/design, or may be a new course in space science or a new course in engineering. In schools offering an engineering option, this new initiative will put enormous pressure on secondary science teachers to teach engineering. Because methods for knowing and learning differ between the sciences and engineering, science teachers with little or no engineering experience will be teaching "out of field" when they teach engineering. Conversely, since few schools will offer full-time engineering teaching positions, a cadre of educators trained only in engineering and engineering pedagogy would also be teaching "out-of-field" when required to teach in the sciences. There is, therefore, a pressing need for pre-service and in-service training that will prepare teachers to instruct in both engineering and the sciences.

To properly address professional development needs in engineering, we are implementing a program comprising four pathways to educate in-service and pre-service teachers in engineering content and pedagogy so that they may, in turn, effectively prepare their students to understand and consider a career in an engineering field. These four pathways are:

1. **UTeach Master of Arts in Science and Engineering Education (MASEE).** This program for in-service teachers will parallel the existing UTeach Master of Arts in Science and Mathematics Education, with which it will share several courses.
2. **Engineering Summer Institutes for Teachers (ESIT).** This program will leverage MASEE content to offer a summer professional development opportunity to teachers who, while not pursuing a graduate degree, are nonetheless interested in becoming leaders in secondary engineering education.
3. **Engineering Certification Track for Physics Majors.** This new degree plan within UTeach Natural Sciences will use undergraduate-level versions of MASEE courses to prepare pre-service teachers for teaching certification in physics, math, and engineering.
4. **Teacher Preparation Track for Engineering Majors.** This new degree plan for pre-service teachers will create an engineering equivalent to the UTeach Natural Sciences programs. It will leverage existing UTeach professional development courses and one MASEE course to prepare engineering majors for teaching certification in engineering and science.

The four pathways of this program will deliver diverse professional development opportunities to a variety of in-service and pre-service teachers from across the state. UTeach Engineering will reach 650 teachers statewide over five years.

This paper reports on the results for Cohort 1 Year 1 of the MASEE and ESIT participants.

Methods

Participants

Twenty-three in-service teachers from the UT Austin site participated (there are 32 more participants divided between the other two UTeach Engineering sites, these sites were not included in Year 1, but will be included in future years' research). Fourteen of the participants are men; nine are women. Though the new official Engineering fourth year science course will not come online in Texas until 2010, one-third of these teachers were already teaching some form of engineering in the 2008-2009 school year. The participants have an average of six years teaching experience. Ten of the participants are enrolled in the MASEE program; thirteen participated in the ESIT only. All of these participants completed both the Fundamentals of Engineering Design and Problem Solving and the Project-Based Lesson Development in Engineering courses; the MASEE participants also completed one additional course. Ten participants teach in our major partner school district, thirteen teach in surrounding area districts near Austin.

Instructional Intervention

Description of Integrated Courses

Fundamentals in Engineering and Design 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 rigorous design challenges and reverse engineering and redesign modules. Lesson modules also present current widely used high school curricula. The course culminates with a final design challenge of the teacher's choosing. The modules are designed so that the students learn specific engineering content as they solve engineering problems in multiple contexts and are taught by university engineering faculty. Instruction by full professors from the engineering faculty promotes high school teacher and higher education faculty communication and collaboration.

Project-Based Lesson Development in Engineering allows teachers participating in the summer institutes to build on their experiences in the *Fundamentals of Engineering and Design* course to develop a set of project-based lessons for immediate use in their high school classrooms. Teachers work in groups to modify and rewrite each design challenge they complete in *Fundamentals of Engineering and Design* as a unit plan to be vetted as lessons in their individual classrooms. The vetted lessons in final form will become part of an online store of engineering modules for teachers to access and integrate into their curricula.

Instructional Modules

Both courses are based on a sequence of four instructional modules:

A. Vehicle Design Challenge

Working in teams, the teachers are challenged to design and fabricate a superstructure on top of a dynamics cart that maximizes the volume (carrying capacity) and minimizes the drag to realize the fastest time down an elevated test track. Teams must characterize their designs with respect to drag coefficients for a variety of head wind speeds so that they can accurately predict their final track time for a wind speed and track configuration that are revealed just before the final competition. Measurements of ambient temperature, drag force and wind speed are made using probe ware, projected areas are calculated and air density values are interpolated from tables. Teams are encouraged to redesign the geometry of their superstructure after they use a wind tunnel to obtain flow visualizations. The students' progress is scaffolded using just in time instruction to facilitate developing an engineering model of their vehicle performance.

B. Reverse Engineering and Product Redesign

Working in teams of two, the teachers are asked to conduct customer needs analysis interviews of a commonly used product (in Year One, a hair dryer) and prioritize the results, which are mapped to quantifiable performance metrics. They are then given one of two types of hair dryers (upper end and travel) and asked to predict the internal workings by sketching the layout of the predicted subsystems and components. The teams then disassemble their hair dryer and compare to their prediction. An actual functional model is created and the hair dryer is reassembled. The hair dryer is then quantitatively characterized through tests and measurements of air speed, temperature setting and current from which volumetric and mass flow rates, net power and efficiency are computed. Other aspects such as time to dry and noise are quantified to complete the characterization, which is compared with the original needs analysis to develop product redesign ideas.

C. National Curricula (Infinity Project and Project Lead the Way)

The teachers are introduced to the two most widely disseminated secondary level engineering curricula. The overviews and specific engineering content come directly from each organization so that a faithful and accurate experience is provided for the teachers. Infinity Project is an Electrical Engineering based curriculum (Digital Signal Processing). The teachers experience a module that addresses digital representations of images through computer-based labs utilizing virtual instruments that run on the National Instruments Lab View programming platform. While Project Lead the Way covers several engineering disciplines, the teachers experience a Civil Engineering module that covers composites and the cantilevered beam.

D. Final Design Project

During the initial four weeks the teachers are encouraged to keep an invention journal in which they record every thought they have about new or improved products in their every day activities. While 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. During the third and fourth weeks they are asked to develop preliminary plans for this project, inventive, redesign or otherwise that can be developed into a lesson that they can

take back to their classrooms. Working in groups or individually, they meet with the professors and make mini presentations to their peers, to vet out their ideas for a final project that is turned into a project-based lesson for their classroom during the fifth and sixth weeks.

Measures and Results

Teachers' classroom practice

We have taken a triangulated approach to understanding teachers' classroom practice. We surveyed teachers about their classroom practice, observed their classrooms, and asked their students about their classroom experiences. These results should be considered primarily descriptive. Due to the timeline in obtaining school district permission and consent forms, many of our summer participants could not be included in this first year of data collection.

Teacher Surveys

The *Approaches to Teaching Inventory (ATI)* measures teachers' own beliefs about how they teach. Teachers reported how often they engaged in directed and inquiry teaching practices in engineering classes as well as mathematics and science classes (ratings were 1 to 5, with 1 being almost never and 5 being almost always). An example question describing inquiry teaching practices is "I encourage students to restructure their existing knowledge in terms of the new way of thinking about the subject that they will develop." An example question describing directed teaching practices is "In this subject I concentrate on covering the information that might be available from a good textbook." Composite results appear below in Figure 3.

Prior to intervention, teachers reported using inquiry practices significantly more often than directed ones in their engineering classes; however, there was no significant difference between use of the two practices in math and science classes.

Posttest results for the *ATI* showed a shift away from direct instruction practices and towards inquiry learning practices in both types of classes. While not statistically significant, these results suggest that the ESIT may have influenced teachers' ideas about teaching science and math as well as engineering. More research is required to corroborate this assertion.

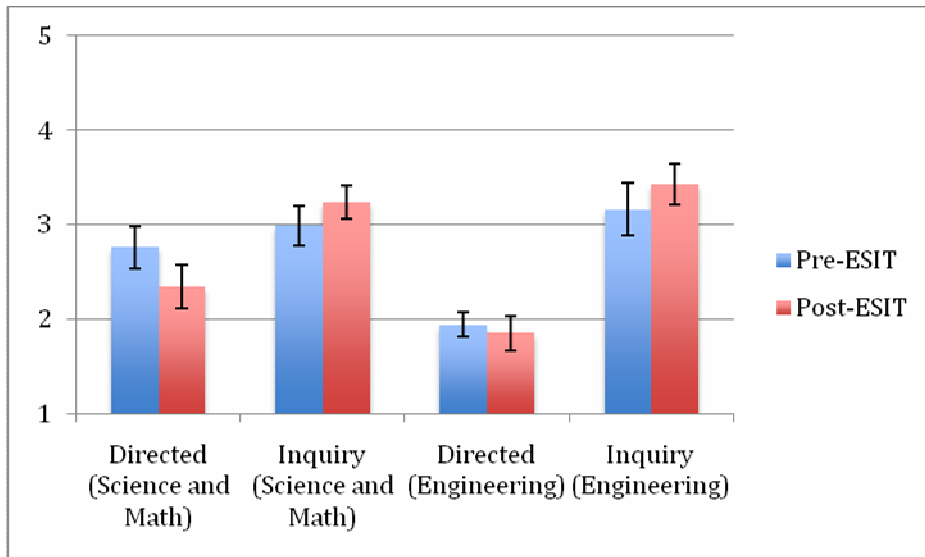


Figure 3 - *Approaches to Teaching Inventory*

Teacher Observations

In spring 2009, five teachers were observed in their classrooms. Three were observed for one class period (two engineering classes and a science class). Two were observed over multiple periods, teaching science as well as engineering courses. The engineering classes were Robotics, Intro to CAD, and Principles of Engineering. The science classes were Chemistry, Physics, and Pre-AP Physics.

We used the *UTeach Observation Protocol (UTOP)*. The *UTOP* is used to assess the overall quality of classroom instruction and was designed to allow individuals to evaluate teaching effectiveness without bias towards any particular mode of instruction. The *UTOP* uses a five-point Likert scale generally describing the student-centeredness of the class in four categories: Classroom Environment, Lesson Structure, Lesson Implementation, and Math/Science/Engineering Content. We conducted training for all our observers using videos of science, mathematics and engineering classrooms. All observers attained at least 80% agreement with a gold standard rating. Two observers attended each classroom and completed the *UTOP*. A classroom's rating was the negotiated agreement of both raters.

Overall *UTOP* results appear below in Figure 4.

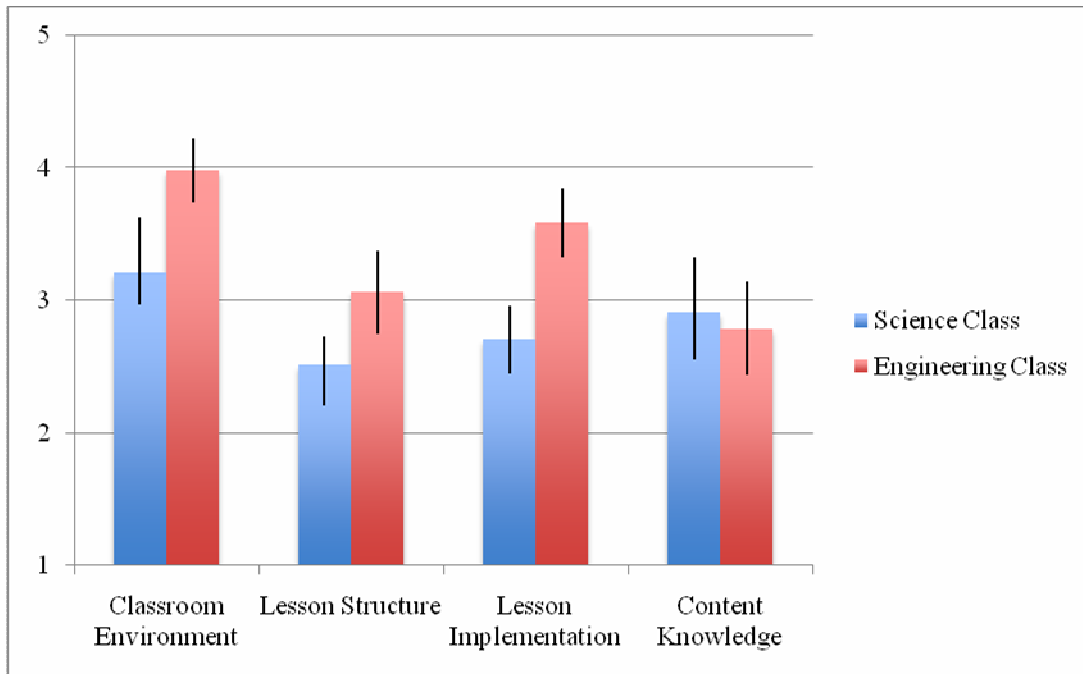


Figure 4 - *UTOP* - Science vs. Engineering Classes

Quantitative analysis of *UTOP* results combined with qualitative analysis of the videotaped observations suggested a number of key differences in classroom practice for science and engineering courses. For example, we observed:

- Different instructional strategies (higher level of questioning, better set up of lesson) for engineering than for science classes.
- Higher expectations for engineering than for science classes.
- Greater student motivation and engagement in engineering classes, particularly when the focus was on exploration of a student's own ideas.
- A stronger focus on accuracy and correctness of procedures in science classes, as evinced by student interactions and questions.

When comparing pre-post results, we can only consider the engineering courses. The science classes we observed in the fall had not submitted consent forms, so their results are excluded here. Figure 5 shows that the teachers maintained their reasonably high scores in their engineering classes. Descriptively, they improved in lesson structure and content knowledge, but the sample is not large enough for statistical analysis.

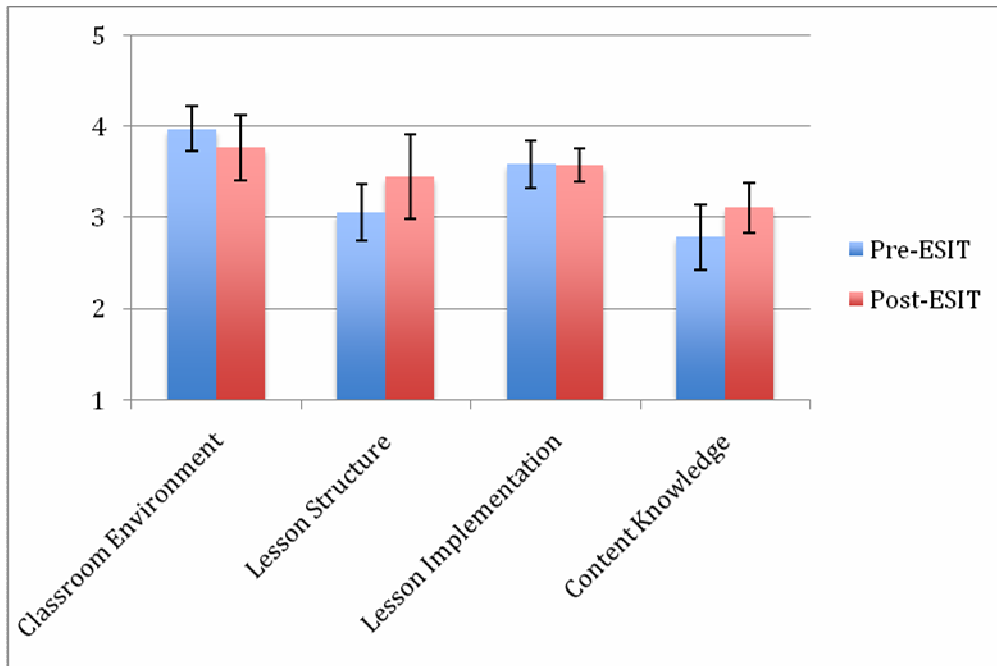


Figure 5. *UTOP*: Pre-Post Engineering Classes

These observations, combined with the trends observed in Figure 3 above (particularly in the areas of Classroom Environment, Lesson Structure and Lesson Implementation) point towards a stronger student focus in engineering classrooms. Beyond being good teaching practice in general, student-centeredness invites deviation from established instructional routines; successfully managing this changing landscape demands innovative and efficient instruction, the mark of AE in teaching.

Student Survey

The *Constructivist Learning Environment Survey (CLES)* is a measure of how often students' perceive certain constructivist practices occur in their classroom. Students completed the surveys in their classrooms.

The CLES has five categories, including a representative survey question:

- Personal Relevance - "In this class, my new learning starts with problems about the world beyond my classroom setting" and "In this class, I learn how engineering can be part of my life beyond my classroom setting."
- Uncertainty of Science - "In this class, I learn that science is influenced by people's values and opinions."
- Critical Voice - "In this class, it is acceptable for me to question the way I'm being taught."
- Shared Control - "In this class, I decide which activities are best for me."
- Student Negotiation - "In this class, I discuss how to solve problems with other students."

Students rated these statements using a 5-point Likert scale describing responses from 'Almost never' to 'Almost always.'

Collected results appear in Figure 6. Overall, students rated their classes as showing many constructivist practices, as most average subscale ratings were above 3.

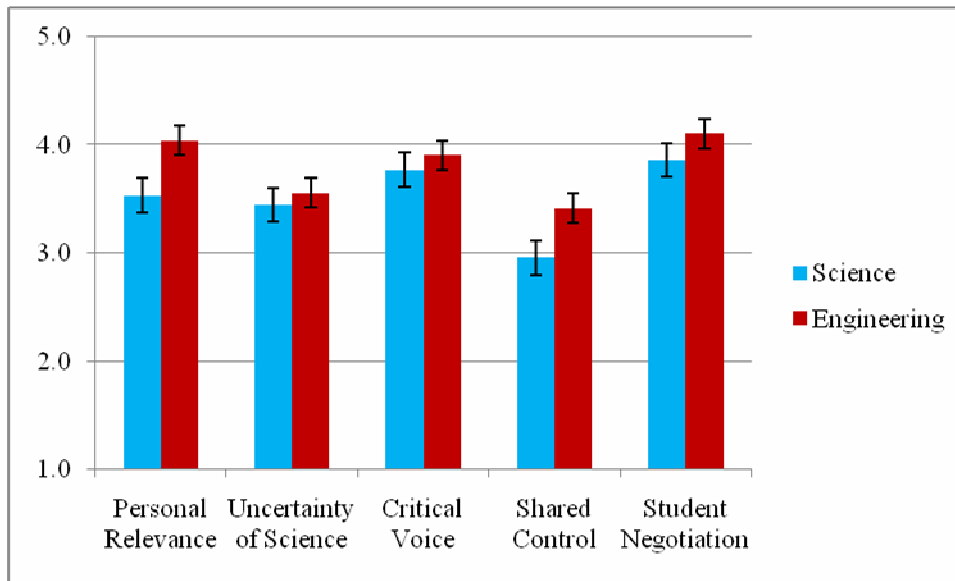


Figure 5 – *CLES* – Student Response

We compared students' ratings of their science classes (Chemistry and Physics; $N = 24$) and their engineering classes (Robotics, Introduction to CAD, and Principles of Engineering; $N = 39$). Students in engineering classes rated their class experiences significantly higher in Personal Relevance ($p < 0.01$) and Shared Control ($p < 0.05$) than science students.

The *CLES* was administered to students in engineering classes¹ before the ESIT ($n = 24$), and after their teacher completed their first summer ($n = 27$). These ratings were quite high already and there were no significant differences in the pre- and post-tests (See Figure 7).

¹ As with the *UTOP*, the students in the science classes we observed in the fall had not submitted consent forms, so their results are excluded here.

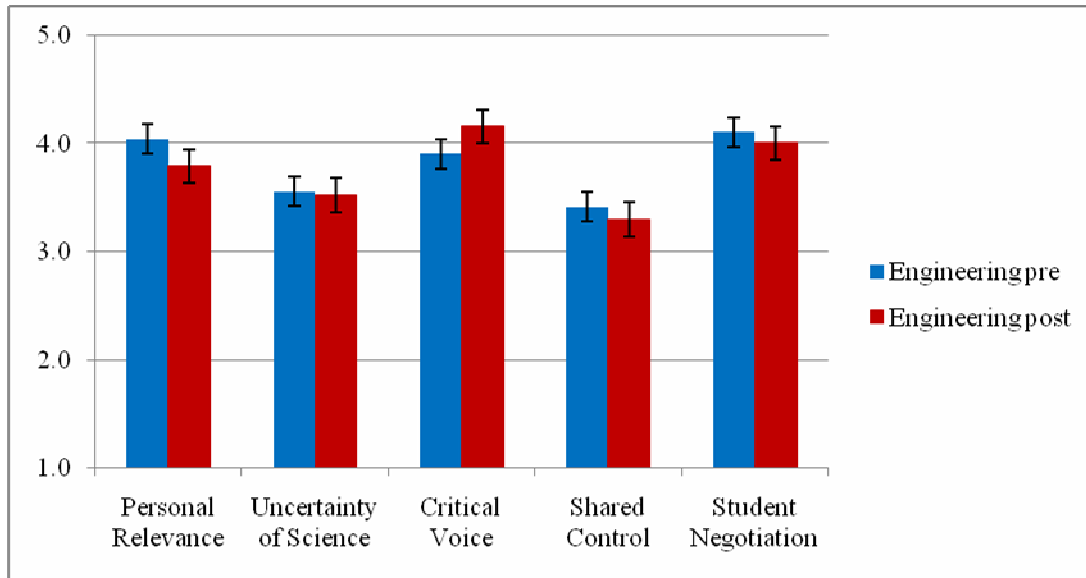


Figure 7 – *CLES* – Student Response: Pre-Post Engineering Classes

Teacher perceptions of engineering

The *Nature of Engineering Survey (NOE)* measures attitudes and perceptions about engineering as a field of study and profession as well as about the respondent’s participation in and preparedness for engineering activities. This survey should be considered exploratory as we combined many items from other similar surveys and included some that we wrote. It uses a 5-point Likert scale to measure agreement with a variety of statements, falling into several broad categories:

- Societal role engineering (ex: “I see engineering as addressing human needs.”)
- Technical characterization of engineering (ex: “I see engineering as a career that uses lots of math.”)
- Self-efficacy (ex: “I am good at technology,” or “I enjoy science.”)
- Engineering education (ex: “Creative students should become engineers.”)

Overall, the participants see engineering as a highly technical field offering great benefits to humanity. They rated themselves as being proficient in pertinent technical areas, value balance within teams, and see teamwork as being commonplace in and essential to engineering.

Only three measures changed significantly from pre- to posttest. (See Figure 8). For reference, sixteen teachers completed the survey before the summer institute, and twelve completed it after.

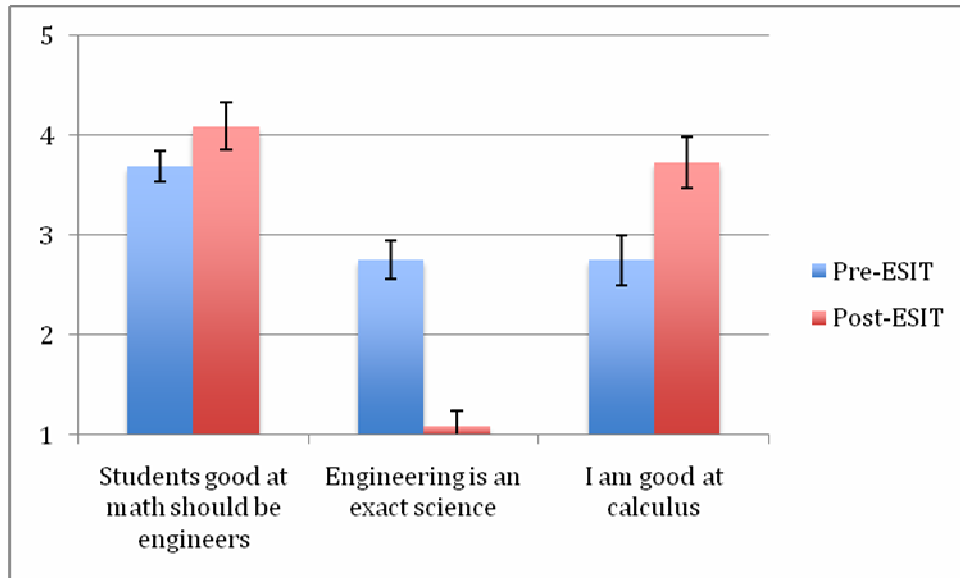


Figure 8 - Changed *NOE* Measures

The *NOE* measures were largely exploratory, and therefore strong claims cannot be made. However, these changes are suggestive for the *AE* framework. Teachers place more emphasis on the value of mathematics for engineering and rate their own math skills as having improved during the *ESIT*. These changes relate to the efficiency aspect of *AE*. In addition, they perceive engineering as less of an exact science after the *ESIT*, suggesting they better understand the innovative and adaptive side of engineering practice.

Engineering Design Knowledge

We developed the Engineering Design Knowledge Test to measure how participants understand the engineering design process (including reverse engineering). It also includes one question testing the specific content knowledge in the reverse engineering module for Year 1.

Questions:

1. What are the stages of the engineering design process?
2. What is reverse engineering? How is it different from the forward engineering design process?
3. What is a performance metric? How is a performance metric different from a constraint?
4. What is the purpose of functional modeling in engineering design?
- 5a. Suppose a flashlight operates with a 3 V battery pack and draws 300mA of current while producing 0.1 W of output light power. How much power does the flashlight use?
- 5b. What is the efficiency of the flashlight?

Teacher participants significantly improved from pre- to posttest on this measure (See Figure 9).

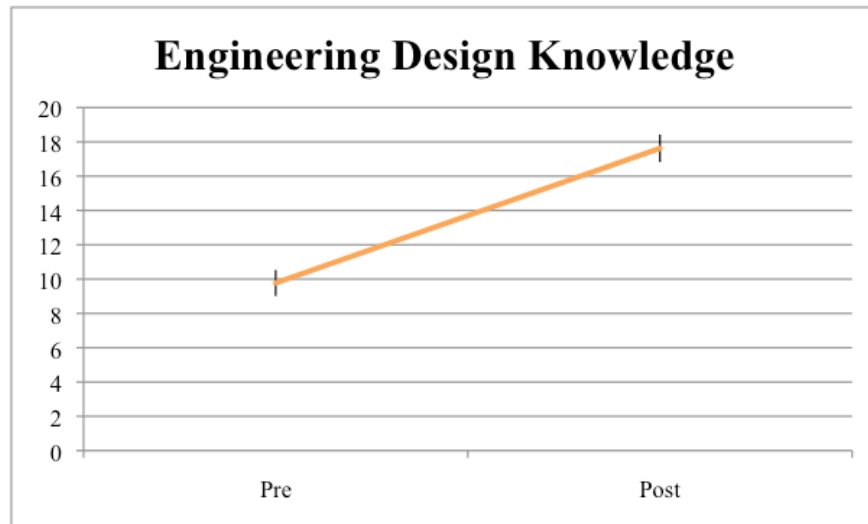


Figure 9. Engineering Design Knowledge Test Results

Conclusions

Our primary research questions were 1) was the ESIT successful in improving teachers' innovation and efficiency (AE)?; and 2) does this change translate to teacher practice?

As discussed, limitations of our current work are clear. Our sample sizes and the lack of a match in our pre-post return sample render inferential statistical comparisons meaningless for many of our instruments at this point. We are relying on descriptive comparisons in most cases. In addition, our first year results suggest the need for measures more sensitive to change for rating engineering classes. Our teacher observation and student survey instruments were both near ceiling before the summer institute.

Our descriptive evidence suggests that teachers' innovation and efficiency in engineering did improve somewhat during the ESIT. For innovation, teachers expressed their intent to use more adaptive (inquiry) practices and showed a more adaptive understanding of engineering on the NOE in the change in beliefs about engineering as an exact science. For efficiency, teachers significantly improved on measures of basic engineering knowledge and expressed more confidence in their calculus skills from pre- to posttest.

Our findings also suggest that these changes may translate into teachers' work. We measured teachers' classroom practice by observing teachers, asking teachers about their practices, and asking the teachers' students about their practices before and after the ESIT. We found that teachers and students rated their engineering classes as fairly inquiry-oriented and design-based, but rated the same teachers' science and math classes as fairly

traditional. These ratings were supported by our observations of the two types of classes. As mentioned, teachers expressed an intent to use less directed instruction practices in science and mathematics classes after the ESIT. Though post observations and student survey results from science and mathematics classes are not available to determine whether and how teachers followed through with their intended changes in practice in those courses, these results suggest that teachers intend to move towards adaptivity in those classes. In addition, the design-based engineering courses remained highly adaptive.

Overall, these results begin to point to a picture of teachers on a trajectory towards adaptive expertise in their work. They increased in both innovation and efficiency in self-report attitudes and plans data and on a design knowledge test. It remains to be seen how these changes transfer to their work in science and mathematics teaching, but current results suggest that engineering teaching remains highly adaptive.

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