

# Increasing Student Awareness of and Interest in Engineering as a Career Option through Design-Based Learning\*

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*This paper describes a rigorous summer research experience and curriculum development opportunity for teachers, supported by professional development and classroom support, culminating with a citywide student design competition. The goal of this Research Experience for Teachers program was to bring real world innovative design into several urban, high school classrooms. The 8-week summer program comprised an engineering component and a learning science component. The goal of the engineering component was to provide an authentic research experience. Teams of 2–3 teachers were paired with a researcher in a school of engineering to further ongoing research of a product realization project. The goal of the learning science component was to scaffold teachers to develop a design-based immersion unit that they would implement in their science classrooms. Teams were organized by their content areas and provided professional development at a learning research center around relevant curriculum development strategies. This paper presents results related to common sets of knowledge and skills that teachers learned from both engineering design and learning science from the cohorts of teachers over the last three years. Findings include documentation of implementation success, changes of teachers' and students' beliefs about engineering and increases in student interest in engineering careers.*

**Keywords:** engineering pipeline; teacher professional development; design-based learning

## INTRODUCTION

### *Goals of K-12 Engineering Education*

THERE ARE MANY DIFFERENT GOALS of K-12 Engineering Education efforts, and the success of a program should be evaluated against its goals. Commonly mentioned goals include: increasing public appreciation of engineering research (especially new areas of research, such as nanoscience or tissue engineering); increasing public appreciation of engineering work; increasing student science and math performance; and increasing the supply of future engineers (overall and with greater gender, socio-economic, and racial diversity). These goals are not directly in opposition and likely have synergistic effects. However, they are not completely overlapping goals either, hence maximizing one goal will not necessarily maximize the others. Further, the infrastructure for achieving K-12 Engineering Education outcomes is very small relative to the whole of K-12 education, and thus choices must be made with respect to goals.

The primary goal taken in the currently reported work is to increase the supply of future engineers, both overall and with greater diversity along a number of dimensions. In recent years, there have been many dire reports about the status of

the supply of future engineers in the US. Essentially, the overall supply of US-made engineers is going down in absolute numbers while the demand is going up. Further, only modest progress has been made in increasing the diversity of the engineering workforce—by and large, engineering in many areas remains largely a white, male profession.

### *Methods of K-12 Engineering Education*

We distinguish five common approaches for bringing engineering to K-12 students, which we discuss from the basis of the limited research literature that exists and our observations of many different programs.

The first two approaches involve staying out of formal K-12 classrooms. The first is to hold a variety of forms of informal programs in the summer, at weekends, or after school. The second is to hold a variety of forms of engineering competitions, the most popular of which these days are robotics competitions, such as the FIRST Lego League. These out-of-school efforts likely do well in promoting interesting in engineering. However, they are difficult to organize with equitable access because they depend upon community intellectual (experience with Engineering) and financial resources, which are rarely held or distributed equitably. Further, complete separation between engineering outreach and formal K-

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12 classroom experiences gives the impression of an irrelevance of formal mathematics and science for engineering applications, and we risk developing students with an interest in engineering but no ability to survive college engineering training.

A third approach is through formal engineering curriculum units that vary in length from one week to multiple years of coursework (such as Project Lead the Way, and the Infinity Project), followed separately from other curriculum content, or integrated with mathematics or science curricula (e.g., such as in FOSS, or STC middle school science curricula). Here there are a number of interesting tradeoffs. Longer curricular units may be harder to insert into the already packed and highly constrained curricula, but may be more likely to produce meaningful levels of changes in students. Our approach involves a compromise of focusing on 6–8 week-long units that are easier to insert into the timetable than full year curriculum units but perhaps are long enough to produce meaningful levels of change in students. This hypothesis is one that we evaluate in this current paper. Another challenge of formal engineering curriculum units is teacher professional development. Most K-12 teachers have little experience with engineering, in addition to commonly having weaknesses in science and mathematics knowledge, and thus they require significant professional development in order to successfully implement engineering curriculum material. Again there is an equity complication: the students with the greatest needs often have the teachers with the weakest knowledge and skills.

A fourth approach involves various forms of professional, faculty, or student engineer visitations into classrooms, conducting demonstrations, guest lectures, or as teaching assistants. This approach is very commonly ad hoc, based on engineers directing attention to their own children's schools, and thus raising further equity of access issues. But this approach also has more structured instances with industry, professional organizations, and university organizations. For example, the U.S. National Science Foundation's (NSF) GK-12 Program provides funds for engineering graduate students to spend 15 hours per week in K-12 classrooms for an entire year [1]. These structured programs can strive towards equitable access. However, by not focusing on teachers or the curriculum, there is relatively little residue left in the school of these classroom visitation programs once they leave the classroom. The teacher is left mostly unchanged and is not given tools to build upon this foundation or continue the work in later years.

The fifth approach of improving K-12 Engineering Education is professional development programs for K-12 teachers, be they elementary generalists, or secondary math, technology, or science specialists. These programs typically occur in a front-loaded fashion, with teachers getting most or all training prior to start of

implementation of new engineering approaches in their classrooms (e.g., in the summer or at a regional, national, or international teacher conference). Such front-loading provides little incentive or support for classroom implementation. Another feature of such programs is that they are carried out as a volunteer effort on the teacher's part, rather than mandated participation by the schools. It is known that stronger teachers are more likely to volunteer for extra professional development opportunities [2], and equality of access issues can arise, unless selection for admission into such programs explicitly addresses equity issues. A variation of the professional development approach that we explore in this paper is the NSF's Research Experience for Teachers (RET) program, in which teachers are paid to participate in engineering research and then must bring some aspect of that experience back into their classrooms. By working with teachers, the theory is that the impact of the program will be felt for years to come. However, teachers often struggle with finding good integrations between their research experiences and classroom implementation.

#### *Research experiences for teachers*

The NSF RET program is but one instance of industry, government, and university-based programs that seek to insert engineering into K-12 classrooms through providing engineering research experiences to K-12 teachers. Although we evaluate a particular NSF RET program, the issues brought up are germane to the general approach of educational change through engineering research experiences for teachers.

It is important to note that different RET programs have different goals, one of which is simply to increase public awareness of new areas of engineering research (e.g., tissue engineering or nanomaterials). However, we focus on the issue of increasing the supply of future engineers and the diversity of such engineers. Our evaluations of RET methods is from that very particular perspective; RET with other goals should not feel criticized by what is to follow.

Related to the issue of increasing the engineering supply is the issue of teacher beliefs about the nature of engineering and the levels of ability of the teacher's own students. For example, one engineering outreach program at the University of Pittsburgh targeting under-represented minority students highlighted the issue for us. This program had almost 100% success in moving students into universities, and a near 50% success rate in having students enroll in science, math, technology, or engineering majors. In short, it was a very successful program. However, it was less than 10% successful in getting students to enroll in engineering, a shockingly low number given that 88% of the students expressed a strong interest in majoring in engineering during program exit interviews. Something happening back in their K-12 classrooms was changing those interests away from engineering. A

broader study found that while 88% of K-12 teachers believe that engineering is important for understanding the world around us, only 30% of teachers feel that their students could succeed as engineers (3). RET programs could address the issue by changing teacher beliefs about engineering; we consider whether this is in fact a likely outcome of RET programs.

A number of different RET models have been proposed; these vary primarily in the extent to which engineering research or K-12 activities are emphasized. As shown in Fig. 1, many RET sites either have a strong focus on engineering research (Fig. 1A) or a strong emphasis on K-12 academic year development (Fig. 1B). In those sites with a strong research component, teachers are placed within a team and perform deep scientific research on a somewhat narrow engineering topic. The research lab experience is rigorous and demanding, and helps the teachers to build content knowledge in that particular domain. However, this experience does not change teacher beliefs that their students could engage and be successful in similar rigorous and demanding practices. In addition, since the focus of these sites is on teacher development, there is no real effort to ensure that the knowledge that teachers obtain gets translated into the classroom during the academic year activities.

In contrast, the RET sites that focus on K-12 academic year activities (Fig. 1) develop in-depth curricular materials that can be implemented in K-12 science and math curricula. In these sites, RET participants often do little hands-on research and are exposed to engineering projects through presentations or observing others doing research. This approach may give the impression that teachers are capable of developing curricular materials but only engineers are capable of solving authentic engineering problems. This 'look but don't touch' model potentially reinforces the belief that their own students cannot be successful engineers. With this RET model, participants are likely to gain a limited perspective on the field of engineering and not very likely to be able to convey to their students what engineers actually do.

A third approach to RET programs that we have developed tries to create a strong linkage between the engineering research and K-12 activities (Fig. 1C). In our case, concentrating on the process of product realization has facilitated the strong linkage. Product realization can effectively be achieved as part of actual engineering research

by a broad cross-section of teachers, and thus allows teachers to experience first-hand what engineers actually do. Product realization, as a process, is also something that can be directly incorporated into a significant chunk of the K-12 curriculum, perhaps more so than particular pieces of engineering research content. In other words, the process of product realization becomes the bridge between research and the classroom.

## THE UNIVERSITY OF PITTSBURGH PRODUCT REALIZATION RET PROGRAM

### Overview

The bulk of this paper describes our particular RET program for high school science teachers and then discusses a sequence of studies and analyses that we have conducted on this program. These documents show that our program is particularly successful in broad implementation in high needs settings, changes teacher beliefs about engineering and their students, and increases interest in a broad range of students in engineering careers.

Overall, the program has six critical components divided across an eight-week full-time summer program and a two-month academic classroom-implementation with support program:

1. Summer product realization project
2. Summer course on product realization to support the project
3. Summer design-based learning curriculum work
4. Academic year implementation of the design-based learning curriculum
5. Academic year teacher workshops and classroom visits to support curriculum implementation
6. A design competition for top student teams from each classroom.

### Summer product realization project and associate course

The purpose of the engineering component was to provide an authentic engineering design research experience that would enable teachers to do the work of engineers. Teams of 2–3 teachers were paired with a researcher in a school of engineering to further ongoing research of a product realization project. The teachers partici-

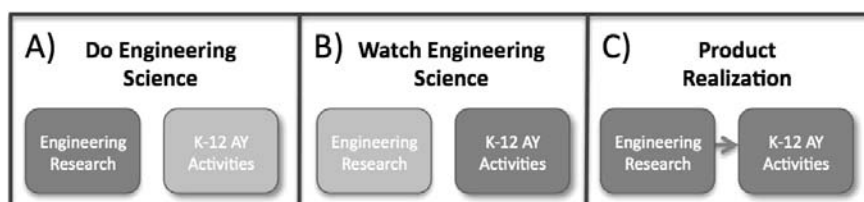


Fig. 1. Models of RET approaches to integrating research and teaching activities.

pated in weekly lectures adapted from an existing undergraduate/Master's interdisciplinary production realization course in the school of engineering. The teachers also had weekly meetings with engineering faculty advisors, collaborated with industry mentors to ensure that the goals of the project were being met, conducted experiments to test ideas, built prototypes to demonstrate proof of concept, and communicated their work with the established learning/engineering community.

#### *Summer design-based learning curriculum work*

Design-based learning (DBL) is a way of teaching content (in our case science) through a design project. A number of researchers have developed frameworks for using DBL in math and science classrooms [4–8]. We have developed a particular structure that serves as a rough template for how student teams can follow a general design process from requirements to prototype [9] on a design project of their own choosing while being forced to confront and master particular science content [10]. We have also developed successful units for biology, chemistry, and physics classrooms that our teacher can adapt to their own classrooms.

Over the same eight-week summer period, teachers in content-specific teams (e.g., two biology teachers) worked two days each week towards developing or refining a DBL unit for their classrooms that would occupy 6–8 weeks of classroom time and lead their students to innovative designs that they could present at a design competition. As a larger group, teachers participated in workshops about design-based learning in general, and particular pedagogical strategies of use to design-based learning in particular. As teams, they re-examined their own existing curriculum for important areas of weakness—central topics that are poorly learned—and built/adapted a curriculum unit to target that area of weakness.

#### *Academic year implementation and teacher workshops*

Each teacher chooses a different point in the curriculum at which to implement their units, although with the constraint that they would be completed in time to have student teams participate in the regional design competition hosted by the University of Pittsburgh for this program. The design competition was scheduled for April in the early years of the program, but was moved up to late January in later years to encourage more uniformity in timing of implementation across teachers as well as greater benefits of gains in student motivation for later learning. Over the course of implementation, teachers participated in four additional three-hour workshops (typically after school) to help address issues that arose during implementation, discuss additional pedagogical strategies not covered during the summer, and share success stories among teachers.

## STUDY 1: IMPLEMENTATION SUCCESS IN URBAN SETTINGS

### *Overview*

The goal of the first study was to document the implementation success. Were teachers able to engage in significant research projects during the summer, while also engaging in very significant curriculum design work? Did they follow through in implementing these relatively large curriculum units that involved a very significant shift in teaching style? Were a large number of diverse students impacted, or were these rich curricular units reserved for only the elite students in each setting?

### *Participants*

Over the first three years of the program, we have worked with three cohorts of teachers representing four distinct school districts in and around a medium-sized Midwestern city. The districts include a diverse range of school settings, including public and parochial schools in both urban and suburban areas. Year 1 included a group of teachers all from the same urban school district. The schools were predominantly high-needs schools as evidenced by the high percentage of students qualifying for free or reduced cost lunch. We had eight teachers: five male and three female. The teachers taught a range of subjects including, physics, chemistry, earth science, mathematics, and environmental science. Year 2 was a heterogeneous group of teachers from two different school districts, one urban and the other suburban. Again, the predominance of schools was high-needs public schools. We had eight teachers: five male and three female. The teachers taught physics, chemistry, biology and mathematics. In Year 3, we again worked with a heterogeneous group, representing four local school districts, including a public urban, a public suburban, and a parochial school system. We had seven teachers: four male and three female. The teachers taught physics, chemistry, and biology.

### *Teacher research projects*

Table 1 shows the scope of the types of projects that teachers successfully produced. Over the three years, the projects completed by the teachers have been diverse, ranging from mechanical systems for crushing large boulders to the use of nanotechnology to detect biological markers of tumors. Each project experienced a high level of success as evidenced by the industry mentors valuing the products of the teacher research. Notably, three of the products developed by the teacher teams proved particularly successful. The vagus nerve stimulator is now patented technology that is currently being manufactured and field-tested. The tumor marker detector is currently being presented at a conference and the work has been submitted to a journal. The balloon angioplasty

Table 1. Scope of engineering research projects teachers worked to solve

	Project	Project objective
Year 1	RF Powered Neural Stimulation	Produce a neurological device that will stimulate the vagus nerve to prevent refractory epileptic seizures, control depression and replace the current VNS system
	Plastic Dental Drill Bit	Design a non-metal, dissolvable drill byte for performing root canals
	Analog Airway Caliper Design	Design an instrument that could be attached to existing endoscopes to measure the narrowing of the trachea or larynx in infants
Year 2	Edible Oil Lubrication for the Aluminum Sheet Metal Stamping Industry	Produce an environmentally friendly, cost effective alternative to common petroleum oil lubricants
	Water purification System	Develop a water purification system for a third world country that filters and disinfects the water
	UHF RFID Effects on Pharmaceuticals	Create method of analyzing the effect of RFID readers on the biophysical structure of pharmaceuticals
Year 3	Boulder Crusher	Develop a more efficient method of crushing the boulders and stones as a source of income for Ugandan villagers
	Balloon Angioplasty Testing System	Design and implement an experimental testing system to study the angioplasty process
	Colorimetric Detection Platform for Tumor Markers on Nanoporous Silicon Photonic Crystals	Design and develop a Matrix metalloproteinases (MMPs) detection platform on a nanoporous silicon photonic crystal

testing system is also currently being considered for field-testing.

#### Curriculum unit success

Teachers successfully developed or adapted many 6–8 week curriculum units that fostered engineering frames of mind by having student teams design a product to meet needs in their own lives. Over the three years, curriculum units have been developed for biology, physics, chemistry, earth science, and environmental science courses (see Table 2). Two of the units were primarily developed by researchers, not teachers, as part of research to promote design-based learning of science [8, 10]. These two units were the ones most likely to be used by teachers in later years. Overall, teachers found it more difficult to develop a new unit from scratch than to adapt an existing unit. It also took a significant time to unpack and understand an existing unit.

#### Number of students impacted

Throughout the first three years of the program, teachers have implemented curriculum units in their classrooms, which resulted in providing an experience for approximately 2000 students to the engineering design process (see Table 3). All but one teacher (who could not complete the unit due to health issues) implemented the unit. Only two teachers implemented the unit with only one classroom. The remaining teachers implemented the full unit in three to five of their classes and brought students to the competition from many classrooms. The program impacted a broad range of students. The teams that won the three competitions (on a detailed rubric that involved design success and ability to integrate design and science concepts) were respectively: 1) four boys from a low-performing high school with 98% minority students, 2) a team from a mid-performing high school with two girls and one under-represented

Table 2. Types of teacher-generated, design-based curriculum units by content area

Content area	Content focus	Teacher generated curriculum units
Biology	Genetics	Designer Bacteria*
Physics	Force and Motion	Artificial Arm
	Simple Machines	Trebuchet
	Projectile Motion	Launcher
Chemistry	Properties of Matter	Heating/Cooling System*
	Energy Conservation	Soil Analysis
	Chemical Reactions	Special Effects
	Thermochemistry	Designer Paint
Environmental Science	Ecology principles	Survival Unit
Earth Science	Recycling	Pittsburgh 2006
	Soil Properties	

\* These curriculum units were adapted by RET teachers from units already developed.

Table 3. Number of students exposed to the teacher-generated design-based units and participating in the citywide design competition

Year	Number of students	Number of student teams in design competition
1	570	24
2	655	32
3	678	32

minority boy, and 3) three boys from a low-performing high school with 100% under-represented minority students. Thus, the program was able to engage a broad cross-section of students and encouraged girls and under-represented minorities to excel.

### STUDY 2: IMPACT ON TEACHER BELIEFS

#### Overview

At the end of the first three years of the program, we administered a web-based anonymous survey to teachers in the program. The goal of the survey was to understand how teacher beliefs about their students changed as a result of various aspects of the program. Teacher surveys are generally an indirect measure for assessing program impact (e.g., on teaching behavior or on student learning). But with respect to the issue of teacher beliefs, a survey is a very direct approach, and anonymity ensures candid responses.

#### Survey instrument

The survey asked about the following (before and after the program): the teachers' own understanding about engineering, their beliefs about who can succeed as an engineering major, and how many of their students could succeed as engineers. It also asked about what they had learned/gained in particular (by naming particular possible results and collecting Strongly Disagree to Strongly Agree Likert ratings for each) from the summer engineering research experience, the summer curriculum design experience, the classroom implementation process, and the design competition experience.

#### Participants

Fourteen of our RET teachers (64%) participated in the survey, a relatively high response rate for a web-based anonymous survey. The demographics (from the survey) of these participants were as follows. The teachers varied in length of teaching experience from less than 5 years to more than 10 years, although the largest plurality had taught for between 5 and 10 years. The teachers came from a range of school settings: more than a third came from schools in which fewer than 10% of students will go on to college, more than a third came from schools with approximately half going on to college, and approximately a quarter came from schools in which the majority of the students go on to college.

Interestingly, a third of the teachers had been previously employed as engineers. A very significant number of high school science teachers become teachers later in life as a second career—at our School of Education, approximately half of the science teachers in training have followed that path. Further, we found that engineering undergraduates are equally interested in teaching careers as physics or biology majors, although all at relatively low proportions [11]. Nonetheless, even in our industrial region, we had a higher proportion of teachers with engineering experience than in all the regional high school science teachers, which probably reflected some bias in the types of teachers who applied to our program. But it is also interesting that our teachers who had previously been employed as engineers were not experienced with product realization, reflecting the relative lack of design experiences in many schools of engineering and the diversity of jobs that engineers can hold. Nonetheless, we examined whether the results differ for our subset of teachers who had engineering experience. We report the data separately for these teachers in the few cases where differences arose.

#### Results

Table 4 presents the changes in beliefs from before to after the RET program with regard to an understanding of engineering, along with the effect size and the statistical significance of paired t-tests that were conducted on before and after ratings. The items in the table are ordered from

Table 4. Mean teacher ratings regarding beliefs before and after participation in RET program, along with pre-post effect size (Cohen's D) and statistical significance level of pre-post differences

Understanding of engineering questions	Before mean	After mean	Effect size	p value
I did not know the engineering design process	3.1	1.6	1.4	0.01
I didn't think that engineering could be used to teach science	3.0	1.8	1.1	0.01
I was not aware of what engineers did.	2.0	1.4	0.8	0.05
I believed that engineering is a difficult discipline	3.9	3.2	0.7	0.05
I didn't think I could do engineering design.	2.5	1.8	0.7	0.05
I believed that only a few of my students could succeed as engineers	3.4	3.1	0.3	n.s.
I believed that engineering is an important career	4.6	4.4	0.2	n.s.
I believed that engineering has a large impact on my daily life	4.3	4.5	0.2	n.s.

largest to smallest effect sizes. Note that the wording of the questions reflects the 'before' phrasing—the tense of the question was changed for the 'after' ratings.

We see large changes in several different, independent factors. The largest changes reflected the development of a better understanding of engineering design and what engineers do (the common element underlying the research and the curriculum work) and the use of engineering to teach science (a focus of the curriculum work). Interestingly, there were also broader impacts, such as changing beliefs about engineering as difficult or the teachers' own ability to do design work. The teachers were basically already at the ceiling on believing that engineering is important and has an impact on daily life. The lack of an effect on beliefs about students being able to succeed as engineers is troubling, but this may reflect an unwillingness to support the negative statement about their students in the 'before' state. Also note that our teachers with prior experience in engineering tended to report higher levels of prior awareness about engineering, but were otherwise similar to the other teachers.

Another question asked about beliefs about student engineering performance in greater depth. Overall there were only minor changes from before to after program participation. In general, the majority of teachers (64% before and 71% after) thought that all of their students could do engineering design. A significant percentage of teachers (21% before and 36% after) thought motivation to learn was an important precursor. There was a small shift reflecting a couple of teachers who initially thought that math/science or creativity would be a bottleneck but who then changed to thinking that motivation was the bottleneck.

Although there was little change in beliefs about the necessary factors underlying the students' ability to do engineering, there was a significant change in teacher belief about how many of their students could succeed as engineers. Before the program, only 21% of teachers thought that most of their students could succeed as engineers; after the program, this number rose to 50%,  $t(13) = 2.28$ ,  $p < 0.04$ . Interestingly, the teachers with prior experience as engineers were significantly less likely to think that many or most of their students could succeed as engineers (Fischer Exact,  $p < 0.005$  before and  $p < 0.03$  after), although even they showed some pre to post change.

Part of the survey especially targeted the process of implementing design-based learning in the classroom and, in particular, how the teachers' beliefs about their students might have changed. It was our expectation that actually observing in-class engagement would be a powerful means of changing teacher views of their students' potential achievement. Table 5 lists the percentage of teachers reporting belief changes on various aspects of their students as a result of classroom

Table 5. Percentage of teachers reporting that beliefs about students changed as a result of implementing the design-based curriculum

Beliefs about students that changed	% of teachers
Do engineering design?	9%
Be motivated to learn science?	79
Be interested in engineering design?	79
Reason scientifically?	71
Think deeply about scientific concepts?	64

implementation (listing only the belief changes reported by a majority of teachers). Most teachers reported changing perceptions of their students in these five different dimensions. The change was observed both with respect to performance capabilities and engagement. The dimensions showing the least change were processes related to science. From our classroom observations, we did observe that some teachers struggled to focus their students on scientific concepts in the move to design-based learning.

Table 6 lists the perceived benefits of participating in the engineering design research and curriculum development process. It includes only those benefits with mean ratings between Agree and Strongly agree (i.e., only strongly endorsed items). The order is from more strongly endorsed to less strongly endorsed, although there was actually little variation (means ranged from 4.1 to 4.5). We see that teachers generally saw many benefits from both experiences. It was especially interesting in that the most strongly endorsed benefit of the summer research experience was becoming a better teacher overall (rather than just a better designer).

Although the teachers with prior experience in engineering did not differ significantly in the benefits they reported deriving from the program, additional comments they made shed light on how they viewed the value added by this program relative to their prior engineering experiences. One participant was particularly articulate on this point:

The RET experience was very beneficial to me in my growth as a teacher. I had worked as an engineer for 8 years and thought of that experience as being isolated from my teaching career. I can see more clearly now how my training and experience in that field can help my students learn science more effectively. The designing of the curriculum really made me think about how students learn and how to help them discover, construct, and apply difficult scientific concepts. The implementation of the unit itself was enjoyed by the entire class and really engaged the students in their learning.

#### Summary

The teacher survey found a number of changes in teacher beliefs about their students' ability to engage in engineering and under what circumstances. The survey also showed that both the

Table 6. Commonly endorsed benefits by teachers participating in the summer engineering design research and curriculum development process

Engineering design research	Curriculum development
Become a better teacher	Know what is design-based learning
Become more aware of what engineers do	Incorporate design-based learning in my science classroom
Realize that I am capable of doing engineering design	Create a classroom environment that promotes innovative scientific discovery and learning
Realize that students need to think in these kinds of ways in my science classroom	Develop a curricula that incorporates engineering design principles
Realize that understanding more about engineering design can help	Realize the benefits of engineering design principles for teaching science
Think differently about the kinds of thinking that promotes learning (in general)	Realize the benefits of engineering design principles for getting students to do higher order thinking
Better understand how science, technology, engineering and mathematics concepts can be applied to solve real-world problems	Translate my own design experience into my classroom practice
Think differently about how I will teach science	Think differently about the kinds of thinking that promotes learning
Realize that my students would be interested in learning about the engineering design process	
Think differently about my students' ability to do engineering design.	

engineering design experience and the curriculum work produced changes in their own thinking.

### STUDY 3: IMPACT ON STUDENT BELIEFS + INTEREST IN ENGINEERING

#### Overview

The ultimate goal of our program has been to increase the number of candidates coming into the pipeline to train to become engineers. This goal requires some patience in tracking students. Here we studied self-reported interest in an engineering career, one step out of many along the career trajectory. Because we are trying to maximize the number of students that we affected, a random assignment of students to our program was not feasible. Instead, we compared the students participating in our program with other students at the same high schools and taking the same subjects, but who had a different teacher. We collected a range of demographic data on each student to reduce the possibility of systematic biases in which students participated in experiment and control as well as to assess the relative impact of our program on different demographic groups. Note that surveys are useful for finding out about beliefs and career intentions. However, surveys administered to high school students in urban settings with full anonymity are likely to be subject to problems with students taking the task seriously. Therefore, the obtained effects are likely to be an underestimate of the true effects. Thus, it will be useful to compare the observed effects of implementation against the observed effects of background variables generally known to influence participation in engineering careers (e.g., gender and ethnicity).

#### Participants

Some 455 high school students from our year three cohort of teacher (physics, chemistry, and biology) were given an anonymous paper-based survey in class in approximately the middle of the school year. Each RET teacher recruited a peer teacher from their school to participate in the study. This resulted in 262 students from similar classrooms but who did not implement design-based learning units in their science classrooms.

#### Survey instrument

For demographic data, the survey focused on variables that were previously related to interest in an engineering career: ethnicity, gender, and a parent with an engineering career. The survey asked about an interest in going to college, studying engineering in college, becoming an engineer, participating in after-school engineering programs, and taking more science courses with design-based learning (using a 1 to 5 Likert rating ranging from Strongly Disagree to Strongly Agree). The survey also examined possible factors underlying increasing interest in engineering careers, such as beliefs about what engineers do (solve problems, work in teams, design solutions, experiment to see how things work, fix things, and understand math and science).

#### Results

To assess the impact of program participation on interest in becoming an engineer, we conducted an analysis of variance on self-rated interest with DBL implementation, gender, minority status, parent as an engineer, and all two way-interactions among those variables as predictors. The main effect of implementation was statistically significant, although relatively small (see Table 7). To



Table 7. Mean student ratings for participating and control teachers along with participating vs. control effect size (Cohen's D) and statistical significance level of participating versus control differences from the ANOVA

Likert rating question (1 = Strongly Disagree, 5 = Strongly Agree)	RET mean	Control mean	Effect size	p value
Interest in becoming an engineer	2.46	2.28	0.15	0.03
Interest in after-school or summer engineering programs	2.34	2.07	0.25	0.01
Engineers understand how to solve people's problems	3.46	3.01	0.45	0.0001
Engineers design solutions to everyday problems	3.86	3.57	0.33	0.0002
Engineers experiment to see how things work	3.94	3.76	0.22	0.005

further contextualize the effect size of implementation, the effect is approximately a third the size of the gender effect, 40% the size of the effect of having a parent engineer, and half the size of the minority effect on interest in engineering careers.

There were no statistically significant interactions between implementation and gender, minority status, or parent being engineer, indicating that implementing the design-based learning units was approximately equally effective on engineering career unit across those student groups.

Another way of examining the effects of implementation on engineer career interest is to focus specifically on the highest levels of interest. The mean levels of engineering career interest in this urban context are low—perhaps it is only changes at the high end of career interest that are relevant to the engineering pipeline. In fact, implementation almost doubled the proportion of students giving the highest ratings of interest in becoming an engineer (6.7% vs. 3.7%).

A similar ANOVA was conducted on interest in after-school or summer engineering programs, which presumably would be useful for sustaining or perhaps further building engineering career interest. There was a significant but small effect of implementation (see Table 7), and no interactions with minority status, gender, or having a parent engineer. However, the effect of implementation was similar in size to the effect of those background factors on this variable.

All of these analyses were repeated again, separating the teachers who had previously had experiences as engineers prior to our program. Although the numbers in each subgroup became smaller, we wanted to make sure that our results were not driven by those few teachers with previously existing engineering experiences. In fact, the effects were identical across subgroups of teachers, thus we need not worry about generalizability to the larger populace of science teachers with no prior engineering experience.

To further understand why implementation influenced career goals, similar ANOVAs were conducted on beliefs about engineers. There were three beliefs about engineers that showed a large effect from the implementation (see Table 7). First, implementers were noticeably more likely to think that engineers understand how to solve people's problems. Second, implementers were more likely to think that engineers design solutions to every-

day problems. Third, implementers were more likely to agree that engineers experiment to see how things work.

A mediation analysis was conducted to see whether these changes in beliefs about engineering might have caused the changes in career goals. Of the three beliefs that changed with implementation, only two were significantly correlated with interest in being an engineer: Engineers understand how to solve people's problems ( $r = 0.20$ ) and Engineers design solutions to everyday problems ( $r = 0.15$ ). Including either of these variables in ANCOVAs with implementation predicting interest in being an engineer (with or without other background variables) entirely removes the effect of implementation. Therefore, it is likely that implementation influenced career goals because it made more salient the relevance of engineering to solving everyday problems.

## CONCLUDING REMARKS

We argue that we no longer have the luxury to hand pick engineers. Every student must be seen as a prospective engineer. In looking ahead to the scientific and technological work-force needs of the next century, the Mathematical Sciences Education Board [12] of the National Research Council has noted that we must draw substantially greater numbers of participants from traditionally underrepresented groups. If we are to flood the market with increasing and more diverse groups of capable young people who are innovative problem solvers, successful in science, engineering, and engineering technology, we must expose a larger number of students to career options in engineering.

Our RET program has successfully provided rigorous engineering design research (product realization) and curriculum development experience for teachers such that they take back to the classroom real world innovative design experiences and a curriculum that promotes engineering awareness, engineering career interest, and increased student achievement. Over the last 3 years, this program has exposed approximately 2000 mainstream and honors students from urban high schools to deliberate, well thought-out opportunities to do the work of engineers (connecting design and science) in their classroom,

in conjunction with their normal curriculum. The design-projects typically require 6–8 weeks of curriculum time in core high school science classrooms (introductory biology, chemistry, and physics), and the curriculum covers core science concepts in a just-in-time fashion throughout the design projects. Learning about design and engineering is an intended outcome of this curricular approach, in addition to helping students learn fundamental science principles, improving students ability to reason like scientists, and helping students learn the skills to conduct authentic scientific inquiry.

This program is successful in three different dimensions. First, it is successful in having a high implementation rate among participating teachers. Second, it is successful in changing teacher knowledge and beliefs about what engineers do and whether the majority of their students are capable of being engineers. Finally, it is successful in increasing student interest in engineering careers.

We note a number of caveats in our arguments and current evidence. First, our program is quite rich, and we do not know for sure whether simpler programs might have also produced equally large effects on students. However, the teacher survey data suggests that each element of the program contributed different benefits to their teaching. However, we do not know whether the changes in teacher beliefs were important in influencing students, or whether the DBL curriculum units could have produced those student effects on their own. More data will be needed to properly assess the relationship between teacher beliefs and student beliefs. However, at the very least teacher beliefs about DBL and student performance will influence whether or not they continue to use (and perhaps expand) DBL in their classrooms, and thus the importance of teacher beliefs on student careers might also be indirect.

A second caveat is that we did not collect teacher belief data before program implementation and the survey responses about the ‘before’ beliefs may be subject to considerable memory flaws. Further,

surveys are subject to halo effects: teachers and students might have been generally positive about the program and thus reported more positive effects of the program than were actually experienced. Thus, it is the relative effect sizes on different variables that is more informative here.

A third caveat is that we did not have random-assignment controls for our student survey for which students took part in the program and which students did not. Thus, it is possible that other variables associated with the teachers or the students could have been responsible for the observed differences. However, such third variable explanations would have trouble explaining the rather sensible patterns in the survey data regarding which belief variables were associated with implementation effects.

Finally, the effects of our program were equally large across various demographic variables, which we view as an important success. However, even better would have been an intervention that began to overcome the exclusionary influences of gender, minority status, and parental background.

There are likely many particular features of design-based learning that may influence student interest in engineering (e.g., how much freedom is allowed in project choice, whether projects are related to commercial or social value, whether projects are successful, how teamwork is handled, etc). Similarly, teachers varied in the degree of success they experienced in their summer research experiences. We do know whether more engineering success leads to greater belief changes. Further, teachers varied in the extent to which they explicitly discussed their engineering research experiences with their students; we do not know whether these discussions are of value to students. Future work should examine these variables to better understand how to further optimize the effects of RET programs on the size and diversity of the engineering pipeline.

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