AC 2008-2304: LESSONS LEARNED FROM A PRODUCT REALIZATION RET SITE: MAXIMIZING SUCCESS FOR TEACHER RESEARCH AND HIGH SCHOOL STUDENT IMPACT

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Abstract

Recent trends suggest a degradation of our nation's technological competitiveness and the significant decline in the number of K-12 students interested in STEM subjects-- science, technology, engineering, and mathematics fields. Educators of our next generation of technical leaders, particularly those at the pre-college level, are the critical links for overcoming these challenges. However, classroom teachers of science tend to have instructional strategies that are not authentic to the work of engineers and scientists and have. Research Experiences for Teachers (RET) are programs focused on facilitating a solution to this problem. The intended goal is to bring knowledge of engineering and technological innovation to the pre-college classrooms by engaging teachers in research experiences that can be "taken back" to the classroom. That is easier said then done. Most RET programs tend to be effective at one objective or the other, that is to say either providing a framework that engages teachers in authentic research experiences or providing classroom experiences that promote engineering awareness. Our RET site is unique in that we have designed our program such that we are able to realize both objectives utilizing engineering design via the process of product realization as the basis of the research teacher conduct. By bringing together two highly recognized departments in fields of product realization and learning sciences we have create opportunities that provide rigorous engineering design research and curriculum development experience for teachers. The outcome has been that teachers take back to the classroom real world innovative design experiences and a curriculum that promotes awareness, interest and increased student achievement.

Background

In 2001, the principal investigator of our RET site began a program to promote diversity within the field of engineering and feed underrepresented minority students into our undergraduate university engineering program. The program, which we will refer to as the Engineering Career Access Program (ECAP), was successful at increasing college enrollment for the students who participated in the program, however, those students rarely enrolled in engineering programs. Table 1 shows how from 2001-2004 almost all of the ECAP participants entered college, but less only 10% of the students enrolled in engineering fields. These numbers were very surprising, because 88% of the students exiting the program expressed a strong interest in majoring in engineering during exit interviews. Further study into this trend suggested that teacher expectations about engineering might be influencing the low enrollment rates. A broader study finding suggested 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.[1] As the college-bound ECAP students went back to school, it is likely that their high school teachers steered them away from engineering majors because many of those teachers did not understand what it meant to be an engineer or did not believe that their students could do the work of engineers. As a result, the principal investigator became interested in hosting an RET program as a vehicle to address this problem by supplementing ECAP. The purpose of the RET program would be to provide high school teachers with authentic engineering experiences that they could take back to their classrooms and further promote awareness of engineering careers with their students. This would create a pool of students who had a heightened awareness of authentic engineering practice and were potential candidates for ECAP. Since starting our RET site with local public school districts in 2005, we have seen a significant increase (25% entering engineering) on the ECAP program; many of our teachers are sharing their engineering knowledge and implementing design-based engineering curricula that reinforces what the students learn during the summer (see the last two columns of Table 1).

Table 1: Engineering Career Access Program (ECAP) statistics before and after onset of current RET site.

	Pre- RET				Post- RET	
	2001	2002	2003	2004	2005	2006
% ECAP-Grads Enrolling in College	100	98	100	98	100	100
% ECAP-Grads Enrolling in STEM Major	41	47	44	58	63	45
% ECAP-Grads Enrolling in Engr Major	7	8	15	13	21	29
% ECAP-Grads Enrolling in Engr Major at the RET Host University	5	6	7	5	12	8

So, what would a program need to look like in order to respond to the challenges of teacher expectations, and student engagement? It's been said that we never really grow up, so might it be possible that in order to change teacher expectations about whether their students could do engineering, the "student in themselves" needed to know that they could do engineering. If you put teachers in a situation where they were successful at engineering might they be more inclined to think that their students could do it too? And if students are socialized to believe that they have what it takes to do the work of engineers, and get the opportunity to do just that, might that influence their desire to explore careers in engineering?

A number of different RET models have been proposed to achieve this goal. As shown in the graphic below, many RET sites either have a strong focus on engineering research (Figure 1a) or a strong emphasis on K-12 academic year development (Figure 1b). In those sites with a strong research component, teachers are typically placed within a team and performed deep scientific research on a somewhat narrow engineering topic. The value of such an experience for the teacher's professional development is obvious, as 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 not a real effort to ensure that the knowledge teachers obtain is translated into classroom activities during the academic year. In contrast, the RET sites that focus on K-12 classroom activities develop in-depth curricular materials that can be implemented in K-12 science and math curriculum. In these sites, RET participants often do little hands-on research and are exposed to engineering projects through presentations or the observation of others performing 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 only reinforces the belief, “if I can’t do this, my students sure can’t.” With this RET model, participants are likely to gain a limited perspective on authentic engineering practices and less likely to able to convey to their students what engineers actually do.

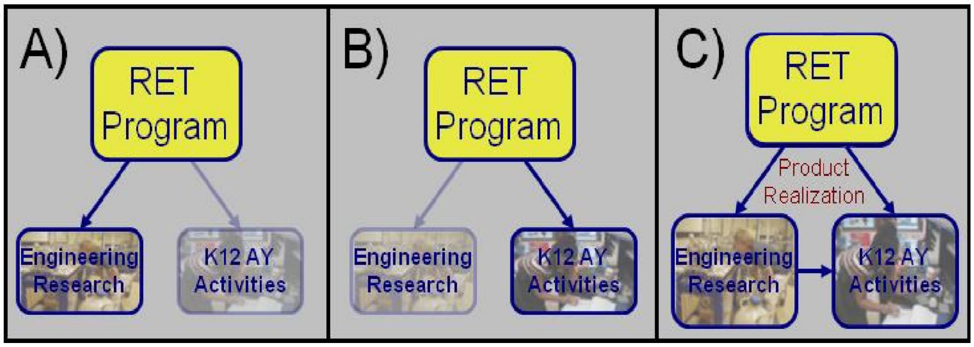

Figure 1: Models of RET sites

We believe that our RET site has been successful because we have focused on directly linking the teachers’ summer engineering research experience with their K-12 academic year activities (Figure 1c). This strong linkage is facilitated by our concentration on the process of product realization, which provides a framework that enables teachers to *do* the work of engineers: solving rigorous, meaningful, and real world problems. Product realization as the basis of the engineering research is critical to teachers being successful doing the work of engineers. This work then gets translated into classroom activities were teachers *do* the work of curriculum designers to embed the engineering principles into a rigorous science learning experiences that align with state standards and supported with effective pedagogical strategies.

Program Design

The 8-week summer RET program was comprised of an engineering component and a learning science component. Participants spent 4 days per week in the engineering product design labs and 2 half-days per week in a learning science seminar on curriculum design. During the academic year participants attended 5 additional workshops, distributed throughout the implementation of their curriculum units. The culminating experience for the teachers and their students was a citywide innovative design competition. The RET program was designed to align the work in the research experiences in the engineering component with the curriculum design activities in the learning science component such that practices, routines, terminology, and methodology were transparent in both components.

We connect the engineering experience to the daily work of the teachers (i.e., teaching and learning) by having them to translate the summer research experiences into design-based learning[2] curricular materials. These curriculum materials engage students in much of the same learning processes that they themselves experienced. Particular aspects that we explicitly connect between their research experience and their curriculum units include understanding that:

- Everyday problems are needs that people have in their lives that are worth solving;
- There are multiple solutions for any problem that must be considered;
- The solution to the problem can be thought of as a system;
- Defining the system requirements helps to guide the process and understanding of when success has been achieved;
- The system can be divided into more manageable entities (subsystems);
- Each subsystem performs one function/goal;
- Scientific principles and technology are necessary to achieve that goal/function;
- Testing ideas facilitates understanding of the relevant underlying science concepts, and
- Documenting and communicating ideas are essential to learning.
- The process of design is iterative---revision is an instrumental part of the process

Engineering Research Component

Product realization as the basis of the engineering research is critical to teachers' successfully doing authentic work of engineers. 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. Interdisciplinary teams of 2-3 teachers were assigned to a researcher in a school of engineering to further ongoing research of a product realization project. The teachers participated in weekly lectures and demonstrations, met with engineering faculty advisors weekly, collaborated with industry mentors to ensure 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.

Our program scaffolds teachers to do the work of engineers having them consider the diverse aspects of the product realization process which include: 1) defining user requirements, 2) concept generation and selection, 3) the creation of a computer based design and analysis models, 4) benchmarking designs with existing products, 4) rapid prototyping and reverse engineering techniques, and 5) the development of a functional prototype. Teachers are given funding to take a product from concept to functional prototype.

Why does this way of working make the work of engineers attainable for teachers? It is a logical way of thinking about problem solving that laypersons can replicate. Each phase provides checkpoints and milestones to create a clear schedule and insure good results; a clear process which defines team member roles, contributions, and whom to interact with. Benchmarking provides external perspective on how to improve products. Additionally, weekly team presentations allow course instructors to formatively assess the understandings and abilities of the teacher groups to enable assisting their performance if needed. At the same time, the presentations present teachers with a forum for collaboratively providing each other with specific and constructive feedback. This establishes a community of learners where teams can take advantage of the knowledge and expertise of the other teachers in the program. The weekly presentation also insures accountability to a timeline so that teams stay on track due to the limited timeframe in which they must operate (8 weeks). Time is structured during the program but it is not rigid. Teachers have a lot of freedom and manage their time similarly to professional engineers.

Learning Science Component

Design-based learning as the basis for curriculum design is critical to teachers' successfully translating the work of engineers into the science classroom. Teams of teachers were re-organized by their content areas, attended weekly professional development, met with content advisors, conducted experiments to test content ideas, wrote and revised curriculum units, and communicated their work with the established learning community.

The ways of thinking and skills (habits of mind) required to engage in the engineering design processes are different from the thinking and ways of working in most high school classrooms. Therefore, teachers were scaffolded to develop curriculum to implement in their classrooms that mirrored much of the engineering design process that they experienced over the summer. The training deliberately connected to the frameworks of education systems (standards, high-stakes assessment, realities of public, urban classroom infrastructures) to promote a deepening of STEM concepts to enhance the ability of teachers to apply these concepts to real world applications.

Participants

Over the 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-reduced lunch. We had 8 teachers, 5 male and 3 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 8 teachers, 5 male, 3 female. The teachers taught physics, chemistry, biology and mathematics. In Year 3, we again worked with a heterogeneous group, representing five local school districts, including public urban, public suburban, and a parochial school system. We had 7 teachers, 4 male and 3 female. The teachers taught physics, chemistry, and biology.

Results and Discussion

Engineering Research Projects

An important aspect of the program was to engage teachers in rigorous, meaningful research experiences. Table 2 shows the variety of problems teachers successfully worked to solve over the summer. 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.

Table 2: Scope of Engineering Research Projects Teachers Worked to Solve

	Project	Project Objective	Project Success
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	3
	Plastic Dental Drill Bit	Design a non-metal, dissolvable drill byte for performing root canals	2
	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	1
Year 2	Edible Oil Lubrication for the Aluminum Sheet Metal Stamping Industry	Produce an environmentally friendly, cost effective alternative to common petroleum oil lubricants	2
	Water purification System	Develop a water purification system for a third world country that filters and disinfects the water	1
	UHF RFID Affects On Pharmaceuticals	Create method of analyzing the affect of RFID readers on the biophysical structure of pharmaceuticals	2
Year 3	Boulder Crusher	Develop a more efficient method of crushing the boulders and stones as a source of income for Ugandan villagers	1

Project	Project Objective	Project Success
Balloon Angioplasty Testing System	Design and implement an experimental testing system to study the angioplasty process	3
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	3

Teacher engagement has been high and teachers were motivated to solve the problems. Every project that has been assigned over the past 3 years have culminated in a finished product and poster which are both presented at the final design symposium at the end of the summer. Industry mentors valued the products of the teacher researchers. Table 2 highlights the success of the projects over the three years of the program, while all projects were successful, 66% of the projects experienced high levels of success as measured by how the project would be evaluated if done by undergrad engineering students. Notably, three of the products developed by the teacher teams proved particularly successful and were beyond the researcher's expectations. 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 was submitted to a journal. The balloon angioplasty testing system is also currently being considered for field-testing.

The projects were evaluated by a faculty member/dean who also taught the undergraduate product realization course. The scale used to measure "success" was defined according to how an engineering student in the 3rd year of their program would be evaluated.

3 -beyond the researcher expectation,

2- better progress than an undergrad engineering student,

1- similar progress to undergrad engineer students

Many factors contribute the success of teachers., including distributed professional development throughout the implementation. However, the scope of the projects may influence teacher beliefs about their ability to do engineering design. Teachers self-report that they could not be successful because the problem seemed too large, as in the case of the water purity group in Year 2; "How are we expected to solve a problem that others have been trying to solve for so many years." This may have influenced how teachers thought about what their students could do as evidenced by the amount of "telling" teachers felt they needed to do in the curriculum units. The units they developed heavily fore-grounded the content that teachers felt students needed to know in order to solve their problem. This limited the kind of discovery that was able to happen in the classroom.

Design-Based Curriculum Units

Teachers successfully developed 6-8 week long curriculum units that fostered engineering habits of mind by having student teams design a product to meet a need in their own life. The units were strategically designed around core science ideas that were a part of the teacher's normal curriculum. Over the three years, curriculum units have been developed for biology, physics, chemistry, earth science, and environmental science courses. Some of the units that teachers produced included a physics unit relying on principles of simple machines to design an artificial arm an environmental unit relying on ecology concepts (biotic, abiotic, climate, etc) principles to design a water purification system, concepts of force and motion to design a rocket.

Table 3: Types of teacher-generated, design-based curriculum units by content area

Content Area	Content Focus	Teacher Generated Curriculum Units
Biology	Genetics	Designer Bacteria*
	Cell Theory	
Physics	Force and Motion	Artificial Arm
	Simple Machines	Trebuchet
	Projectile Motion	Launcher
Chemistry	PH	Heating/Cooling System*
	Properties of Matter	Soil Analysis
	Energy Conservation	Special Effects
	Chemical Reactions	Designer Paint
	Thermo-chemistry	
Environmental Science	Systems Analysis	Survival Unit
	Water Properties	
	Purification Techniques	
	Ecology principles	
Earth Science	Recycling	Pittsburgh 2006
	Soil Properties	

** Learning researchers and RET teachers designed these curriculum units.*

Design-based learning is a particular form of project-based learning, which in turn is a form of active learning. In design-based learning, the activity that is meant to drive learning is a design-project: students are required to use and extend their knowledge of science and math to develop a technological solution to a problem using available resources. Engaging students in engineering design-based learning activities within a science classroom can help students develop problem solving skills and science inquiry skills (Kolodner et al, 2003; Silk, Schunn, & Strand, 2007). However, the practices associated with DBL are very different from typical science classroom practice. Therefore it was necessary to scaffold teachers ability to design quality DBL units. Over the course of our three years, 3 curriculum framework approaches have been utilized that emphasized design and science in varying degrees. In Year 1, a general engineering design model was employed with an organizational structure that utilized the PISCOE method. In year 2, teachers were given the same general engineering design steps and were tasked with incorporating them into a coherent, content rich curriculum. In Year 3, teachers were given field tested DBL units (chemistry, biology and physics), designed by researchers, which where rich in content, pedagogy, and aligned with a slightly modified engineering design model previously used. Teams had to revise and improve the unit, based on data from pre/post test results.

Student Impact

Teachers have implemented curriculum units in their classrooms exposing approximately 2000 students to the engineering design process (see Table 4). As a culminating experience after each year's implementation, student teams, representing the most innovative designs, participated in a citywide design competition. The teams effectively communicated both the innovativeness of their designs and the underlying science that formed the basis for their design choices. The Year 3 student teams will compete later this year.

Table 4: Number of students exposed 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	36*

** This is a projected number, as Year 3 student teams will compete later this year.*

Following Year 3 implementation, we surveyed 455 students who had implemented design-based learning curricula in their physics, chemistry, or biology classrooms. We compared those students to 262 peers (in the same school) who did not implement design-based learning units in their science classrooms in terms of engineering interest and awareness. The results indicate statistical significance along four dimensions; students involved in design-based learning experiences were more likely than non-implementers to agree with the following four important dimensions:

1) I know what engineering is
2) I want to be an engineer
3) I would like to take classes that let me design products that solve problems and
4) I would like to participate in after-school or summer engineering technology experiences.

These dimensions are important because they directly relate to the reasons students often cite for not going into engineering. Teachers reported an enthusiasm that they had not seen with many of their students. One teacher reported that she had a group of students that came to class consistently during the implementation of the design unit, but that when she finished the unit the students stop attending class.

Lessons Learned and Conclusion

Our RET has proven successful because it connects an authentic research engineering design experience with a rich curriculum development that promotes increase awareness, interest and student achievement.

Each team experienced a high levels of success with their engineering product and curriculum designs during the 8 weeks RET program. This indicates that the teacher could do quality engineering research in design from understanding the needs of the client to producing a proof of concept prototype. They were also able to successfully translate that experience into a curricula that engages students in the same authentic engineering practices. This resulted in students expressing increased awareness and interest in science.

Over the three years, teachers have generated or revised numerous DBL units in chemistry, biology, earth science, physics and environmental science. Whether teacher generated units using a template, or created units from scratch, or modified researcher generated units, all implemented the units with students. During classroom observation, it was realized that students were motivated to produce products based on their own needs just like engineers and were able to use the engineering design steps to do the work of engineers. In addition, during the culminating design competition, students successfully communicated the ideas of their design and the underlying science.

The systems design-based approach to the unit utilizes many of the same strategies that teachers used to design solutions for the problems they were solving over the summer. Students articulate their own needs for an alarm system and develop requirements, which become design specifications that guide their design process. This approach differs from other project-based learning units because the design and its specifications are students generate rather than teacher or curriculum proposed. This is similar to what teachers do (in collaboration with their client) over the summer. In this way, the design process that the teachers did throughout the summer, were translated into activities enacted with students during the academic year.

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