Connecting Research and Teaching Through Product Innovation: Quality of Life Technology RET Site

Ms. Mary R Goldberg, University of Pittsburgh

Mary Goldberg, M.Ed. received her bachelor's degree in Psychology and Spanish and a Master's of Education in Administrative and Policy Studies from the University of Pittsburgh. She has been the Lead Education and Outreach Coordinator at the Department of Rehabilitation Science and Technology and Human Engineering Research Laboratories since 2007, where she has served as co-PI on four training programs in the field of assistive technology for undergraduates, veterans, and graduate students. She is dually involved with the Research Experience for Undergraduates and Teachers programs, in addition to other education initiatives at the Quality of Life Technology Center, all funded by National Science Foundation. Ms. Goldberg is pursuing her Ph.D. in Administrative and Policy Studies of Education at the University of Pittsburgh.

Dr. Jon Pearlman
Dr. Christian D Schunn, University of Pittsburgh

Dr. Christian D. Schunn is a professor of Psychology, Intelligent Systems, and Learning Sciences and Policy at the University of Pittsburgh. He is also a senior scientist at the Learning Research and Development Center. He received his Ph.D. in Psychology from Carnegie Mellon in 1995. His basic research involves cognitive/social psychology studies of science and engineering problem solving and creativity. His educational research and design work focuses on K-12 urban education in writing, science, technology, engineering, and mathematics—both in isolation and in various combinations.

Birdy Reynolds, University of Pittsburgh
Ms. Shelly Renee Brown MEd, The Quality of Life Technology Engineering Research Center; University of Pittsburgh

Shelly Brown, M.Ed. is an education and outreach coordinator for the QoLT Center at the Human Engineering Research Laboratories and the University of Pittsburgh Department of Rehabilitation Science and Technology. Ms. Brown is responsible for all K-12 outreach projects and initiatives including LEGO robotics programs, job shadowing experiences, and high school internships.

Ms. Brown also works with the continuing education department to coordinate the State of the Science Symposia Series, quarterly workshops that highlight technological developments within the rehabilitation community. The symposia are held at Walter Reed National Military Medical Center in Bethesda, Maryland.

Ms. Brown obtained her BS and MEd in elementary education from Duquesne University and is passionate about connecting minority youth, particularly girls with cool science, technology, engineering, and math experiences. Ms. Brown is currently a doctoral student at Duquesne University, pursuing a degree in educational leadership. She is a retired Pittsburgh Police officer and an active member of the Pennsylvania Coalition Against Domestic Violence/ Women of Color Caucus, an advocacy organization for women and families experiencing domestic violence.

Ms. Brown is a proud wife, mother of four children, and grandmother of one.

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The purpose of this paper is to introduce an innovative model for the NSF Research Experience for Teachers (RET) program named "Connecting Research and Teaching Through Product Innovation: Quality of Life Technology RET Site" at the Department of Rehabilitation Science and Technology at the University of Pittsburgh. This RET has a Quality of Life Technology (QoLT) engineering research theme and emphasizes math using product development economics applications. Teachers are involved for a full year where they incorporate research and academic year teaching via a common product innovation and experiential learning focus. The multidisciplinary approach and multi-step program includes key partnership between the design and fabrication capabilities at the Human Engineering Research Laboratories (HERL), the curriculum development expertise from the Learning Research and Development Center (LRDC), and the innovative research and product ideas from the QoLT Engineering Research Center (ERC).

This model deepens participants' understanding of engineering by involving interdisciplinary pairs, comprised of a science and math or economics teacher from the same school, to refine and/or develop curricular units that integrate high quality mathematics instruction, the language of engineering, science and technology, and engineering methodology to promote the development of 21st century skills. We strategically target big ideas in mathematics and science by supporting the growing recognition that the silo approach to teaching science and mathematics and the general absence of engineering and technology in K-12 are contributing to an inadequate educational system.

Our multidisciplinary and multi-step approach is motivated by the emerging policy interest in instruction that better integrates science learning across years[1], includes modern workplace skills[2] and more exposure to engineering[3]. Math as rote procedures can be a barrier to conceptual understanding in science. But math is the language of science and it explains critical conceptual components of scientific ideas (e.g., the differences between constraints on area vs. constraints on volume, differences between linear and exponential growth). Studies have found that math can serve as a thinking tool for making conceptual analysis of complex scientific situations more approachable for students[4, 5] by focusing attention on more conceptually relevant features[6]. Currently, a very large proportion of US students are ill prepared in math overall and certainly ill-prepared to simply use existing math skill to support science learning. Fifteen-year-olds in the U.S. ranked 25th among peers from 34 countries on an international math test and scored in the middle in science and reading, while China topped the charts, raising concern that the U.S. is not prepared to succeed in the global economy[7]. A similar situation exists with respect to engineering and math: math is a fundamental component of engineering concepts and processes, but most students are not well positioned to use existing skills in K-12 engineering contexts.

Unfortunately, the poor ranking is in part due to current high school science classrooms that suffer from many problems: 1) state standards typically require many different topics to be reviewed in a time-frame that is unrealistic; 2) students do not appreciate why the material is relevant to everyday life or their future careers; 3) many teachers do not fully understand the content they are teaching; and 4) many teachers have weak pedagogical skills. To change this situation, we must have teachers do more than create a few lectures/demos based on their summer research experiences and we must provide a large amount of support for teachers to help them create powerful learning experiences in their classrooms. Rather than simple lectures or demos, our curricular approach is 6-to-8-week-long DBL experiences that can be implemented at the beginning of high school.

Additionally, unlike most RET programs, we incorporate math teachers and add concepts of innovation economics (e.g. technical models, product forecasting, break-even points) as additional practical outlets for math and science. We added these concepts to both diversify the types of practical application the teachers and students would be working on as well as make the 'product innovation' theme of our RET comprehensive. These mathematical modeling-related topics of the product innovation process are consistent with our QoLT ERC Foundry, a QoLT ERC initiative that fosters commercialization of new technologies, and thus we have technical expertise available in this area. To facilitate the teachers' research and development teams, we also draw upon an existing successful model from our Technology Innovations for Persons with Disabilities (TIPeD) program, an initiative funded by the National Collegiate Innovators and Inventors Alliance that fosters commercialization of assistive technologies from engineering and business/law student teams. Through in-depth engineering experiences, a product innovation course, and professional development experiences, we help teachers better convey engineering and product development principles to their students. The table below and following sections demonstrate the program timeline and describe our program activities.

Table 1: Program Timeline

Months	3	6	9	12	15	18	21	24	27	30	33	36
Recruit Teachers												
Recruit at least four returning science teachers from previous RET cohorts and four new counterparts from the same school in math or economics	■				■				■			
Teacher Orientation Meeting		■				■				■		
Engineering Research												
Teachers assigned research projects. Design projects come from the pool of projects from QoLT. Projects introduced during the product innovation course. (12 weeks)		■				■			■			
Teachers concurrently work to develop project solutions.		■				■			■			
Design Symposium with REU students to present work.		■				■			■			
Curriculum Development												
Redesign DBL units to integrate product development economics to strengthen the mathematics and learning. (4 weeks)				■				■				■
Classroom implementation of units												
Teacher distributed professional development training to support unit implementation					■				■			
High School Innovative Design and Business Competition						■				■		
Student Summer Internship (winners of the design competition)								■				

In-depth engineering experiences

QoLT, the overarching theme for our RET site, is related to the development of products and processes that transform lives of people with reduced functional capabilities due to aging or disability, who are a large and growing segment of our population. These products, processes, and service models are a result of the translational research that occurs in our laboratories. Therefore, in our RET program, as opposed to conducting basic or applied research, participants conduct research and development related to product innovation in teams of 4 teachers (2 science and 2 math from 2 different schools). Each team has a faculty advisor, graduate student mentor, and client and is placed within a laboratory that has an existing research group that will serve to support the teachers. The client is generally an individual with a disability with a specific need that can be achieved by a QoLT (or assistive technology). Once teams and projects have been assigned, the week begins with a weekly research and development meeting between the faculty advisor and the core team members (other graduate and undergraduate researchers). Each week the teachers attend a lecture on product innovation and expand their understandings of the engineering design/commercialization process. Throughout the week teacher teams meet to conduct independent research and product development. They have access to their advisor, client, and graduate student mentor at all times. Each week during the product innovation course, teams present progress updates on their project where they receive critical feedback from the other teachers and site PI to assist their performance. We carefully select potential innovation projects based on two factors: 1) the opportunity for teachers to perform hands-on product development, and 2) the potential for the product to be prototyped during the duration of the program. We also encourage our teams to complete the product innovation cycle by considering commercialization opportunities through an existing or new company.

The RET participants have access to state-of-the-art equipment in the Human Engineering Research Laboratories (HERL) at the Department of Rehabilitation Science and Technology (RST) at the University of Pittsburgh and the Robotics Institute at Carnegie Mellon University to turn their concepts in to functional prototypes. They have direct access to the most current engineering and technical software applications in addition to 11,000 square feet of design, fabrication, and testing facilities. Also of note is that RST and HERL have high concentrations of persons with disabilities as faculty, staff, and students. As such, RET participants are exposed on a weekly basis to people who use assistive technology on the job and in their daily lives. Our close relationship and proximity to UPMC, one of the largest healthcare networks in the US, allows us to utilize their services for any additional research and/or assessment needs.

Product innovation course

Participants complete a course on product innovation that includes design, development, and evaluation of technologies in addition to the processes of bringing these products to market. The course covers the steps in the establishment of a technology venture using the hands-on equivalent of a laboratory course. Teacher teams provide technical enhancements to new or existing product/service ideas and construct business plans to form a proposed startup business. Activities include identifying user needs from real clients, developing concepts, evaluating and selecting concepts, prototyping, opportunity evaluation, market analysis, financing, intellectual property, regulatory issues, and business organization and management. The final goal of the course is to formulate and present proposed start-up company business plans before a board of potential financial stakeholders and/or industry partners.

Through lectures, guest speakers, and readings we cover the essential ingredients of product innovation. Lectures and structured activities span the product development process and are configured to provide guidance through specific deliverables that the teachers complete during the following week on their individual projects. The topics covered in these lectures are based on the state of the art; for example, social networking may be used to gather user needs and feedback for the designs. State of the art fabrication techniques such as rapid prototyping are used to bring the products from conception to fruition and enhance training for teachers in this area. By going through a carefully structured design process as part of their research and development experience, we enable the RET participants to pass on their knowledge to a new generation of innovators; who will ultimately generate new products, create employment opportunities, and strengthen the national economy. Each week the RET participants provide formal update reports on their research and product innovation activities. These presentations include specific material that is required for performing translational activities as outlined during the lectures from the previous week. The presentations, which are peer reviewed by the participants themselves, are an important open forum in which the participants share their research experiences and provide constructive feedback on their research and translational activities.

Professional development experience

Through a 4-week professional development series over the summer, the participants create design-based learning (DBL) units that include product development economics and other math concepts related to innovation. These workshops are directly focused on implementing and assessing innovative design practices into a pre-college classroom and provide a forum for the teachers to discuss the relationships between their current engineering experiences and design-based learning experiences for their students. Science and math teachers work together to facilitate units that allow their students to produce prototypes and commercialization plans of QoLTs in science and math/economics classrooms.

The goal of these design-based learning (DBL) units is to inspire a broad cross-section of high school students to want to become engineers and transform their science classrooms so that they will graduate high school with a foundation of knowledge such that they will do well as undergraduate engineers. Therefore, we must have teachers do more than create a few lectures/demos based on their summer research experiences and we must provide a large amount of support for teachers to help them create powerful learning experiences in their classrooms. Rather than simple lectures or demos, our curricular approach is 6-to-8-week-long DBL experiences that can be implemented at the beginning of high school.

We infuse Model Eliciting Activities (MEAs) throughout the DBL units. MEAs were originally designed for middle school math classrooms, but have become popular in many kinds of engineering classrooms, primarily at the college level, but also in middle and high school settings[8,9]. MEAs are broadly constructed authentic problems that groups of students solve over a few hours and require students to express, test, and revise models in order to solve the problem. Modeling is a critical component of mathematical thinking and learning[10] that has also been shown to be critical to thinking and learning in science[1] and engineering[8]. Thus, building expertise in modeling is critical for strengthening skills related to STEM. For students, MEAs involve the practice of mathematical/engineering modeling, physical objects to support problem solving alone and in groups with abstract ideas, and opportunities to reveal thinking to teachers, who then can provide more targeted feedback. Well-designed MEAs immediately engage problem solvers with a broad range of math skills, making them an especially powerful form of DBL that works for many learners and contexts.

We created a general template for such a curriculum unit that can be applied across physics, chemistry, biology, and earth sciences, and we have multiple existing units in all four areas. There are four basic phases of activities, all of which is done in groups of three or four students including developing a list of design specifications, conducting market research, testing prototypes and conducting scientific investigations, and drafting a mock patent application and commercialization plan for in-class design symposium, to synthesize all the elements of the final design and the science that underlies it. Top teams advance from each classroom to compete in a district-wide design competition against other RET participants' students (approximately 125 students each year). The structure of the units follow aspects of the product realization experience that the teachers engage in during their research experience.

Building such a unit is quite challenging. Therefore, we have teachers 1) re-design/improve an existing unit rather than build a new one from scratch; 2) work in teams by content area (e.g., the physics teachers together) on a shared unit rather that each develop their own; 3) work on these units throughout the summer rather than wait until the end of the summer; and 4) attend workshops throughout the summer that help them understand the many layers of the units that must be in place for successful classroom implementation. For example, last year the RET biology teachers improved the Design Bacteria unit by examining prior student test data, noticing that the activities related to the role of the environment on cell regulation was not understood by any students. They developed improvements to that section of the unit, while also building in some extension activities for their students that connected to the teachers own summer engineering research experiences. This year teacher teams will incorporate new math components to their students' innovation projects by working with math teachers from their respective schools. For example, the design bacteria unit will now have complementary components in a math RET participant's classroom where the students will provide feedback to the biology team in the form of a financial analysis of what such a product would cost.

Program evaluation

It is a challenging task to rigorously evaluate a project that touches such a large number of students, as in our program, especially using the very limited funds available in an RET site program for research and evaluation. It is tempting to rely primarily on teacher surveys, but our experience is that these surveys tend to be very positive (and in an undifferentiated way) and not particularly aligned with what actually happens in the classrooms. We utilize a multi-pronged approach to assessment that is rigorous, cost-effective, and aligned with our goals. Our program goals and corresponding metrics are displayed in the figure below. They include benchmarks for recruitment, engineering research excellence, and student interest and learning. We will complete our first new RET cycle in 2013 and will evaluate each cohort using similar metrics.

Table 2: Program Goal Metrics

Program Goal	Metrics
Recruitment of Teachers from High Needs Settings	• % of participating teachers from schools with more than 50% free/reduced lunch students and minority status [target = 80%]
Engineering Research Excellence	• % of summer projects resulting with teachers included in patent, journal article, or invention disclosure [target = 50%]
Exposure of Engineering Design to Large Numbers of Urban Students	• # of students completing full design-based learning experiences, based on classroom visit observations of actual implementation [target = 1000 yr1, +1500 yr2, +2000 yr3 = 4500 total]
Increases in Student Interest in Pursuing Engineering as a Career	• In-class survey on career interests, given to consecutive cohorts of participating teachers' students at end of school year, just before teachers begin the program and at end of year of program participation [target = overall 0.5 st. dev. increase in interest in engineering]
Improvements of Student Learning in Science	• In-class test of science knowledge and reasoning, administered in same fashion as survey in item above. [target = overall 0.5 st. dev. increase in general performance, 1.0 st. dev. increase in performance on content targeted by design-based unit]
Improvements of Student Learning in Mathematics	• In-class test of mathematics knowledge and reasoning, administered in same fashion as survey in item above. [target = overall 0.5 st. dev. increase in general performance, 1.0 st. dev. increase in performance on content targeted by design-based unit]

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