Enhancing the pre-engineering curriculum – a multi-partner initiative

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Abstract

This paper describes a project involving a major research university and fifteen secondary and post-secondary schools to develop and implement a career cluster program for the Research, Development and Technical Services career major. This Engineering Science Technology Tech-Prep grant, sponsored by the New Jersey Department of Education, has three main career goals for this project. These goals include preparing a skilled workforce that meets industry and educational standards in the fields of engineering, science and technology, establishing a consortium to improve training opportunities for students and teachers, and improving and expanding articulation between the secondary and postsecondary providers of education and training. The methodology of the project is to develop a local consortium of comprehensive schools, county vocational schools, two-year colleges, four-year colleges and research universities, and the R&D industrial base to ensure that New Jersey's youth are adequately prepared for entrance into two-year and four-year engineering, science and technology degree programs. The ultimate goal is to prepare these students for careers in engineering, science and technology, through the use of articulated curricula during grades 11 (high school) through junior year (college).

Introduction

With a population of over eight million, New Jersey has a very diverse technological industrial base. It is the corporate home of such companies as AT&T, Lucent Technologies, Johnson and Johnson, Becton Dickinson & Company and Warner Lambert. It ranks seventh in technology jobs, which is the third largest employment category in the state, exceeded only by financial services and education.[1] To help fulfill an economic need for qualified people seeking career opportunities in the state's R&D industry, a program was established to develop a pool of academically prepared, technically sophisticated youth.

This program was sponsored by a grant from the New Jersey Department of Education, starting in September 1998. Its purpose was to develop a local consortium of comprehensive schools, county vocational schools, two-year colleges, four-year colleges and research universities, and the R&D industrial base to ensure the New Jersey's youth are adequately prepared for entrance into two-year and four-year engineering, science and technology degree programs. The ultimate goal is to prepare these students for careers in engineering, science and technology, through the use of articulated curricula during grades 11 (high school) through junior year (college).

This program is a multifaceted tech-prep program, oriented to more than just creating introductory courses to engineering and science. While numerous tech-prep programs exist,[2-4] these programs must insert career and technical education into the center of all its programs.[5] Furthermore, these programs need to deliver material to its partners in a timely fashion, address the education of its teachers, and provide a seamless path from the secondary school through college.

This grant is based on a five-year development cycle, where career clusters[6] are developed for over ten disciplines within engineering, science and technology. Each year, there is a focus on one of these major career clusters, and Table 1 lists the sequence for these career clusters. During each year, various activities are directed at these specific disciplines, including linkages between the educational and industrial partners, project based learning modules, professional development and articulation agreements. This paper describes the activities that were completed during the first four years of the grant, and those projected for year five.

Table 1. Sequence for career clusters

Year One	Mechanical engineering, physics and engineering technology
Year Two	Chemical engineering, chemistry, environmental science and technology
Year Three	Electrical and computer engineering, computer science and technology
Year Four	Civil and environmental engineering, material science and technology
Year Five	Engineering life sciences, including biomedical and biotechnical engineering, biology and technology

Project Participants

School participation was restricted to schools that had an approved engineering/pre-engineering Classification of Instructional Program (CIP) code, which is part of the New Jersey Department of Education classification of high school programs. The two major participants in this grant are Bergen County Academy and New Jersey Institute of Technology (NJIT).

Bergen County Academy incorporates The Academy for the Advancement of Science and Technology and The Academy for Engineering and Design Technologies. These two academies are public magnet schools for science and technology located in Bergen County, New Jersey. NJIT is one of only three designated public research universities in the state of New Jersey and ranks among the leading engineering/technology research universities in the United States

The ten additional secondary schools that have participated in this grant include: Camden County Technical School, Cape May County Vocational School, Gloucester County Institute of Technology, Middlesex County Vocational & Technical High School, Monmouth County Vocational School, Morris County School of Technology, Newark Public Schools, Red Bank Regional High School, Salem County Vocational Technical School, and Union County Vocational Technical Schools. Because these graduates can articulate to a two-year community college program, five community colleges were also included as educational partners. These schools included Essex County College, County College of Morris, Gloucester County College, Salem County College, and Union County College.

Coordination with industry is one of the key factors in developing successful educational programs. In addition to the educational partners, there were over twenty industrial partners, representing many of the major industrial corporations within New Jersey, such as Lucent Technologies, Allied Signal Corporation and Becton Dickinson & Company. Another part of the industrial linkage were representatives from the Research & Development Council of New Jersey, which is a non-profit association representing over 50 major New Jersey companies. The purpose of this organization is to creating a strong, healthy environment for the continued growth of R&D within the state of New Jersey. Its responsibility under the grant includes a mentoring program for representatives of the educational partners and cultivating internship sites for students at the representative high schools.

Skill Set Lists

New Jersey Institute of Technology developed an extensive skill set list, to be used as a foundation for engineering study. These competencies/skill levels were identified in the areas of mathematics, science, engineering principles, design, technology and communications (written and oral), and were considered prerequisite competencies for the specific career cluster. Success both in a university setting as well as in the job market requires competencies in areas such as oral and written communication and interpersonal relationships. There was one category of the skills set list oriented to included these "soft skills" such as the ability to organize projects, work in groups, problem solve, communicate and meet deadlines within a team format. Table 2 lists the skill sets categories and subcategories developed for the first year. A total of 106 competencies, comprising seven subcategories, were developed.

As an example of the detail within each category and subcategory, the category Dynamics included the following skill sets: Effect of gravity, particle dynamics, motion around a curve, projectiles, mention of Newton's first, second and third laws, history of Sir Isaac Newton and his theories, and introduction to force systems. An example of the detail within a "soft skills" category, the category Writing included the following: Spelling or knowledge of 'spellchecker', grammar and writing in complete sentences, order of information, table of contents, how to write an abstract, and ability to write a lab progress in a journal.

Table 2. Skill set categories and subcategories developed during Year 1

Main Category	Sub-Category
Year 1	
Math	Algebra
	Graphing
	Geometry
	Trigonometry
	Calculus (desired, but not required)
Physics	Time and motion relations
	Simple electric circuits
Dynamics	Newton's Laws
Computer Knowledge	Windows environment
	File Management
	Use of the Internet
Problem Solving Skills	Defining the problem to be solved
	Collecting and sorting information
	Ability to estimate or predict a solution
	Working within given constraints, recognizing those constraints
	Drawing a conclusion
	Results that meet the objective
Communication Skills	Reading
	Speaking
	Writing
Team Skills/Project Management/Personal	Time Management
	Team Management
	Personal
	Communication

While the first year represented the development of specific career clusters for Mechanical Engineering and Physics, the development of these skills sets have proven to be general in nature. Table 3 illustrates some of the additional skill set categories and subcategories developed during years two through four. Although many of the categories were repeated and additional subcategories were included, there were only five new skill set categories added during years two through four. For example, during the second year when the Chemical Engineering, Chemistry and Environmental Science career cluster was developed, most of the skill set categories crossed multi-disciplines within engineering, science and technology and only chemistry was added. A complete listing of all the skill set categories, subcategories and corresponding New Jersey Core Content Curriculum Standards is available through Bergen Academy on the Tech-Prep Website. (http://www.bergen.org/EST)

Each of the partner schools was given the skill set, and the creation of a particular project involved marking the specific skills that were covered. The individual projects covered a small fraction of the entire skill set list, but when there were sufficient projects available from the educational partners; all skill sets were linked to one or more projects. The industrial partners for this grant also reviewed the skill set lists.

Table 3. Additional skill set categories and subcategories developed during Years 2-4

Main Category	Sub-Category
Year 2	
Chemistry	Stoichiometry
	Classical Principles: Mass and energy conservation
	Classical Laws: Dalton, Charles, Boyle
	Systems of Measurement
	Units Conversion
	Quantitative Representations
Year 3	
Research/Information Skills	Questioning: Independent discovery of issues and problems when looking at a topic
	Coherent structuring and organization of information
	Synthesizing: Reconstruction/combining of information to make sound/original decisions
	Reporting: Translation of findings into a persuasive, instructive, or effective arguments/facts
General Technology Skills	Ability to assess usefulness/application of basic information technology
	Basic understanding of the relationship between career choices and specific information technologies
	Knowledge of the critical importance of continuous learning, and information technology skills development
Ethical Skills	Understanding of important issues of a technology-based society
	Recognition of ownership, security, and privacy issues
	Understanding of copyright and citation issues
Year 4	
Chemistry	Organic chemistry
	Industrial products
	Waste generation
Environmental Studies	Earth sciences
	Biology and microbiology
	Field observations and sampling
Computer Knowledge	Word processors Spreadsheets Scientific application software packages, e.g., MathCad
Personal Skills	Knowledge of various cultures and diversity in the community

A curriculum project template, developed by Bergen Academy faculty, facilitated establishing a relationship between the skill sets and the New Jersey Core Curriculum Content Standards. The

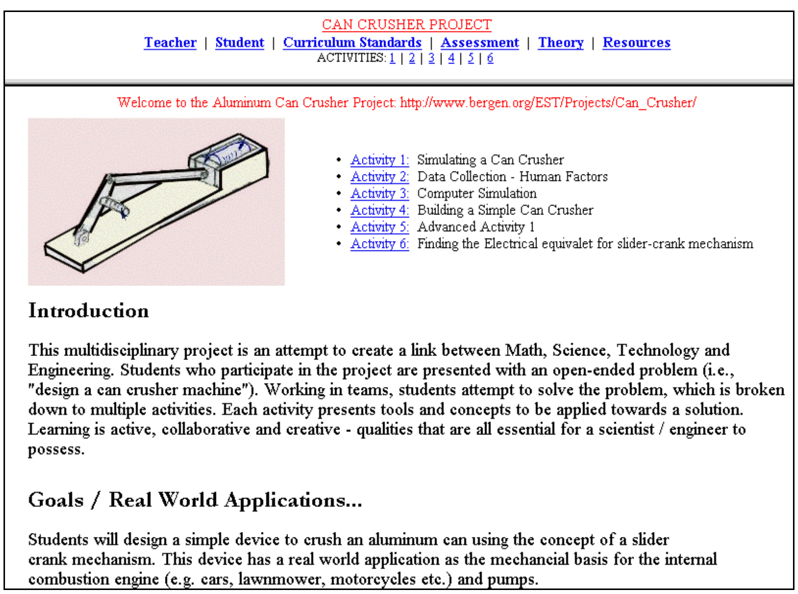
Core curriculum content standards were an attempt by the state to define the meaning of "Thorough" in the context of the 1875 New Jersey State constitution that guarantees that students would be educated within a Thorough and Efficient, i.e., "T&E", system of free public schools. These standards ensure that all children receive a "T&E" education despite the fact that in New Jersey there are approximately 600 independent school districts that exercise considerable local control over curriculum. These standards describe what all students should know and be able to do upon completion of a thirteen-year public education.

Project based learning

In the first year of the grant, a project development format was created to coordinate with the skill set list and set the groundwork for the succeeding years. During the first year, a total of 14 problem-based, interdisciplinary projects were established, representing the 106 competencies. These projects were delivered to approximately 45 of a total of 120 participating students, at 3 demonstration sites. The initial projects and their access were improved, and new projects were added during the second, third and fourth years of the grant. During these years the number of participating students increased to 274, 865, and 1149 respectively, and access was improved to 100 percent.

NJIT developed several “seed projects”, and the other educational partners used this format to continuously develop additional problem sets. Once these projects were developed, they were also placed on the Tech-Prep website for use by all the educational partners. Figure 1 shows the main project page of a seed project called the Custom Can Crusher. This project is divided into six activities using the concept of developing a custom can crusher to illustrate several of the skill sets previously described. The six activities included simulating the can crusher, data collection, computer simulation, building the unit, an advanced activity upgrading this unit, and finally, finding an electrical equivalence for the slider-crank mechanism. Links from the project page go to an instructor page, a student page, and a resource link, which provides websites for related physics tutorials, similar projects, and existing products.

Figure 1 Can crusher project page


CAN CRUSHER PROJECT

Teacher | Student | Curriculum Standards | Assessment | Theory | Resources

ACTIVITIES: 1 | 2 | 3 | 4 | 5 | 6

Welcome to the Aluminum Can Crusher Project: http://www.bergen.org/EST/Projects/Can_Crusher/

- Activity 1: Simulating a Can Crusher
- Activity 2: Data Collection - Human Factors
- Activity 3: Computer Simulation
- Activity 4: Building a Simple Can Crusher
- Activity 5: Advanced Activity 1
- Activity 6: Finding the Electrical equivalet for slider-crank mechanism

Introduction

This multidisciplinary project is an attempt to create a link between Math, Science, Technology and Engineering. Students who participate in the project are presented with an open-ended problem (i.e., "design a can crusher machine"). Working in teams, students attempt to solve the problem, which is broken down to multiple activities. Each activity presents tools and concepts to be applied towards a solution. Learning is active, collaborative and creative - qualities that are all essential for a scientist / engineer to possess.

Goals / Real World Applications...

Students will design a simple device to crush an aluminum can using the concept of a slider crank mechanism. This device has a real world application as the mechancial basis for the internal combustion engine (e.g. cars, lawnmower, motorcycles etc.) and pumps.

The student page has a link to a website describing the process of recycling, as well as a link to the McAllen International Museum website, which showed the use of recycled aluminum for furniture. The student page also lists the project description, the project outline, and means of assessment. The teacher page describes the goals of this project, which is to have students work in groups to apply the physics, mathematics and ergonomic data to solve a real world-engineering problem. The theory of the slider-crank mechanism was introduced in the context of torque and rotational motion, and its real world applications, e.g., within internal combustion engines and pumps as shown on this website. In addition, the teacher's page lists the contents and objectives in terms of the skills set list, the faculty and instructional material required for the project, links to the theory for this project, and suggestions for further related projects. Also, there is a resource link on the project page, which provides websites for related physics tutorials, similar projects, and existing products. The activities in this project were then related to the New Jersey Core Curriculum Content Standards.[7] An example of this relationship can be seen in Table 4 for the Mathematical category. This table represents only a few of the Core Curriculum Standards for mathematical activities.

Table 4. Relationship of the New Jersey Core Curriculum Content Standards and the mathematical activities of the Can Crusher Project.

New Jersey Core Curriculum Content Standards	Activities from Can Crusher Project
Standard 4.1 (cumulative Progress H.S.): Use discovery-oriented, inquiry-based, and problem-centered approaches to investigate and understand the mathematical content appropriate to the high school grades.	Geometry and basic calculus is required for the measurement of the force calculations in activity 1 (see Mathematical concepts).
Standard 4.1 (cumulative Progress H.S.): Recognize, formulate, and solve problems arising from mathematical situations, everyday experiences, applications to other disciplines, and career applications.	The can crusher project is designed to fulfill this standard by translating mathematical formulation into the creation of a mechanical device.
Standard 4.3: All Students Will Connect Mathematics To Other Learning By Understanding The Interrelationships Of Mathematical Ideas And The Roles That Mathematics And Mathematical Modeling Play In Other Disciplines And In Life.	Math is used in the project in conjunction with Physics and Mechanical Engineering. It is used as an essential step for design and simulating the product.
Standard 4.7: All Students Will Develop Spatial Sense And An Ability To Use Geometric Properties And Relationships To Solve Problems In Mathematics And In Everyday Life.	Geometry is used in order to understand the slider-crank mechanism and calculate the force needed for performing the crushing (see Slider Crank Geometry).

Other Project Based Learning Concepts

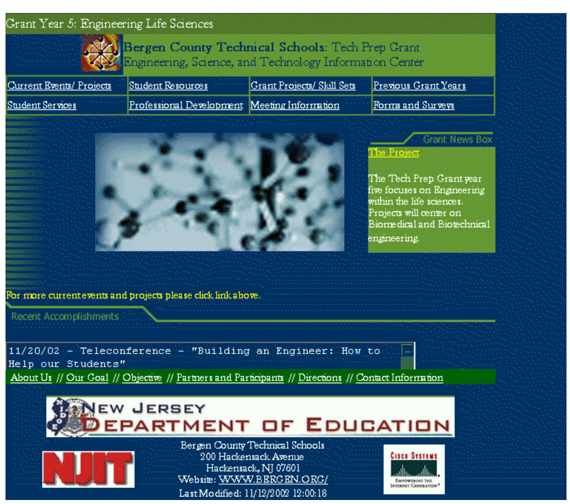
Several other methods to disseminate project-based learning that have been developed tested during this grant. As part of a collaborative identification of competencies interactive teaching modules, instructional CD-ROMs, curriculum guides and various other resources were posted on the Tech-Prep website, including the West Point Bridge Designer Project[8]. In addition, a major factor in increasing the project-based learning modules for the high school educational partners was to integrate Project Lead the Way[9] (PLTW) programs into the high school curricula. By the end of year four, 30 New Jersey schools, including eight of the Tech-Prep partners, used this pre-engineering program[10]. Its purpose is to increase the quantity and quality of engineers and engineering technologists graduating from the nation's educational system. PLTW has a four-year sequence of courses that combines with traditional mathematics and science courses in high schools. During year five NJIT will be the PLTW training site for New Jersey.

Website

In order to disseminate various information on projects and events, the New Jersey Department of Education Engineering Science Technology Tech-Prep Grant website was developed by Bergen Academy. This is the main vehicle to communicate throughout the consortium. Figure 2 shows a portion of this webpage, http://www.bergen.org/EST/, which contains nine main areas, including:

- Goals and objectives
- Skills sets
- Contact Information
- Project Information
- Resources
- Articulation agreements
- Career Awareness
- Internship Information
- Summary of meetings

Figure 2 The main Tech-Prep grant website



Professional Development
Educational staff development is an important part of this grant. The original intent for professional development during year one was to have a series of seminars that would be attended by participating teachers at the educational partners. However, due to time restrictions placed on the teachers, it was decided that the creation of training material that could be delivered remotely and asynchronously would be more acceptable to these participating teachers. Therefore, a main part of the professional development centered around the development of a modular videotape series with a focus on creating web-based projects. Participating NJIT faculty developed two video taped modules per year during years two through four. These 1-hour tapes also included career information to be disseminated by the teacher.

Staff development, on-line resources and on-site technical assistance combined to foster and reinforce project replication by all EST districts. Staff development opportunities ranged from onsite workshops to individualized technical assistance services and online resources. The posting of projects, curriculum recommendations, resources and materials, supply lists, textbooks, software and equipment on the EST website enabled teachers to both develop and more effectively implement project-based instruction. These activities proved to be important supports of project replication/implementation.

The PLTW model was also used to facilitate staff development for both teachers and counselors. All participating schools have access to PLTW software through individual contracts, and NJIT will provide PLTW training during year five.

Student Focus Events
To adequately encourage students to enter careers in research and development industry, students from partner schools were able to visit a series local education/industry career fairs. The two career fairs, a fall NJIT/Rutgers Newark Collaborative Career Fair, and a spring NJIT career fair, had over 120 companies each, and students were able to observe the interviewing process, as well as understand the tremendous career potential in engineering, technology, and science.

Career based information is also posted on the project's web page, with links to areas such as the Young Engineers Forum (sponsored by PBS); Lucent Technologies Career Page; Tech Expo (the northeast's leader in Technical Career Fairs); and NJIT's Division of Career Development Services.

Another areas that will help students understand careers in research and development include internship and mentoring. The R&D council, an industrial partner, sponsored 15 internships at its member corporations. One of the educational partners, Monmouth County's High Technology High School, had a student mentorship program that placed a senior in a science/technology firm part-time for one semester. The students work on a research or design project selected jointly by the mentor, faculty project consultant and the student, and a final presentation on this effort is required.

One of the educational partners, County College of Morris, arranged visits between its students and members of SCORE. SCORE is a national network of volunteer retired business executives and professionals. These members meet with the students, both in person and over the Internet, to both discuss careers in the research and development areas as well as arrange worksite visits.

To help with the career development of underrepresented minorities, there were a series of student oriented events geared to women in engineering. Female high school students from the educational partners attended the 6th annual "Women Who Dare" Conference, sponsored by the County College of Morris. Five tape modules were purchased from the American Management Association on non-traditional careers in science and technology. In addition, NJIT offers a program called FEMME (Females in Engineering: Methods, Motivation and Experience). Through this program, NJIT's pre-college center encourages post ninth-graders to enroll in advanced mathematics and science courses, and to consider engineering and related careers. The academic component runs from April through June, and there is a four-week summer component in July. These programs have been successful, and by the end of year four at least 37 percent of the participating students are female, and 29 percent represent minority groups.

Articulation agreements

There is a difference in the type and levels of pre-engineering programming currently in operation at various secondary school sites. Some schools were ready for advanced project development, while others were more interested in basic curriculum and alignment work. Thus, there was a need to look at curriculum from several viewpoints, and from the perspective of several different career ladder goals.

The development and/or revision of articulation agreements between the community colleges and the participating high schools, community colleges and NJIT and between the participating high schools and NJIT are an integral part of this program. NJIT has worked with the educational partners, to review such items as curriculum, student subject matter performance levels, the degree to which students demonstrate an ability to work on projects and on teams, teacher qualifications and teacher methodologies. In addition, NJIT has negotiated two agreements with the community college educational partners – Union County College and Raritan Valley Community College – for their Associate Degree in Science.

NJIT also has an agreement with the Academy for Engineering and Design Technologies (AEDT), enabling students to have advanced standing (sophomore year status) upon their enrollment in NJIT. The advanced standing is dependent upon completion of an articulated curriculum (the model for this project) which was developed by the faculties of NJIT and AEDT, students graduating from AEDT with a GPA of B or better, and success on NJIT's placement tests. The twelve articulations that were under development in Year Four reflect the above combination of PLTW curriculum models and EST curriculum-based projects (which reflect NJIT Skill Sets and NJCCCS). It is anticipated that most of these agreements will be finalized during Year Five.

A student tracking system, which facilitates the tracking of student achievement after program completion, has been finished. Continuity within this system is maintained through the inclusion of competency-related items in all follow-up instruments. Also, a number of the participating schools maintain active and detailed alumni connections, and these will be used in the future to determine the success of this program.

Conclusion

An overview of a project entitled Engineering Science Technology Tech-Prep grant, designed to develop and implement a career cluster program for the Research, Development and Technical Services career major, has been presented. The program will be consistent with industry expectations for new workers and will define the educational standards required for successful postsecondary study and entry into career positions, through the use of project based curricula, articulation agreements and coordination with industrial partners. By the end of the fifth year of this project, all the major engineering and science career clusters will have been completed.

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