INTEGRATING CHEMICAL ENGINEERING AS A VEHICLE TO ENHANCE SECONDARY SCHOOL SCIENCE INSTRUCTION

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Introduction

Engineering plays a major role in shaping the world today. Yet many bright, capable students choose not to pursue sciences in high school, and therefore have no opportunity to enter high paying engineering and technology careers (1). Engineering appears to be invisible to students. Many secondary school students lack an understanding of how almost everything they use is dependent on various forms of engineering. They also are unaware of the benefits that engineering provides people in their daily lives.

There are several factors that impact student interest in the technological fields. Many students are not exposed to topics in these fields at all during their K-12 studies because K-12 teachers have not been trained in incorporating these topics into their programs. In addition, the curriculum materials need to fit the instructional classroom needs of the teachers by addressing the content standards in science and technology/engineering. Although curricular materials are becoming more available in the technological fields, most do not appear to consider the issues that could hinder or facilitate their adoption into K-12 classrooms.

There are two issues related to a pipeline of engineering talent - the number of students entering the pipeline to earn BS degrees in engineering or science is low and the pipeline leaks. Efforts are necessary for the current generation of students to develop the joy and excitement of science, mathematics and technology in the students, raise aspirations, enrich backgrounds in science, mathematics and technology, and provide counseling, support and motivation that will encourage preparation for higher education and careers in engineering, science and technology. At the same time, collaboration with K-12 systems to continue efforts with the current generation as well as reach future generations is also necessary, in order to impact on classroom practice.

There has been a growing interest by higher education institutions to bring engineering and technology principles and applications to the secondary school classrooms. Summer enrichment programs for K-12 children are offered on universities, colleges, and other educational entities across the country (2). Technology education programs have been implemented, and programs for science teachers have included training and curriculum development that integrates engineering applications with scientific principles has been reported (3). Exposure to engineering principles has been extended to include pre-service teachers (3).

The Center for Pre-College Programs

NJIT, through its Pre-College Center, offers initiatives and programs designed to increase educational opportunities for inner-city youngsters while improving the quality of education at the elementary and secondary grades in the City of Newark, and its environs (4-6). Since its establishment in 1978, NJIT's Pre-college Center has undergone several fundamental transformations of its identity and goals. It has evolved from a locally focused Center working with 40 high school students from Newark schools into a comprehensive academic service department helping a widening geographical audience of over 4,000 students, teachers, parents and educational professionals from kindergarten through twelfth grade.

Since its inception, the Pre-College Center has sought to become a driving force in providing increasing access to scientific and technological fields to all students. Through its careful and thorough planning the Pre-College Center has been remarkably successful in reaching, those populations that are traditionally underrepresented in STEM areas (4-6). All pre-college initiatives are fully incorporated into NJIT's community mission.

The Pre-College Center's models for success bring academic opportunities to children who need them most, and develop and disseminate resource materials, classroom lessons and practices, laboratory experiments and demonstrations to teachers for use in their schools. Also, the Center provides:

- Enrichment studies in science, mathematics and technology not normally available to students in elementary and secondary schools and encouraging students to pursue careers in science mathematics, engineering or technology as a meaningful and realistic goal;
- Professional development programs for practicing teachers and counselors through modification of current curricula and/or development of new curricula to strengthen the quality of elementary and secondary schools teaching and counseling methodology in science, math and technological subjects; and
- Workshops to students' parents and guardians to increase their participation in the educational process of their children in order to support them through the barrage of negative peer pressures that will distract them from achieving their full potential.

NJIT has long recognized that "minding" the engineering pipeline at the secondary level is no longer sufficient. Instead, we must reach the youngsters at the elementary level and provide a continuous nurturing environment that minimizes "leakages" in the pipeline (7). Further, our programs focus on applied engineering principles, basic scientific and mathematical concepts, and problem-solving skills, critical areas for successful pursuit of science, technology, engineering and mathematics (STEM) careers. Our programs' academic curricula follow state and national standards and therefore, provide students with the opportunity to gain the skills and knowledge detailed by such standards. But this only reaches the current generation of youngsters. NJIT's pre-collegiate models go further into the areas of teachers' training and curriculum reform, both elementary and secondary grade levels (6), to impact future generations of students earlier and with greater intensity that is currently possible.

NJIT Enrichment Programs for Students

Special programs can expose students to the traditional engineering and scientific disciplines as well as such emerging high-tech design and manufacture, hazardous and toxic substance management, and bioengineering and biotechnology.

Among the earliest enrichment programs for students was High School Urban Engineering Program (8) at NJIT, which was offered first in 1970 for 25 students. This was expanded in 1974 to 100 students and included both junior high school and high school students. The focus on attracting women in engineering began in 1981 with the FEMME Program for 25 ninth grade students. Recognizing the need to reach the students earlier, programs for rising sixth and then seventh graders was initiated in the early 1990's (9). After that additional programs for female students were initiated so that a Continuum of programs is now provided that start with rising fifth graders through rising tenth graders. Each year within the continuum focuses on a different field of engineering. It was also recognized that parallel coed programs were also necessary to serve the needs of the region. Thus a parallel continuum of programs were implemented that served both boys and girls. Our consideration in this paper is on those programs that focus on chemical engineering concepts and careers.

Within our continuum of Women in Engineering Programs is FEMME7, which has a theme of Chemical Engineering & Chemistry. Designed for girls completing the seventh grade, the Chemical Engineering & Chemistry thematic focus was selected to introduce the girls to chemical engineering and chemistry principles and to view of the world through the lens of a chemical engineer.

The program includes such hands-on activities as:
Chemical reactions in a Bag
Consumer chemistry: better picker upper
Chemical engineering in everyday life—toothpaste development, and toothpaste testing lab
Shampoo evaluation lab.
Introduction to polymers and a glue production lab.
An introduction to chromatography
Extraction and dyeing lab

Classes in communications skills, relevant topics in mathematics and computer applications are included. Participants attend seminars by chemical engineers Students are taken on field trips to corporations such

National Starch and Chemical Company
Firmenich Factory which creates perfumes, flavors and aroma chemicals.

The comparable co-ed program is the Jr. ChIME (Chemical Industries for Minorities in Engineering) Program. Initially a program that focused only on chemical engineering concepts and chemical engineering careers, the program now includes the different engineering and scientists that work in the chemical industry (e.g., mechanical engineering, etc.).

The ChIME Summer workshop for 7th and 8th grade students is designed to expose participants to career role models, engineering and technological careers, technological college entry requirements, hands-on laboratory experiments and technical lectures by faculty and industry personnel. Career guidance material from professional and industrial groups was given to each participant. Sessions on Fundamentals of Engineering Design with particular emphasis on written and oral communication are included.

We have used other approaches to provide enrichment activities for secondary school students.

Almost 23 years ago, NJIT initiated the New Jersey Chemistry Olympics for high school students. Originally developed as a competition in chemistry related events, it has since evolved to the inclusion of events with a chemical engineering focus (10). Using faculty from the departments of chemistry and of chemical engineering, the competition is broken down into three categories, research events, general events, and laboratory events. Within this framework, event topics vary each year. The competition has become quite effective as a large number of schools participate each year, and the events have helped teachers develop and extend their classroom content.

A chemical engineering module from the NJIT Freshman Engineering Design course had been adapted to use with high school students in several of our high school summer programs (11). Prior to each summer, about eight undergraduate students were trained to become teachers of the high school students. Under the supervision of university faculty, each undergraduate student then worked with a group of three to four high school students. Using the freshman Chemical Engineering Measurements module, students were taught data measurement, collection, recording, analysis, reduction, correlation and presentation of results.

The undergraduate students first ran all the experiments in teams of two, and correlated their measurements. Then, under the supervision of the faculty, these students become teachers and mentors for the pre-college students. Experiments included:

- A primarily bench scale Flow through Pipes experiment and the larger fluid flow experiment in the Unit Operations Laboratory.

- The study of heat transfer and temperature profiles with a double pipe heat exchanger.
- The use of different types of temperature measurement instruments for comparative studies.
- The study of air and water fluidization.

Impacting the K-12 Curriculum and Classroom Practices

The engineering community generally agrees on the importance of introducing engineering into K-12 curricula as a strategy for increasing student interest in engineering, and ultimately increasing enrollment of qualified students in engineering degree programs. Integration of engineering principles into science instruction, and presented through problem-solving inquiry/discovery pedagogy can stimulate students as well as enable them to recognize a direct link between their course work and the tasks performed by engineers in the real world (3,12). When engineering and science are taught in tandem, they extend and reinforce each other. Unlike the engineering and technology curricula approach, this strategy can reach all students, not just those in pre-engineering and technology programs.

However, science teachers are not trained in the content and skills of engineering (13). The United States teacher education continuum, in its current configuration, neglects pre-engineering education at the secondary school level (14). Further, science teachers lack relevant professional preparation and experience that would prepare them to teach principles of engineering.

Many science textbooks fail to include engineering/technology applications of the science concepts presented in the textbook (15). Most textbooks do not have any laboratory activities that allow students to apply engineering principles and design to scientific concepts. Only occasionally is an engineering activity found in the physics part of a physical science textbook, e.g., design and testing of a model bridge. Teachers can design their own activities to give more engineering applications of the science concepts but without formal courses in their pre-service programs or in-service training programs that address engineering principles, they are unlikely to do so.

Curricular materials in support of the integration of engineering into science instruction have been made available through professional organizations such as ASME and IEEE, as well as universities and teacher developed lesson plans (3).

The National Science Education Standards, NSES, (16) supports a broad exposure to a variety of topics in science and teaching students to design a solution to problems and the relationship between science and engineering/technology. NSES calls for a student-centered learning environment that uses an inquiry-based approach. That is, it should actively engage students in asking questions and designing experiments to solve problems. Also, science and technology is one of the standards at all grade levels. According to NSES, "The relationship between technology, engineering and science is so close that any presentation of science without developing an understanding of engineering or technology would portray an inaccurate picture of science" (p. 190). In addition, the standards "introduce them to laws of science through their understanding of how technological objects and systems work." Scientific investigations by students can be complemented by engineering-type activities that lead to a product. The national standards emphasize the students' abilities to design a solution to problems and the relationship between science and technology.

State standards are informed or derived from national standards, districts develop curricula from state standards, and teachers develop lesson plans for the classroom using the district curricula. So, if teachers are to make their new knowledge a part of the instruction for student learning in their secondary science classes, engineering principles and design must support and/or augment the learning of the skills and knowledge specified by the state science standards. Teachers will only be accountable for what is in the standards. In general, only concepts that are in the standards are taught in classroom instruction. Students who are taking the minimal science program for the state assessments will only learn what is included in the standards for which they will be tested. Hence, the importance of engineering principles must be emphasized in the achievement of the state standards. The fact must be accepted that if curriculum materials are to be considered, let alone implemented, they must reinforce state content standards, since student achievement (and the schools and districts) is measured in large part by student performance on the statewide assessments.

The education of science teachers generally does not include courses that promote an understanding of engineering principles and design. There is a need for states to have teacher certification requirements and in-service training for science teachers that provide exposure of science education majors to engineering so that these teachers are provided with the means of introducing engineering into their classrooms.

Most high school science teachers are not familiar with the application of science concepts to the practical world of engineering. Hence, there is and urgent need for in-service training for science teachers that include programs to increase their knowledge of engineering principles and to provide those teachers with the means of introducing engineering principles and design in their class rooms.

We have developed several approaches to bringing chemical engineering principles and applications to secondary school chemistry and physics curriculum and classrooms.

The first formal effort was a one-semester course first offered in 1984 for graduate credit entitled "A Course in Fundamentals of Chemical Engineering for High School Teachers (17). The course included formal class meetings and plant trips. The plant

trips were integrated into the course content as teachers were required to develop lesson plans relevant to the plant trips (18). Topics covered in the course included:
Chemical Engineering as a Career
Material and Energy Balances
Chemical Thermodynamics
Kinetics and Catalysis

More recently a grant from the New Jersey Commission on Higher Education allowed for the development modules and intense teacher training on different engineering topics for middle school and high school classrooms (12). These modules were meant to support and augment existing science curriculum. They were meant to focus on pre-engineering skills and include instructional strategies that emphasize the connections between science, mathematics and engineering. Assessment of impacts and changes in attitudes toward and knowledge of engineering was a significant part of the project (19 - 20). One of the modules focused on principles of chemical engineering (21).

The chemical engineering module was designed to utilize chemical concepts to introduce high school students to principles of chemical engineering that takes a real process and shows how chemical engineers use science principles to develop the process technology for the manufacture of a commonly available and well-known product, such as the manufacture of the pharmaceutical Aspirin. The module was meant to show how the chemical engineer must create a large-scale flow process with recycle of un-reacted reactants, solvents, and their recovery. They must be concerned with the disposal of large quantities of undesirable by-products and waste, pollution abatement and prevention and an operating plant the runs for 24 hours per day, 365 days per year with periodic shutdowns for scheduled maintenance.

Using the Aspirin manufacturing plant, the module focused on those science concepts taught in high school that are relevant to chemical engineering principles. For relevant processes, the chemical processes and chemical and physical concepts that are involved were identified and related to chemical engineering principles and practices. Diverse topics such as heat transfer, mass transfer, fluid dynamics, chemical reaction and separations technology are introduced and related to scientific concepts. Key components of the manufacturing process of Aspirin can be utilized to illustrate relevant chemical and physical principles to the Unit Operations.

As important as the development of these modules is to the effort, it is just as important to assess the impact of the modules and the teacher training for a time after the completion of the teacher training programs. A follow-up study of high school science and mathematics teachers who participated in the one of the pre-engineering training programs in 2003 was conducted (22). Teachers' attitudes to and knowledge about engineering careers, concerns about implementing the curricula and self-reported preparedness to teach the new curricula were examined longitudinally across two academic years. Significant increases were found in students' attitudes to engineering and knowledge about engineering careers from the beginning to the end of the school year following teachers' participation in the program. The attitudes to engineering and knowledge about engineering careers for students taught by some of the teachers during the second academic year were significantly higher than for students taught by colleagues who didn't participate in the program.

Another approach is a series of one day workshops of two types:

1. Workshops on specific topics related to engineering or chemical engineering, including Scientific Inquiry & Engineering Design, The Laws of Energy: Key Concepts, and Chemistry & Chemical Engineering: Chemical Reaction and Separation Processes.
2. A series of one day workshops for high school teachers on current topics of interest in both chemical engineering and chemistry. A very important goal of these workshops is to provide the teachers with background information that they can incorporate into their lesson plans and thus provide the students with knowledge of contemporary issues. Previous workshops have focused on:
   a. A general introduction to chemical engineering and careers in industry.
   b. Pharmaceutical engineering.
   c. Polymers.
   d. Nanotechnology.

   This year's topic will be on Alternative Energy Sources.

Conclusion

The relationship between the subjects of Chemical engineering and Chemistry provides a vehicle to readily enhance currently available curriculum materials, and create connections between the science used in engineering applications in the real world and standards–based science. It can also provide content that fits the instructional classroom needs of high school science teachers.

We continue to look for new approaches and new topics to use chemical engineering concepts to enhance and enrich the high school science curriculum and classroom practice. For example, we are beginning collaborations with a new Engineering Research Center in which NJIT is a partner. We will be looking to develop curriculum units and conduct teacher training in the subject of structured organic composite materials, which can have applications both in the chemistry and in the physics curriculums. In addition, the Society of Plastics Engineers (SPE) student chapter at NJIT has recently produced a CD containing a description of the major polymer processing operations. We will explore how this material can be used in high school science instruction.

It is opportunities like these that we must seize upon to bring the field of chemical engineering into K-12 classrooms.

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