The Pre-Engineering Instructional and Outreach Program at the New Jersey Institute of Technology

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Abstract *— Engineering and Engineering Technology education are essential today and influence almost every aspect of our society. Yet, engineering enrollments and the number of engineering degrees awarded continue to decline throughout the United States. The Pre-Engineering Instructional and Outreach Program (PrE-IOP) at the New Jersey Institute of Technology seeks to enlarge the future pool of qualified high-tech workers, including those who have been historically underrepresented, minorities and women.*

The PrE-IOP program uses several strategies to achieve this goal, including the development of a pre-engineering curriculum and the training of grade 6-12 teachers. Instructional components developed through this program are aligned to the State of New Jersey Core Curriculum Content Standards to facilitate their adoption in New Jersey's middle schools and high schools. The PrE-IOP program also includes an outreach component that offers career workshops, teleconferences, and summer programs for students.

This paper describes the PrE-IOP program and the strategies it employs. It also describes in some detail Integrated Curriculum Modules developed in the areas of Machines and Energy; Electricity and Magnetism; and Integrating Chemical Engineering into High School Science. In these modules, the participants learn fundamental science and engineering concepts by building simple models and performing experiments which they can duplicate in their classes.

Index Terms *— K-12 outreach, Teacher training, Pre-College engineering.*

INTRODUCTION

For over 25 years, the New Jersey Institute of Technology's (NJIT's) Center for Pre-College Programs has helped minimize America's critical shortage of engineers by reaching out to K-12 teachers and students. The Center partners with local school districts, non-profit educational organizations, and corporations to improve science teaching in the classroom and to reform the elementary science curriculum starting as early as kindergarten.

This paper focuses on one specific program of this Center, the Pre-Engineering Instructional and Outreach Program. This program runs short courses for primary and secondary school teachers that introduce them to scientific concepts and methods to introduce this material to their students.

The remainder of this paper is organized as follows. First, the Center for Pre-College Programs and some of its main programs are introduced, followed by a description of the Pre-Engineering Instructional and Outreach Program. Then three modules developed for this program, the chemical engineering module, the electricity and magnetism module, and the machines and energy module, are discussed in detail. Finally, concluding remarks are presented.

PRE-COLLEGE PROGRAMS AT THE NEW JERSEY INSTITUTE OF TECHNOLOGY

New Jersey Institute of Technology, through its Center for Pre-College Programs (CPCP), offers initiatives and programs designed to increase educational opportunities for inner-city youngsters, and to improve the quality of education at the elementary and secondary grades in the City of Newark, and its environs and the state of New Jersey [1,2]. The Center 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 [3]. Through careful and thorough planning, we have succeeded in providing increasing access to scientific and technological fields among traditionally underrepresented populations. All pre-college initiatives are fully incorporated into NJIT's community mission.

Our models for success bring academic opportunities to children who need them most while providing knowledge and the skills to apply it. NJIT's Center for Pre-College Programs is dedicated to help schools and school districts in providing all children the opportunity to learn and meet the high academic expectations of the NJ Core Content Standards, with an emphasis on science, mathematics, and technology [4]. The Center's teaching and training approaches and methodologies are carefully planned in order to make a crucial contribution to participants' comprehensive development. They provide teachers with the skills and support needed to meet and implement in their classrooms the NJ Core Content Standards so that their students can achieve the requisite skills and knowledge of the Standards. In addition, the teachers are prepared to provide their students with access to appropriate science, mathematics and technology education. Our programs focus on applied engineering principles, basic scientific and mathematical concepts, and problem-solving skills, critical areas for successful pursuit of science, mathematics, engineering and technology (SMET) careers.

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.

The Center's programs are systematically organized into complementary categories:

- Instruction, Curriculum Reform & Standards
- Urban Partnerships
- Women in Engineering & Technology
- Pre-College Trio Programs
- Bridge to STEM

THE PRE-ENGINEERING INSTRUCTIONAL AND OUTREACH PROGRAM

The Pre-Engineering Instructional and Outreach Program (PrE-IOP) has been initiated to enlarge the future pool of qualified high-tech workers in New Jersey, including those who have been historically underrepresented (such as minorities and women). A collaboration of the Newark College of Engineering and NJIT's Center for Pre-College Programs, the design of PrE-IOP is based on the assumption that effective science/pre-engineering secondary school curriculum (and effective teacher training), coupled with better understanding of the profession would eventually lead to significant increases in engineering enrollment. Hence, this comprehensive program has two major components. The Instructional component, under the auspices of an Education and Training Institute, includes the adaptation and/or development of pre-engineering curricula for use in middle and high school science and math classrooms and the provision of summer institutes for teacher professional development [5]. The Outreach component involves the implementation of an "Engineering the Future" outreach program and the formation of alliances with three groups of stakeholders: educators, counselors and parents [6].

The Institute provides two curricular strategies: Project Lead The Way (PLTW), a national pre-engineering curriculum, and Integrated Curriculum Modules (ICM). The two approaches provide educators and schools with the flexibility to adopt either a complete engineering curriculum or integrate selected curriculum modules into their science curriculum.

Project Lead The Way Inc. (PLTW) is a national program which forms partnerships among Public Schools, Higher Education Institutions and the Private Sector, as well as provide a Fully Developed Curriculum for High Schools and Middle Schools [7,8]. The goal of both the partnerships and the curriculum is to increase the quantity and quality of engineers and engineering technologists graduating from our educational system.

The other pathway is called Curriculum Integrated Modules (ICM). Science courses can provide the opportunity to generate an interest in engineering and technology. A study of science and technology should be intended to help students develop abilities associated with technological design and problem solving. The ICMs are adaptations, enhancements, or newly developed units, meant to create connections between the science and mathematics used in engineering applications in the modern workplace and standards-based science [5]. The curriculum materials are designed to fit the instructional classroom needs of grades 6-12 teachers by addressing the content standards in science, mathematics and technology. They focus on teaching the pre-engineering skills of design and problem solving needed to convey the skills and knowledge required for successful admission to undergraduate engineering education programs. Summer institutes will be designed to familiarize the teachers with the curriculum and the associated pedagogy, with appropriate follow-up and support during the school year. The focus of this paper will be on the Integrated Curriculum Modules.

Training teachers are considered a critical element in the successful implementation of curriculum modules [4]. First they must see how the integration of principles of engineering and design into their teaching practice is a vehicle that can help their students learn the skills and knowledge of the standards. In addition, the teachers must be exposed to engineering principles and design in formal classes if this integration is to be institutionalized in the curriculum for the time beyond the training period. Teacher training programs and curriculum development have been implemented with the emphasis on engineering design, as well as on specific engineering disciplines including electrical and mechanical engineering.

THE CHEMICAL ENGINEERING MODULE

The connections between the science used in engineering applications in the modern workplace and standards-based science is conveniently seen in the subject of chemical engineering, as most of the principles of chemical engineering have applications in both chemistry and physics. Thus, the development of the module began with a matrix relating relevant chemical engineering concepts topics in typical chemistry and physics courses.

The processes for the manufacturing of a commonly available and well-known product was selected as the vehicle for relating the concepts taught in the high school science classroom to the applications to chemical engineering practice. A simple process, the manufacture of baking soda, and a more complex process, the manufacture of aspirin, were explored.

Initial discussions focused on an overview of the chemical engineer and comparisions between the work of a chemist and the work of the chemical engineer. In addition, the concept of a process was explored and applied to a very important system, the human body, where it is seen that the subprocesses occuring within the body are analogous to that of a chemical plant. There is the input of “raw materials”, the “chemical reactor”, and the “separation of the products”.

Using the Aspirin manufacturing plant, the module focuses on those science concepts taught in high school that are relevant to chemical engineering principles. For relevant processes, different process units (Unit Operations) are used and the chemical and physical concepts that are involved can be identified and related to chemical engineering principles and practices. The approach should allow the selection and retrieval of acquired science concepts that are relevant to a given engineering problem, then be able to assemble the concepts, and finally apply them to solve the problem. Recognizing the complexity of the chemical plant, the approach used in the module was to focus on the three primary components of t he manufacturing process:

- Pre-reaction physical preparation steps
- Reaction steps
- Post-reaction physical separation steps

The pre-reaction steps included the introduction of the raw materials, and the preparation of the raw materials for the reactor. Preparation usually includes processes such as mixing and dissoution.

For example, an overall system material balance based upon stoichiometry must be made, after the capacity of the proposed plant is determined. Starting with the basic chemical principles, a “Basis for the Chemical Process Design” is developed and after determining the proposed plant capacity, the overall system material balance is carried out. The study of stoichiometry is greatly enhanced by applying species, molar, and element balance techniques to batch and flow processes. During the discussion of process variables, mass, volume, flow rate, chemical composition (mass fraction and mole fraction), pressure and temperature concepts and relationships are discussed and applied in the material balances. The different phases of matter and the ideal gas law come into play. Solving the species balance for processes extends the students’ capability for solving single-unit design, and will allow them to explore the design of processes that are environmentally responsible right from the beginning of the design.

A key topic of the components of the manufacturing process is heat transfer. Temperature control and heat transfer are important in all phases of the manufacturing process. Conductive, convective and radiation heat transfer are discussed and related to the efficient use of heat in chemical processes. Thermal conductivity, heat capacity, and heat transfer coefficients are also considered as well as the concept of temperature driving forces needed in design of heat transfer plant equipment. Heat transfer involving phase change in condensation and boiling is a relevant scientific concept. The heat exchanger is introduced in the discussion of heat balances in each of the major components of the chemical plant. The "hands-on" activity to illustrate the principles poses the problem: "How Fast Does a Cup of Coffee Cool"? [9]

Chemical reactors used in chemical plants are introduced. The importance of thermodynamic principles in the selection of reaction conditions is also considered. Several activities such as the Drinking Bird was used to illustrate some thermodynamic principles [10]. For the chemical reaction steps, chemical kinetics and chemical reactor design are the important aspects of producing almost every industrial chemical. In fact, it is primarily the knowledge of chemical kinetics and chemical reactor design that distinguishes the Chemical Engineer from other engineers. Chemical Reactor Design and various types of plant reactors are introduced. The Chemist working with the same chemical reactions that a chemical engineer is working with does not encounter the problem of reactions in large reactors. For example, the mixing in a small laboratory flask batch reactor is much more rapid then the mixing in a large batch chemical reactor. There are other factors that are important. The Chemist is interested in reaction time to achieve a desired conversion of reactants. So is the Chemical Engineer. However, the Chemical Engineer is as much interested in batch cycle time because it is the total time to complete one batch cycle in a plant chemical reactor that will determine the production rate of the product. These operations involve the basic concepts used in fluid flow and heat transfer and the related chemical concepts. The concepts of reaction rate law, concentrations of reactants and the Arrhenius equation are related to the design of a reactor. A study the rate of progress of a chemical reaction is done by boiling potatoes of about the same spherical size for different boiling times, cutting the potato in half and noting the diameter of the uncooked part and its relation to the original diameter of the potato. Hence, the progress of the reaction, or conversion of the reactant, can be followed [9].

The post-reaction component must include recovery of the pure product(s) as well as recycling of unreacted reactants and solvents, and their recovery. The chemical engineer 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. Two post reaction physical separation processes selected for discussion were crystallization and distillation. Crystallization is recognized as the reverse process of dissolution and crystallization affords a good, practical method of obtaining pure chemical substances, which after washing and drying are ready for packaging and the market.

The principles and importance of process control in the chemical industry are important in all part of the manufacturing process and was considered in terms of simple process control concepts used in ancient civilizations and in our present daily living. Using the simple example of liquid level in a tank; the feedback loop is developed and discussed and the same process control and feedback principles are related to taking a shower bath.

As a culminating component of the module, the concepts used in "A Chemical Plant: From Conception to Construction" are discussed and the basic concepts of process and plant design are very nicely demonstrated on an interactive disc for the manufacture of a "Mystery Product", its scientific concepts, the economics and conclusion. The "Mystery Product" involves the manufacture of chocolate chip cookies. Additional details are available [11].

THE ELECTRICITY AND MAGNETISM MODULE

The Electricity and Magnetism module is a two-week short course for teachers of science at the middle school level, typically grades 5 to 8. In New Jersey, as in most states, teachers at this level are certified in K-8 education, not in any specific subject area, so their backgrounds vary widely. When offered in July 2003, students enrolled in this course had undergraduate and graduate degrees in fields ranging from sociology to physics. An important goal of this module is to introduce the material at a level that is sufficiently simple for teachers with non-science backgrounds while keeping the presentation useful and engaging for participants with some prior experience with the material.

The course is divided into three sections. The first is an introduction to engineering. This section introduces information on the roles of engineers in society and the role of engineering in everyday life. It lists some famous engineers and their engineering accomplishments, as well as some engineers famous for their non-engineering work. It also includes several case studies and an analysis of the problem solving process. The National Academy of Engineering's "Greatest Engineering Achievements of the 20th Century" [12] are also discussed. This section of the course includes team design exercises created to introduce participants to the engineering design process. For this exercise, the students design "flying" machines constructed from a set of parts including sheets of paper, index cards, paper clips, and adhesive tape. The team score is based on the time it takes for their flying machine to fall from a height of about five meters to the ground and how close it comes to a predetermined target.

The second section of the course introduces the basics of electricity and magnetism. Given the diverse educational background of the participants, this section starts with the basics of electricity, the electron, charge, current, and AC and DC electricity. Next, voltage, resistance, and Ohm's Law are presented, along with the resistor color codes and series and parallel circuits. Participants also perform a laboratory exercise in which they measure current and voltage in series and parallel circuits to determine the value of an "unknown" resistor.

The magnetism portion of this section focuses on magnetism in nature and in everyday life. Electromagnetism is discussed in some detail and participants perform a laboratory experiment in which they vary the voltage applied to an electromagnet and observe how this affects the strength of the magnetic field.

The final section of this module focuses on Boolean logic and digital circuits, drawing on the author's previous work [13]. This section begins with the basics of binary numbers and the fundamental AND, OR, XOR, and NOT functions. Participants also study basic TTL chips that realize these functions. They perform a laboratory experiment in which they use a logic probe to verify the output of TTL logic gates for various inputs. The participants also take measurements for an "unknown" chip and determine its function.

Students then study more complex Boolean functions that combine the basic logic operations. To reinforce these concepts, participants perform a laboratory experiment in which they design and build a simple game. The player must set three switches to match a previously set pattern, and the game must light an LED when the player matches the pattern.

Finally, this section introduces more complex digital components and circuits. These components include registers, decoders, binary and decimal counters, encoders, multiplexers, and BCD to 7-segment decoders. Students design and build a "Boardwalk Wheel" circuit that flashed a series of LEDs sequentially using a counter and a decoder.

Throughout this module, worksheets are incorporated in to the lecture portion for each topic to provide immediate practice with concepts just introduced. For example, after introducing Ohm's Law, students are given a circuit with a DC voltage source and a single resistor, and two of the three values for the circuit's voltage, current, and resistance. They then calculate the missing parameter for several different data values.

In general, students have enjoyed their work in this module and have learned or re-learned the material. By far their favorite part of the module is the laboratory experiments. They feel these experiments provide something they can bring back to their students to explain the underlying concepts.

THE MACHINES AND ENERGY MODULE

In our module, we present a two-week curriculum which uses hands on experience to illustrate scientific laws related to mass, motion, work, power and energy. The concepts of machines and energy are presented for the training of grade 6-12 teachers. Principles such as Newton's Laws of Motion are explained through practical examples. The concepts of simple machines and mechanisms to solve practical real-life design problems are presented through geometrical constructions and model building. This section describes in some detail Curriculum developed in the areas of machines and energy; work and power, simple machines and laws of motion. The concepts are presented through eight chapters described below.

The first chapter deals with what is science and engineering. This discusses such questions as what is engineering ? What is an engineer's day-to-day work like? What abilities are important for an engineer to be successful? What are some of the major benefits to be had from an engineering education? In considering what is science, we describe key scientific discoveries and their adaptation to useful products The participants study the affect of science on technology throughout history and compile a list of unsolved problems which need engineering and science for their solution.

The second chapter deals with engineering design. The participants are taught engineering design problem solving through problem definition, statement of human needs and developing design objectives. They learn how design progresses through various stages and how creative solutions are obtained. They are asked to list design short comings in daily use household devices. They learn to do marketing surveys and simple statistical analysis of consumer information and emphasis is also placed on the role of ethics and professionalism in design.

The third chapter deals with simple machines such as inclined plane, lever, wedge, screw, pulley, wheel and axle. They learn through models how these simple machines work. They also learn about forces acting and types of motion used in these simple machines. Simple calculations such as determination of efficiency of machines are performed.

The fourth chapter is on mechanisms and robots. They are taught how arranging machine elements such as joints and links form mechanisms. Examples of mechanisms such as four-bar linkage and slider crank mechanism are provided through physical models which are given to each participant to take with them for demonstration to their classes. Different types of mechanism design problems such as motion generation, path generation and function generation are illustrated through physical models and computer simulations. They are taught simple geometrical constructions such as drawing similar triangles, drawing a circle through a prescribed number of points etc. Then they design new mechanisms for motion generation using geometrical constructions and finally learn to cut and build the designed mechanisms using card board etc.

The fifth chapter is on complex machines. Examples are given on how combination of simple machines produce complex machines such as a bicycle, pendulum clock and auto transmission

Chapter six deals with work and power. They learn definitions and units and Newton's laws of motion are explained through examples. Examples of work and how machines make work easier are provided. Calculations of work and power are done with simple formulas. Powering of simple machines is demonstrated.

The last two chapters deal with energy. First they learn various types of energy. The concepts of potential and kinetic energy are explained through a physical model depicting a roller coaster. They also learn how energy is stored, and examine the impact of energy on environment. Demonstrations are used showing different moving machine parts using different forms of energy. They are also shown a video which illustrates the concept of energy conservation. This module is explained in detail in another paper [14].

EVALUATION

Evaluation of the modules and the teacher training programs was multi-faceted using traditional methodologies as well as in-house developed instruments. We were interested in the assessment of the workshops themselves, teachers' perceptions as to how the teacher training will impact on their teacher practices, and impact of the training and the modules on the classroom. Accordingly, the following instruments were used:

- Workshop Assessments
- Teacher's Attitudes to Engineering Survey
- Readiness to Teach
- Concerns-Based Adoption Model
- Follow-up Assignments - Lesson Plan Development and Implementation
- Classroom Observations

An illustration of the type of results we have obtained is shown in the "Readiness to Teach" survey we have done in the Machines and Energy program (Table 1). It is seen that for topics like "Engineering Design", the majority of teachers would have to study their notes before teaching the topic. Topics like "Work and Power" and "Simple Machines" are more comfortable topics for them since a large majority of them could teach them "tomorrow". This is not surprising since these topics are normally taught in middle school science classes. On the other hand, about 50% of the teachers believed that a topic like "Machine Design" could not be taught without more training.

ITEM: HOW READY ARE YOU TO TEACH ABOUT	I WOULD HAVE TO START FROM SCRATCH	I WOULD NEED MORE TRAINING ON THE TOPIC	I WOULD HAVE TO LOOK AT MY NOTES	I COULD TEACH A LESSON ON THIS TOPIC TOMORROW
Engineering Design	6.3(1)	25(4)	56.3(9)	12.5(2)
Work & Power		12.5(2)	31.3(5)	56.3(9)
Simple Machines		6.3(1)	25(4)	68.8(11)
Machine Design		43.8(7)	50(8)	6.3(1)

TABLE 1: Readiness to Teach Machines and Energy

SUMMARY

The Pre-Engineering Instructional and Outreach Program at the New Jersey Institute of Technology is part of a comprehensive series of programs designed to increase the future pool of qualified high-tech workers. By training middle school and high school teachers in scientific concepts and applications, this program provides tools that teachers can bring directly in to their own classrooms. By exposing their students to this material, the program generates interest among these students in pursuing degrees and careers in engineering and science.

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REFERENCES

[1] Kimmel, H., Martino, N., and Tomkins, R.P.T. "An Approach for Increasing the Representation of Minorities in Engineering and Science," *Engineering Education*, 78, 1988, pp. 186-189.

[2] Kimmel, H. and Cano, R., “K-12 And Beyond: The Extended Engineering Pipeline”, *Proceedings 31 st ASEE/IEEE Frontiers in Education Conference* , October 2001, Reno, NV.

[3] Kimmel, H. and Cano, R. “Model for a K-12 engineering pipeline”, *Proceedings of the 2003 American Society for Engineering Education Annual Conference,* , June 2003, Nashville, TN.

[4] Kimmel, H., and O'Shea, M., “Professional Development for the Implementation of Standards-Based Instruction.” *Proceedings of the 29 th ASEE/IEEE Frontiers in Education Conference* , November 10-13, 1999, San Juan, Puerto Rico.

[5] Kimmel, H. and Rockland, R., “Incorporation Of Pre-Engineering Lessons Into Secondary Science Classrooms”, *Proceedings 32 nd ASEE/IEEE Frontiers in Education Conference* , November 2002, Boston, MA.

[6] Rockland, R., Kimmel, H., and Bloom, J., “Engineering The Future: Enhancement Of Pre-Engineering Programs Through Outreach”, *Proceedings of the 2002 International Conf erence on Engineering Education* , August 2002, Manchester, England.

[7] Adelson, G., and Blais, R.R. “Project Lead the Way. A Model Program for Initiating, Funding, and Maintaining a Successful Pre-Engineering Program in the Nation’s High Schools.” *Proceedings of FIE’98 Frontiers in Education Conference* , November 4-7, 1998, Tempe, AZ. http://www.pltw.org.

[8] Kimmel, H., Burr-Alexander, L. and Rockland, R., “PLTW: One State’s Perspective.” *Proceedings of the 2004 American Society for Engineering Education Annual Conference* , June 2004, Salt Lake City, UT.

[9] Fraser, D. M., “Introducing students to basic ChE concepts”. *Chemical Engineering Education* 33 (3), 1999, pp. 190-195.

[10] Spooner, W. E.., “Energy is for the birds, too!” *The Science Teacher* , September, 1977, pp. 34-35.

[11] Hanesian, D., Burr-Alexander, L., Kimmel, H., Kisutcza, J. and Tomkins, R. P. T., “Integrating Chemical Engineering as a Vehicle to Enhance High School Science Instruction”, Proceedings of the Annual Conference, ASEE, Session 2113, June 22, 2004, Salt Lake City, Utah

[12] URL: www.greatestachievements.org

[13] Carpinelli, John, *Computer Systems Organization and Architecture* , Addison Wesley Longman Publishing Company, Boston, MA, 2001.

[14] Sodhi R. and Kimmel, H. “Introduction to Machines and Energy through Model Building for Pre-Engineering Instruction,” *Proceedings of the 2004 International Conference on Engineering Educatio n*, October 2004, Gainesville, Florida.