

A U.S. Working Model for the K-16 Engineering Pipeline

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Abstract - The Center for Pre-College Programs (CPCP) at New Jersey Institute of Technology (NJIT) offers initiatives and programs designed to improve the quality of education at the primary and secondary schools in the region and the State. The Center and its programs provide the connection with the University that creates a K-16 continuum. The approach is multi-faceted, providing a comprehensive set of programs for students and long-term, professional development for teachers as well as providing comprehensive, technical assistance to school and districts in engineering, technology, science and mathematics. Of special significance are the long-term relationships that have been established with major urban districts such as Newark and Union City, and with individual schools. Many of the programs are targeted towards specific schools within the districts. In addition, we have been able to assist schools to address and meet their specific needs. This paper describes the organization of the Center and its programs in order to meet the needs of the pre-college students, their teachers, and other stakeholders. The connection between the K-12 programs and initiatives and University programs are discussed.

Index Terms - K-16 Continuum, Pre-engineering curriculum, Primary and secondary education, Teacher training.

INTRODUCTION

The Center for Pre-College Programs (CPCP) at New Jersey Institute of Technology offers initiatives and programs designed to improve the quality of education at the primary and secondary grades locally, regionally, and throughout the State of New Jersey [1-4]. Simultaneously, collaboration and articulation between the pre-college initiatives and the University's academic programs contribute to its undergraduate and graduate programs. 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 (STEM) careers. Additionally, our programs' academic curricula follow state and national standards and therefore provide students with the opportunity to gain the skills and knowledge specified by these standards. But this only reaches the current generation of youngsters. NJIT's pre-collegiate models go further into the areas of

primary and secondary grade level teachers' training, curriculum reform, and technical services to schools and districts, so that future generations will be impacted earlier and with a greater intensity that is otherwise possible.

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. The Center's models for success bring academic opportunities to children who need them most in the Science, Technology, Engineering, and Mathematics (STEM) areas, as well as development and dissemination of resource materials, standards-based classroom lessons and practices, laboratory experiments, and demonstrations to teachers to integrate into their academic curricula in their schools.

A major step forward was taken with the establishment of the Pre-Engineering Instructional and Outreach Program (PrE-IOP) at New Jersey Institute of Technology's Center for Pre-College Programs [5]. Funded by a three-year grant from the New Jersey Commission on Higher Education, it was designed provide teachers with training and curricula materials in engineering concepts and applications, and to inform students, teachers, parents, and school counselors about careers in engineering. The Instructional component included training programs that provided teachers with pre-engineering curricula that not only better prepared students to study engineering but helped increase their attitudes towards, and interest in, engineering careers [6]. The curricula focused on pre-engineering skills and included instructional strategies that emphasize connections between science, mathematics and real-world engineering. The Outreach component involved the implementation of an "Engineering the Future" outreach program, a comprehensive information campaign about the rewards of science, engineering, mathematics and technology (STEM) professions to students, parents teachers and counselors [7].

NJIT's Pre-College Center is dedicated to helping schools and school districts to provide all children the opportunity to learn and meet the high academic expectations of the NJ Core Curriculum Content Standards. Our activities are based on the belief that all children, including those with special needs, must be given the opportunity to achieve those skills and knowledge addressed in the content standards. The Center provides leadership in the development and

assessment of science, mathematics, engineering and technology education. Its teaching and training approaches and methodologies are carefully planned in order to make a crucial contribution to participants' comprehensive development, providing teacher training, curriculum reform and technical assistance to K-12 schools and districts, locally and across the state. This approach provides the teachers with the skills and support needed to meet and implement in their classrooms the high academic requirements demanded by the NJ Core Curriculum Content Standards, school districts with professional development and technical assistance to help them align with the Standards, and the students with access to appropriate science, mathematics and technology education. The approach is systematically organized into complementary pathways.

- **“Minding” the Technological Pipeline** - Offer enrichment studies in science, mathematics and technology not normally available to students in elementary and secondary schools, encouraging students to pursue careers in STEM fields as a meaningful and realistic goal;
- **Impact the Classrooms of New Jersey: Aligning Practice with Standards within the Inclusion of Real World Engineering & Technology in Classroom Instruction** - Create and implement 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, and providing the teachers with the skills and support needed to implement in their classrooms the high academic requirements demanded by the NJ Core Content Standards, and providing the students with access to appropriate science, mathematics and technology education.
- **“Engineering the Future” Program** – This program assumes that effective science/pre-engineering secondary school curricula (and effective teacher training), coupled with a better understanding of the profession, would eventually lead to significant increases in engineering enrollment. It promoted science, technology, engineering, and mathematics careers through numerous programs: Engineering Career Days, workshops for parents and guardians, best practices' conferences, and educational DVDs (including instructional guides). The DVDs are based upon teleconferences held at NJIT, which included panel discussions on various aspects of engineering as a career, along with interviews of practicing engineers.
- **Partnerships with Businesses, Educational Systems, and Professional Organizations** – Partnerships serve to promote science, technology, engineering and mathematics careers, while enhancing and enriching educational experiences for students.

“MINDING” THE TECHNOLOGICAL PIPELINE

The Center provides programs for students that focus on the middle school and high school levels, with coherent sets of programs at each level. All programs are designed to pique students' scientific interest, fill in the math and science gaps in their education, create new learning opportunities, and provide new skills, academic support and career motivation. At the middle school level, two pathways are available, one for female students and the other a series of programs for both boys and girls. Different sets of opportunities are available at the high school level, a continuation of enrichment offerings, and college-level work.

The Middle School Bridge

The Women in Engineering and Technology Initiative (FEMME) Program is designed to provide post-4th through post-9th grade girls with opportunities to enhance their mathematics, science and technological academic achievement, and to develop problem-solving and critical thinking skills [8]. The program's goal is to encourage girls to choose careers in scientific and technological fields in which women are traditionally underrepresented. Engineering themes include: Environmental Engineering – post 4th grade, Aerospace Engineering – post 5th grade, Mechanical Engineering – post 6th grade, Chemical Engineering – post 7th grade, Biomedical Engineering – post 8th grade, and Electrical & Computing Engineering – post 9th grade.

The Early Science, Technology, Engineering And Mathematics Initiative is designed for both boys and girls to enhance the academic achievement of these youngsters and motivate them to consider careers in the technological fields.

- The Environmental Engineering Program introduces post-fourth students to terrestrial and aquatic environments as well as preferred environments of certain organisms.
- The Aeronautical Engineering Program (AEP) introduces post-fifth grade students to the principles of physics, astronomy, and engineering of air and space exploration and flight, aerodynamics, and laws of motion.
- The Pre-Engineering Program is designed to provide post-6th grade students with an introduction to various disciplines in engineering, with a focus on mechanical engineering.
- Explore Careers in Technology and Engineering program is designed to encourage post-7th grade students to learn about careers in technology and engineering, including aeronautical, biomedical, chemical, and environmental engineering, and computer science.
- The Introduction to Chemical Industry for Minorities in Engineering Program (IChIME) is designed to give post-8th grade urban students an opportunity to increase their awareness, understanding, and participation in the fields of chemical engineering and chemistry.

The High School Connection

The College Prep is designed to prepare students for college-level work while they are still in high school with instruction in Advanced Mathematics, Communications, Computers, and a science discipline. The Early College Programs allow high school students to earn college credits, either on the NJIT campus or at their home schools.

IMPACT THE CLASSROOMS OF NEW JERSEY

Under the auspices of the Center for Pre-College Programs (CPCP), the Education and Training Institute (ETI) provides K-12 educators with professional development that deals with pre-engineering content, and with the implementation of standards-based lesson plans in the content areas of science, technology, engineering, and mathematics. The professional development programs are designed to fit the instructional classroom needs of grades K-12 teachers by addressing the implementation of content standards in science, and the teaching of pre-engineering skills of design and problem solving [6, 9]. To accomplish its goal, the professional development programs include the following:

- Standards-based STEM Professional Development Workshops are designed to address the academic needs of K-12 students through a hands-on, inquiry-based instructional strategy of applying problem-solving, engineering design and communication skills to mathematics and science principles.
- Scientific Inquiry and Engineering Design compares the processes of engineering design and scientific inquiry through design challenges while enhancing problem solving skills.
- Engineering Content Workshops provides academic year and summer workshops that integrate real-world engineering applications into the middle and high school science or mathematics classroom.

Academic Programs for Teachers

Professional development is integral to increasing teachers' knowledge and skills, and to learning effective application of the skills in the classroom in order to meet the needs of all learners. However, traditional teacher training institutes and after-school workshops have often been seen as ends in themselves. Our current professional development efforts seek to improve and enhance teacher skills and knowledge in the content areas and in the implementation of standards-based lesson plans that include the assessment and documentation of students' achievement of those standards in their lessons. Our endeavors include the preferred practices described for professional development, where we:

- 1) Focus on planning and instructional needs, while extending the model over time as new skills are practiced in the classroom; and
- 2) Create a peer learning community to assist teachers with planning and implementing curricula.

Real-world Engineering Applications

The content area emphasis on science, mathematics and engineering education can result in improvements to science curricula for secondary schools and increases students' interest in science, mathematics and engineering. A curriculum containing engineering and real-world problems and applications would stimulate and engage both students and teachers while enriching curricula in secondary school science and mathematics courses. However, it must be designed to supplement, rather than replace, current science and mathematics curricula. Our professional development programs that focus on the enrichment of science and math curricula demonstrate to teachers how the integration of principles of engineering and design into their teaching practice can be utilized to help their students acquire the skills and knowledge specified by the standards. Connections are developed between the concepts used in engineering applications in the modern workplace and standards-based science and math instruction.

“ENGINEERING THE FUTURE” PROGRAM

Engineering the Future is an outreach program meant to promote science, technology, engineering and mathematics careers through partnerships with businesses, educational groups, and professional organizations. Engineering the Future has created and organized numerous programs, including Fall and Spring Engineering Career Days, Faculty Visitation Program, Engineering Outreach Visitation Program (on and off NJIT campus), and Summer Education Best Practices Conferences. This outreach program brings together an alliance of three groups of stakeholders: educators, counselors, and parents, through networking, coordinating, and distributing information from STEM professionals and their professional associations. Workshops, conferences, and the website provide information on STEM careers and the pathways to achieve success in these professions. Engineering-A-Career “hands-on” presentations are given at schools to increase interest in STEM and to motivate young people to strive academically and succeed professionally. Outreach uses state-of-the-art multimedia presentations, videos, interactive CD-ROMs, brochures, public television announcements, and billboards.

To help teachers and other stakeholders understand the role of engineering, and to reach the largest number of teachers, the Engineering the Future Outreach program undertook the development of a series of teleconferences entitled “Building an Engineer”. Three teleconferences were held at NJIT, and the last two were broadcast on the web. These teleconferences included panel discussions on various aspects of engineering as a career, along with interviews of practicing engineers. In addition, a DVD (along with an instructional guide for use in the classroom) was created for each of the teleconferences. These DVDs are available from the Center for Pre-College Programs upon request.

PARTNERSHIPS WITH BUSINESSES, K-12 SCHOOLS, AND PROFESSIONAL ORGANIZATIONS

Partnerships have been the backbone of the efforts of the Center for Pre-College Programs. The collaborative efforts

of NJIT, with local school districts, community groups, corporations and foundations, and science centers have given us the opportunity to serve an increasing number of students and expand our programs to younger students in the elementary schools. Of special importance are the long-term relationships that have been established with major urban districts such as Newark and Union City, and with individual schools. Many of the programs are targeted towards specific schools within the districts. In addition, we have been able to assist schools to address and meet their specific needs. One example is the Newark Public Schools (NPS)-NJIT FIRST Robotics partnership.

As part of a comprehensive effort to support and enhance the participation of Newark students in the US FIRST Robotics Competition (FRC) and the FIRST LEGO League (FLL) Competition, New Jersey Institute of Technology (NJIT) and the Newark Public Schools (NPS) expanded our long time partnership by initiating a program that should lead to enhanced knowledge and skills of teachers and students for participation in these competitions. The partnership provides assistance to high school student teams and their coaches for participation in the FIRST Robotics Competition and to middle school students and their coaches for participation in the FIRST LEGO League tournament.

The staff of the Center for Pre-College Programs (CPCP), NJIT's Newark College of Engineering, and the Career Development Services Office at NJIT collaborate to provide Newark Public Schools with follow-up programs, including mentoring, training workshops, Saturday help clinics, and a robotics virtual help desk for both high school and middle school groups, as well as site visits by NJIT students to each middle school team meeting and campus space and facilities for the high school teams, as teams of Newark students prepare for participation in the next US FIRST Robotics and LEGO League Competitions. NJIT college students work with 2-3 high school teams each under the supervision of an NCE technician from an engineering department and use the departments' machine shops for the six week "design and build" phase of the competition period. The college students assist the teams in the design, fabrication and construction of the robots, as well as the autonomous programming of the robot using "C" programming language. These programs lead to more enriching learning experiences for all students participating in these competitions.

EVALUATION AND ASSESSMENT

Outcome measurements and assessments are an integral part of all pre-collegiate initiatives at NJIT. Instruments for assessing student learning and the impact in the classroom are a major component of the assessment process. The methodologies are varied, due to the variable nature of the different programs, most notably student programs versus teacher training programs. Variation in student or teacher exposure to subjects and experiences further complicates the task. Many assessment methodologies are being field tested for student programs. For the student programs, an evaluation coordinator is on staff to analyze and develop

appropriate tools to determine student's quantitative and qualitative skills, basic process skills, establish guidelines, and modify curricula if necessary to accomplish program goals [10]. Evaluations focus on impact in the classroom. Survey instruments measuring attitudes to and knowledge of engineering, have been developed, validated, and utilized for students, [11-12] and their stakeholders – teachers [13], parents and guidance counselors [14]. Evaluation of teacher training includes the development, validation, and implementation of workshop assessment instruments, as well as an assessment of impacts of curriculum and training programs on teacher practice and classroom implementation. Teachers were asked to self-evaluate the degree to which they felt they were ready to teach the topics or concepts from the workshop using the Readiness to Teach Questionnaire. Teachers' concerns about integrating engineering into their classrooms were measured using The Concerns Questionnaire for Teachers [13].

Results of summative evaluations indicate that knowledge about engineers and engineering as a career increased for middle and high school students' whose teachers attended a professional development program [15]. A recent 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. 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. The long term impact of NJIT's Pre-College Programs for alumni of these programs have shown over 70% of responding Pre-College alumni that have graduated high school have enrolled in Engineering, Technology, Science, and Mathematics undergraduate programs and/or have gone on to careers in those fields.

CONNECTING K-12 EDUCATION WITH THE UNIVERSITY

NCE faculty and students play key roles in many of the activities of the Center for Pre-College Programs, as we enrich students' academic preparation, increase their motivation for entry into SMET undergraduate programs and careers in these fields, and provide training and technical assistance to educators in the schools and districts. The primary areas of involvement include (but are not limited to):

- Freshman Engineering Design modules adopted by faculty for use in secondary level student programs [15].
- Engineering faculty providing professional development programs for secondary grade level teachers.

- Pre-College programs designed specifically for engineering disciplines.
- Engineering graduate students assigned as GA's for professional development of teachers and providing lessons for school children (Science Outreach Program).
- Competitions in engineering and science subjects hosted by NJIT, with the support of NCE faculty and students.
- Research experiences for high school teachers in university research laboratories and research centers.

The Center brings the experience and expertise in education and evaluation/assessment to the University level, that which has been gained from collaboration and effort in the K-12 sector. Several of the outcomes of our pre-college programs are transferable to the university environment, including:

- Instructional methodologies.
- Expectations and assessment of student work.
- Assessment/evaluation of programs and instruction.

CONCLUSIONS

We have recognized the need for the University and its faculty to be involved in K-12 education. Maintaining the talent pool in the K-12 part of the pipeline is essential to the health of the science, engineering, and technology professions. We have successfully developed enrichment programs for secondary school students that provide them with a continuum of learning opportunities, aligned with the N. J. Core Curriculum Content Standards in science and mathematics. It also integrates the learning content with the development of an awareness of the excitement and challenges of these professions, and the track to be followed to enter the professions. The need for accountability has led to the development of alternative assessments for our diverse program goals. Of equal or greater importance are the teachers of these students, who need our help to maintain and improve their practice and content background, as they help their students to achieve the skills and knowledge demanded by the standards.

Finally, while we have been able to utilize our strengths to benefit the K-12 population, we have also been able to demonstrate that there are reform practices in the K-12 sector that we should adopt to strengthen our part of the pipeline.

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