

Model for a K-12 Engineering Pipeline

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Abstract

The Center for Pre-College Programs at New Jersey Institute of Technology (NJIT) 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 schools in the region and the State. 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.

Engineering is used as the vehicle to involve pre-college populations in technological education and to motivate the children to pursue technological careers. For example, NJIT's Women in Engineering & Technology Initiative - FEMME program is an intensive four-week single-gender program offered in the summer to post-fourth through post-eighth grade girls. Academic curricula and coursework is specially designed in alignment with the New Jersey Core Curriculum Standards (NJCCS). A main thematic unit created for each group introduces each grade level to a different engineering specialty: fourth grade girls study environmental; fifth, aeronautical; sixth, mechanical; seventh, chemical; and eighth, biomedical engineering. 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 parents.

Introduction

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 environs¹⁻². 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.

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 pipeline³⁻⁵. 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 levels⁶⁻⁷, to impact future generations of students earlier and with greater intensity that is currently possible.

Systemic reform means changing the way teachers teach and students learn. There is a critical need to restructure the methodology of teaching science and mathematics. The traditional way of teaching is through reading from the textbook and doing problems through rote memory of formulas and facts. Laboratory experiences are then used to verify "the facts" stated in the textbook. There is no substitute for actually doing science and mathematics. We need to integrate the content and teaching strategies. Students need to learn from their own experiences rather than just listening to lectures and then passively verifying those facts stated in textbooks through laboratory activities.

Professional development of teachers provides an enhanced learning environment for the students of these teachers. Systemic reform that will: a) change the teaching of science at all grade levels in all classrooms; and b) provide the integration of science with mathematics and in other subject areas in each school is needed. Such systemic reform must extend throughout the K-12 pipeline.

The Center for Pre-College Programs

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.¹⁻² 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's Pre-College Center 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. 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's teaching and training approaches and methodologies are carefully planned in order to make a crucial contribution to participants' comprehensive development. 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 Content Standards, and the students with access to appropriate science, mathematics and technology education. The Center's programs are systematically organized into seven complementary categories:

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

Instruction, Curriculum Reform & Standards

NJIT provides various professional development programs and technical assistance in the alignment of instruction, curriculum, and assessment with the New Jersey Core Curriculum Content Standards (NJ CCCS) ⁶. The goal is to assist schools and districts in the achievement of systemic change with a focus on implementing standards-based-instruction in all classrooms.

Urban Partnerships

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. School collaborations include teachers, parents, and administrators.

- *The Science Outreach Program* trains NJIT graduate students to provide weekly in-class support to elementary and middle school teachers. The Program has led to teacher instructional change in keeping with both national and New Jersey State standards in teaching and learning of science^{3,7}.
- *Gaining Early Awareness and Readiness for Undergraduate Programs (GEAR UP) Partnership*, funded by USDOE, is a partnership of NJIT and Newark's Camden Middle School. It provides grade level cohorts of students with the necessary guidance, skills,

and motivation needed to successfully complete high school and enroll in post-secondary education and professional development for teachers.

Women in Engineering and Technological Initiative

Through its Females in Engineering initiative, NJIT's Pre-college Center encourages post-fourth to post-ninth graders to enroll in advanced science and mathematics courses and to choose engineering and related careers⁸⁻⁹.

TRIO Programs

The national TRIO programs and activities are authorized under Title IV of the Higher Education Act of 1968 and funded through the U.S. Department of Education. NJIT conducts three of these pre-college programs: Upward Bound, Talent Search, and Upward Bound Regional Math and Science Center.

Bridge to STEM

NJIT's Pre-College Center offers programs that 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.

- *Experimental Math, Science and Communication (EMSCP) Program*, for post-seventh graders, uses an inquiry-based, student centered approach to develop basic concepts in algebra, trigonometric, geometry, and statistics and apply them to topics in engineering and science, such as aerodynamics and structures.
- *Introduction to Chemical Engineering (IChIME) Program* is designed to introduce post-eighth grade urban youngsters to the excitement of engineering within the chemical industry¹⁰.
- *Urban Civil Engineering Summer Institute (UCESI)* uses an inquiry-based, student-centered approach to introduce for post ninth graders to the engineering approach to urban problem solving and confront problems that affect the quality of life in urban areas¹¹.
- *Engineering Prep Physics Program (EPPP)* will prepare high achieving post-tenth or post-eleventh grades students to take and successfully complete Physics in high school while improving their science and mathematics academic achievement.

Interfacing with Engineering Faculty

NCE faculty and students play key roles in many of the activities of the Pre-College Center as we enrich students' academic preparation and increase their motivation for entry into SMET undergraduate programs and careers in these fields. This occurred as a natural process in the University as the Center has its origins in the Department of Chemical

Engineering and Chemistry with a Director who is a member of the faculty in the Department of Chemical Engineering. The primary areas of involvement include (but not limited to):

- Freshman Engineering Design modules adopted by faculty for use in secondary level student programs.
- 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 opportunities for high school students in university research laboratories and research centers.

For example, the chemical engineering module from the Freshman Engineering Design Course has been adapted for several of the Pre-College student programs, including the ChIME Program, the FEMME programs, and the Upward Bound Program¹². Undergraduate chemical engineering students eligible for work-study funds or the Undergraduate Research Experience program work with the faculty. They first run all the experiments in teams of two, and correlate their measurements. Then, under the supervision of the faculty, these students become teachers and mentors for the pre-college students. Experiments include:

- 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.

A Closer View – Prototype Programs

The Women in Engineering & Technology Initiative - FEMME program provides intensive four-week summer programs to post-fourth through eighth grade girls. The program aims to enrich academic skills in science, mathematics and technological fields, develop problem-solving & critical thinking skills, and promote careers in engineering, by enhancing the students' sense of efficacy in scientific, engineering and technological fields in which women are traditionally underrepresented.

Developed by the Center for Pre-College Programs, FEMME concentrates on those technological areas necessary for the future. Academic curricula provide students with opportunities not available in their high school to master higher level problem solving skills in mathematics, science and technology; learn about architecture, computer science and engineering principles, and practice written and oral communications. The structure of the program includes classroom discussions, lectures, laboratory experiments and demonstrations, projects, and field trips. Projects and field trips relevant to the group theme enhance all classroom activities. Problem solving skills are stressed throughout the program to allow students to feel confident in their abilities to make decisions, while encouraging

them to attain their academic potential through hands-on projects related to any scientific and engineering discipline. Students work in teams in an effort to increase group dynamic skills so important in today's workplace. All activities utilize non-biased "gender friendly" instructional methodologies, problem solving cooperative techniques, and a teamwork approach. Students learn by "*doing rather than viewing*," the best methodology for all students, but especially for girls who tend not to have as many opportunities or to be as encouraged as boys to work with their hands, use tools, equipment or any type of scientific apparatus. Students participate in counseling and mentoring sessions to learn first-hand about career opportunities available for women in scientific fields and interact with female scientists and engineers in industry and academia.

The first FEMME program was developed and implemented in 1981 for young women designed to encourage and motivate them in science and mathematics and pursue careers in such fields⁸. This four-week summer and academic year program targeted post ninth grade female students at a time when they could still be positively motivated and influenced in their choice of mathematics and science courses in high school and encouraged to pursue careers in SMET fields.

The success of the first FEMME program was remarkable. A 1987 follow up study of 75 FEMME alumni elicited 72 responses indicating that 98% had taken 4 years of mathematics, and 91% had taken 4 years of science in high school, 92% had enrolled in a 4 year college or university, and 73% had declared a SMET major. Again, in 1994, a follow up study of 340 FEMME alumni elicited responses from 170 participants. Of those 135 girls had graduated from high school and 134 were pursuing post-secondary degrees: 24% science based, 25% mathematics based, and 21% engineering (according to the Engineering Manpower Commission report for the 1993-1994 academic year, only 16.1% of graduating engineers were women). Of the respondents still in high school (35) 77% were taking advanced mathematics and science courses. All FEMME alumni participated in other SMET enrichment programs.

Based on our studies in the late 1980s and early 1990s³⁻⁵, the need for a program to counteract the movement of girls away from science and engineering in the middle schools became apparent to the Pre-College Center's administrators. Youngsters, especially female students, must be reached earlier than ninth grade in order to provide a continuous nurturing environment to minimize "leakage" in the engineering/scientific pipeline. Girls should receive science and mathematics enrichment and personal motivation prior to ninth grade, and such intervention should start at the point when they are still not influenced by "expectations," academic courses are mandated by school curricula and not minimum requirements, and their sense of self-efficacy is positive.

Since academic instruction in the fourth grade moves from concrete to abstract concepts, in 1993, with seed funding from the National Science Foundation (NSF), the Femme program was expanded to encompass post-fourth and fifth grade girls. The second FEMME group was born! The Introduction to FEMME (IFEMME) was designed to offer 48 fourth and fifth grade high-ability girls an opportunity to improve their science and mathematics achievement, promote healthy self-esteem and self-confidence and inspire feelings of

competency while challenging their fear of failure. The academic curricula included environmental science, mathematics, communications and introduction to computer science. In addition, projects and field trips complemented the curricula.

Building upon the success of IFEMME in 1993, NSF once again provided seed funding for FEMME Continuum (FEMMEC) for IFEMME alumni. Forty of the original participants (83.3%) returned and completed FEMMEC. This program expanded the academic activities started in the original IFEMME program. Thus, by 1994 there were three FEMME programs at NJIT as IFEMME was open to a new cohort of 24 students.

Since then, the programs expanded under the umbrella of the Women in Engineering & Technology Initiative - FEMME program. Currently, FEMME is an intensive summer four-week program offered to post-fourth through post-eighth grade girls⁹. Academic year workshops are also included. Specially designed components introduce each grade to a different engineering specialty: fourth grade girls study environmental; fifth, aeronautical; sixth, mechanical; seventh, chemical; and eighth, biomedical engineering.

Environmental Science & Engineering-FEMME4

Designed for girls who have completed the 4th grade, the Environmental Science thematic focus follows the New Jersey Core Curriculum Standards for grade level five and thus gives students sufficient prior knowledge from which they could build during their fifth grade academic year. The program is designed to provide students with an opportunity to investigate terrestrial and aquatic environments as well as preferred environments of certain organisms.

Aeronautical Engineering-FEMME5

Designed for girls who have completed the 5th grade, the Aeronautical Engineering participants learn how; a) since the early days of flight, women have been active in aviation education and development; b) opportunities for women in aviation did not come easily but were born on decades of struggles and determination; and c) aviation improves lives economically, technologically and socially. Topics include: properties of air, flight, and aerodynamics, airports, history of aeronautics, airplanes, and helicopters, comets, hot air balloons, and rockets.

Mechanical Engineering-FEMME6

Designed for girls completing the 6th grade, the Mechanical Engineering thematic focus gives girls an understanding of what mechanical engineers do and what it takes to become a mechanical engineer. Through hands-on activities students designed, constructed, and analyzed different projects dealing with machines, forces, acceleration, aerodynamics, and Newton's Laws of Motion.

Chemical Engineering & Chemistry-FEMME7

Designed for girls completing the 7th grade, the Chemical Engineering and Chemistry thematic focus introduces the girls to the world through the lens of a chemical engineer and/or chemist and how chemical reactions affect our everyday life. Topics covered include chemical reactions--acids, bases, and pH, proper measurement of solids, liquids, gases and solution concentrations, and separation methods. As a final project, the students will test claims made by manufacturers about a chemical product in their laboratory experiments.

Biomedical Engineering-FEMME8

Designed for girls completing the 8th grade, this program introduces participants to an engineering discipline that integrates engineering sciences with biomedical science and clinical practices in order to improve methods to solve clinical problems in the fields of health and medicine. Topics are divided into the study of biology, biomechanics, bioinstrumentation, bioengineering, biotechnology, and rehabilitation and clinical engineering.

Outcomes

Outcome measurements and assessments are an integral part of all pre-collegiate initiatives at NJIT. Traditional program evaluation methodologies are utilized to assess the programs. Program participants complete evaluation questionnaires regarding academic curricula, teachers and methodology at the end of each program. Instruments for assessing student learning are a major component of the assessment process. 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. Prior to the start of each summer program, directors, teachers and teaching assistants meet with the Center's Evaluation Coordinator, to analyze and develop appropriate tools to determine student's quantitative and qualitative skills and establish guidelines. Traditional methods of measurement are utilized to assess written assignments including standard and multiple choice tests and essays, the use of rubrics, student journals, student portfolios, and pre and post test results are utilized as valid methods of measuring process skills

As an example of the results of the pre- and post-tests, we can look at the pre- and post-tests for one of the FEMME Programs. The FEMME6 program for post-sixth grade girls focused on mechanical engineering. For the summer 2001 FEMME6 program a comparison of students' individual scores in the pre and post-test indicated that students scored significantly higher in the post test. Both exams contained the same content. For creditability, the format and sequencing were changed. The results were remarkable given that it was a four-week program and the diverse pool of student participants. On the pre-test, there were 38 (of 45) students scoring less than 40%. The average of the pre-test scores was 17%. The highest pre-test scores were two scores of 54. On the post-test, 14 girls scored above 80% (7 above 90%). Of the 45, 40 scored at least 51%. The average of the post-test scores was 68%. Of the two girls who had pre-test scores of 54%, one had a post-test score of 99% and the other a score of 87%

In 2002, only one group of 25 girls for FEMME6 was accepted due to staffing limitations. Hence we were able to be more selective in choosing the participants, and the differences between the pre-tests and the post-tests were not as dramatic as the 2001 group. Thus, the pre-test scores were higher with an average of 51%. Nine of the 25 scored over 70%. The average on the post-test was 91%. Thirteen students had scores of 91% or better, and five others scored above 81%.

Program teachers developed rubric assessment instruments to evaluate the extent to which their students improved their hands-on skills in their subject area – engineering, computers, science, math, and communications. Because of the diversity of courses, each teacher has to develop an appropriate instrument for assessment. For all academic subjects in all groups they are required to:

- 1) Include detailed lesson plans of topics covered in class, including handouts and assignments.
- 2) Submit documentation outlining student academic advancement in their classes at the conclusion of the summer component.

Completed rubrics assessing individual student's performance in group activity work and portfolio sampling of the work done by the students in class were also included.

Most important to the pipeline issue is the tracking of participants after completion of the student program. All participants are followed-up on long term basis to determine: students' progress in middle and secondary school, choice of courses, personal development, and choice of career and institution of higher education. The Center for Pre-College Programs has in place a computer database for the purpose of research and to accurately track all pre-college participants. Statistical information is currently available for students who participated in programs between 1981 and 2000.

The total number of CPCP alumni of student programs operated between 1980 and 2000 was about 3800 students. All were sent questionnaires in 2000. We received responses from 1292 former participants, a response rate of 34%. For these types of surveys, 34% is considered a very good response rate.

Of the responses received, 984 (76.1%) were either graduated from a post-secondary institution or still in an undergraduate program. The remaining 294 respondents (22.8%) were still attending an elementary or secondary school and had not indicated a career choice at this time. Fourteen (1.1%) did not attend college. About 65.5% (847) of respondents have selected a technological career (engineering, science, computer and information systems, math, or architecture). The primary career options of the respondents were Engineering (34%), Science (20%) and Management (13%). About 8% indicated Computer and Information Systems, and 2% were in Mathematics-based careers.

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Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition
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