

A FRESHMAN DESIGN EXPERIENCE: RETENTION AND MOTIVATION

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INTRODUCTION

New Jersey Institute of Technology has seen an improved retention rate of freshman students in the past two years. Reasons for these positive changes include curriculum changes and incorporation of new teaching methodologies. Freshman students are more motivated to learn about engineering and to be successful in their studies. Involving the students in their learning process through enhanced active learning methods has resulted in improved interest and participation in their engineering education.

A change in curriculum has introduced a new course into the freshman year, Fundamentals of Engineering Design, FED 101. The course introduces the new engineering student at NJIT to the various engineering disciplines and the design process that engineers experience in industry. The course is taught by a team of professors representing the various traditional engineering departments who direct projects related to their areas of expertise. Freshman students work through these projects in teams of three or four with an emphasis on active learning. Students learn by doing and by researching topics relevant to their project.

BACKGROUND

New Jersey Institute of Technology is one of ten engineering schools who are partners in the Gateway Engineering Education Coalition (NSF Award EEC 9109853), supported in part by the Engineering Education and Centers Division of the National Science Foundation for a period of 5 years starting in 1992. The Gateway partners are:

Cooper Union, NY
Columbia University, NY
Polytechnic University, NY
New Jersey Institute of Technology, NJ
Drexel University, PA
University of Pennsylvania, PA
Ohio State University, OH
Case Western Reserve University, OH
University of South Carolina, SC
Florida International University, FL

During 1991, initial planning sessions of the ten Gateway Coalition partner schools identified Curriculum Innovation and Development (and design) as a principal area of interest to all partners. Thus, NJIT dated a **high priority** on curricular innovations with **special emphasis** on the freshman engineering program. This priority was motivated by desires to alleviate retention problems identified "at many



engineering schools. Improvement of engineering design throughout the curriculum has been a popular topic in many engineering education meetings and other interested groups. In particular, the Manufacturing Studies Board of the National Research Council issued a timely report entitled Improving Engineering Education [I]. The Manufacturing Studies Board includes industrial leaders and academicians and several recommendations and comments are most appropriate for development of engineering design courses. For example:

“Design education is clearly weak; it must receive increased emphasis and introduce modern design practices if it is to educate engineers who will contribute to the drive towards greater industrial competitiveness.”

“Undergraduate engineering design education must:

- show how the fundamental engineering science background is relevant to engineering design;
- teach students what the design process entails and familiarize them with the basic tools of the process;
- demonstrate that design involves not just function but also producibility, cost, customer preference, and a variety of life cycle issues; and
- convey the importance of other subjects such as mathematics, economics and manufacturing.

To achieve these goals, design must be distributed throughout the engineering curriculum, beginning with introductory design courses, which serve the dual purpose of introducing the design process and demonstrating the relevance of the engineering courses to design, and continuing as part of the more advanced engineering courses.”

The first four NSF Engineering Education Coalitions (SYNTHESIS and ECSEL, in 1990, and SUCCEED and GATEWAY in 1992) suggested that freshman design was an important area focusing on improved engineering education and listed design and the freshman year as priority areas.

During 1991-1992, the efforts for the first year of the Gateway Coalition at NJIT focused on planning the freshman design course and included exploration of the various modalities used to teach freshman engineering design at other schools. In particular, parts of other partners' freshman engineering curricula were reviewed, and where appropriate, adapted for use in the NJIT freshman design course. A faculty committee with representation of mathematics, physics, chemistry, humanities, social science, and all engineering departments was formed and began considering possible incorporation of an engineering design experience in the freshman year. The freshman year curricula is common to all NJIT engineering students. The existing course EG 101, Engineering Graphics, was selected as an appropriate candidate for revision and upgrading. The Committee considered several Gateway models and after careful deliberations proposed a replacement course, Fundamentals of Engineering Design, FED 101, which would retain most basic graphics content of EG 101 but changed course teaching methodology to provide learning of skills during the process of working through engineering design modules. Instead of following chapters in a text for the purpose of learning a specific body of knowledge and testing students to determine how well the information was retained, an improved approach was developed. Thus, freshman students now become part of a design team working on a deliverable. In developing a solution to the design problem, a variety of skills are learned “just in time,” often termed “concurrent engineering.” Thus, when students need to produce drawings, a CAD program is learned and used. Or, if students need to collect data and arrive at some conclusions, some simple principles of statistics are learned and used. The faculty committee developed modules in order to provide the student teams with realistic design learning experiences. Each module focuses on one or several traditional engineering fields. NJIT's resources such as: laboratories containing testing equipment, chemical analysis equipment, machine shops, robotics labs, among others, are available to freshman students. Also, recently built computer rooms equipped with modern Sun workstations are designated for freshman use.



HISTORY

In the summer of 1992, Drexel University offered a workshop for the participants of the Gateway Engineering Education Coalition and many others. Drexel had developed a unique curriculum of blending courses and topics into a full two year program that was called their E⁴ program, or Enhanced Engineering Education Experience. The idea was centered around particular engineering type projects that incorporated the skills of mathematics, physics, chemistry, statics, dynamics, economics, humanities and social sciences. E⁴ was intended to be an ongoing experience during the first two years of Drexel's engineering education. Drastic changes were made in the lower division engineering curricula. Faculty from the engineering programs as well as the mathematics, science, and humanities departments joined together to collaborate on numerous topics for projects that cut across the disciplines and involved all the support departments. Faculty did team teaching and students worked in teams. Most of the projects were open ended design concepts that required creativity and ingenuity on the part of the student. Students were encouraged to research answers to their questions and to seek assistance from any of the faculty on campus. As the need arose at different stages of the project, faculty from a particular department or engineering program would lecture on the topic relevant to the progress of the project. The humanities faculty played a key role in developing technical writing skills and improving oral communication. Students were graded on final reports and presentations of their project designs. Since students worked as a team, the team shared the grade of the final reports.

ADOPTION AND ADAPTATION OF THE E⁴ PROGRAM AT NJIT

The original intent of the FED 101 course at NJIT was to offer one project covering all major areas of engineering. However, the logistics of teaching schedules for team teaching and the type of project has varied over time and is still evolving. In the interim, each of the individual modules offers a unique project pertinent to that discipline, yet all have a common goal. That goal is to have the students work together as a team while using some creativity in solving a typical engineering problem. The students are also exposed to decision making, time management, data collection and analysis, concurrent engineering, manufacturing, quality assurance, and even marketing strategies while at the same time practicing and enhancing their communication skills. Most of all, the students are learning about working together as a team while solving engineering problems through hands-on experience. A primary objective in each module offered is to motivate the students to be creative in their approach to solutions for any particular problem. Emphasis is on the entire engineering process from the initial problem description and objective through the final problem solution which may involve many aspects of analysis relevant to that particular engineering discipline. The faculty are there to facilitate the work of the students with minimal time spent on formal lectures. Instead, individual group discussions bolster the student teams through their decision making process.

During the 1992-1993 academic year, a core group of professors representing three of the engineering disciplines worked together in planning the Fundamentals of Engineering Design course. The outcome of their efforts resulted in four pilot sections of the FED 101 course being taught in fall 1993 and four in spring 1994. This totalled approximately 136 incoming first-time, full-time, freshman engineering students. The course had eight professors representing the Civil, Electrical, and Mechanical Engineering disciplines. A seven week civil engineering module was followed or preceded by a seven week electrical engineering module taught concurrently with a fourteen week mechanical/manufacturing engineering module. Thus, students enrolled in FED 101 met six hours a week with eight different professors, learning and participating as teams in three different projects.

This team effort includes not only the engineering disciplines, but also includes the Humanities and Social Science Departments. The FED 101 course has been paired with a new Humanities and Social Science course, HSS 101. The sections of students taking FED 101 are kept together in the HSS 101 course. The HSS 101 professors work very closely with the FED professors and this collaboration integrates material presented in the two courses. For example the topics presented in the FED modules are matched to reading and discussion assignments in the HSS course. The HSS professors also help the



students with creative thinking, technical writing skills in the preparation of the final written reports, and communication skills in preparation for oral presentations required in each of the FED 101 modules.

The Civil Engineering Module used a unique team teaching approach with two professors teaching each section, offering differing opinions of how to resolve a typical environmental issue of supplying water from the Round Valley Reservoir to a nearby community. Students were required to visit the geographical area and study maps while planning their route. They learned about pipe flow and pipe sizes, hydraulics and pumping stations, property easements and community regulations pertaining to construction, and how to determine the cost of such construction. This year, the project objective challenged the students to design a route to ease traffic flow into the inner city of Newark from a major highway north of the city and one south of the city.

The Electrical Engineering Module introduced the students to electrical components and circuitry. Classroom instructions acquainted the students with series and parallel circuits and the purpose of each electrical component. With this knowledge, they worked in teams in a dedicated freshman design lab to assemble circuits that would work with solar energy. The specific project objective was to design a circuit that used a photo-sensitive resistor that could turn a light on when the room was dark and to turn it off when it was light.

The Mechanical Engineering Module included a graphics portion which taught the students about drafting techniques using a solid modelling software package, Pro/ENGINEER. Students were asked to create a toy made of several mating components. When modeled in CAD, this file was exported to a Stereolithography Apparatus (SLA) to produce a solid, plastic, prototype of their toy components. This rapid prototype manufacturing approach helped to deliver a tangible product and to teach the students about fits in assembly and quality assurance. A dimensional check of their prototypes made it clear to them the necessity of tolerancing for machinability. A cost analysis of their prototypes led to researching estimated production costs by contacting vendors in industry. Subsequent projects included disassembling and modifying kitchen electric appliances and designing applications for slider crank mechanisms.

In the fall of 1994, a module in Chemical Engineering was introduced. It consisted of measurement experiments where students were placed in a laboratory setting and used various instrumentation to measure the effects on flow through different valves and orifices. Students learned about relationships of flow, pressure, and water level by running the experiments, collecting data, plotting, and analyzing this information. Some of the experiments included rotometers, air filtration through a packed column, and flow through parallel and series pipes with valves and orifices.

In the spring of 1995, Bio-medical Engineering was added to the selection of modules that are now offered to the students. The first design project analyzed the simulated blood flow through the heart. The second design project entailed some creativity in redesigning a leg extension machine used for therapeutic exercise after knee surgery.

Along with these modules, the students were encouraged to use electronic mail to communicate with their team mates as well as their professors to maintain steady progress on their projects. Journals were maintained throughout the semester to keep professors abreast of project progress or to make the professor aware of conflicts within the team or problems with any other course work. Many times, the journals were used to convey personal messages which helped the professor to inform these new freshmen of services available to them.

A unique element of the ME Module was the use of poetry readings. Students would read or recite poetry to help alleviate their inhibitions of speaking in front of an audience. These readings helped improve their public speaking skills. Classmates were asked to critique each other in these recitations in order to make them more aware of voice projection, voice inflection, and body language so as to keep the attention of the audience. This prepared them for oral presentations required at the end of each module.



Professionals from industry were invited as guest speakers to present lectures on several topics, to enhance student understanding about an engineering career. For example, guest **speakers** discussed: industrial design and sketch renditions presented by a professional designer and owner of his own consulting business; safety in design presented by a certified safety expert; copyrights and patents of original designs discussed by a patent attorney who is a board member of NJIT; design of prosthetic devices for human limbs presented by a technician from the Kessler Institute for Rehabilitation; and a discussion of consulting in engineering by a distinguished NJIT professor.

In the current academic year (1995-1996), the team teaching concept is to be employed as the team of **professors** continue working to develop projects that cross all engineering disciplines with inclusion of humanities, social sciences, economics and management. The team of professors are also planning a second course in Fundamentals of Engineering Design for a two semester sequence of FED 101 and FED 102. This sequence is to include more computer applications to enhance students' skills in the use of their own PC's and UNIX workstations in the freshman computer laboratories.

SURVEY RESULTS AND STUDENT FEEDBACK

Formal and informal student feedback on the course work (and described in their oral reports) indicate that students consistently show enthusiasm about this new learning process. The course is very different from their high school experience, and definitely requires a student mind set change. However, students quickly realize that they are very much responsible for their own education.

In some cases, it has been difficult for students to adapt to the flexibility in the classroom structure where they are encouraged to speak up and ask questions of faculty, to pose possible solutions to project ideas, to query their peers on responses made to other questions, and to consider alternative solutions to problems that arise while working on modules. Students are often surprised to learn that their ideas and input count and are taken seriously.

In many cases, it has also been difficult for some of the students to adapt to the amount of responsibility placed on them. In each of the modules, deadlines are set for the different stages of the project. If students meet these deadlines, they realize that the work goes smoothly and the project will be finished on time. Thus, students learn that the work is progressive and each piece of the project is dependent on the completion of the part before it. A certain continuity becomes evident. If deadlines are not met, they become pressured to "catch up" in order to complete the entire project. In one module, the milestones are presented to them electronically through a home page on the World Wide Web. This medium was chosen as a way to introduce the students to the electronic network and to help them become more resourceful and gain self confidence.

Several results have been observed using this approach. One is teaching time management. Budgeting time and work is basic to any student's success in college and later as a professional in industry. Students are juggling all their freshman courses and learning to prioritize. They are encouraged to budget their time based on the various phases of the project and meeting intermediate deadlines as the project progresses. Another result is that students learn that any or all material learned is important for success in arriving at results. In a traditional course, it may be possible for a student to slide through one or two chapters of the textbook and perform average on one of four exams and still do well in the course. In FED 101, the final project determines their grade. And since the work is cumulative and progressive, any errors committed during their research, design, or analysis could result in erroneous conclusions on their final report. Student experience working as a member of a team is also a valuable feature of the course. Students learn that they can find each others' strengths and learn to pool their unique talents. They learn to delegate tasks and to monitor each other because their final grade depends on the work produced by each individual team member.

Team dynamics sometimes can present difficulties. Each year, a different approach was followed in forming student teams. In the first year, the SAT scores were used to place students with one high score,



one low score, and two average scores on every team. The purpose was to have “balanced” teams. It was anticipated that the student with the high SAT score would emerge as a team leader and take responsibility for coordinating the project and delegating the tasks. The student with the lower SAT score might be pressured to produce a higher share of the work and thus learn responsibility and possibly ask many questions. Inadvertently, the lower score student would learn from the others on the team. However, this was not always the case. Personalities played a major role on team performance. Sam Hilborn (University of South Carolina, a Gateway Coalition partner school) employs the Myers-Briggs Type Indicator to determine personality types for team formation criteria [2]. Not having the availability of the Myers-Briggs Type Indicator at NJIT, a different and random method of assigning students to teams was developed. The random method consisted of assigning students to teams based on their birthdates and the Zodiac. Strangely, this approach worked better but was still not perfect because, academically, some teams were extremely weak and some exceptionally strong. This past year, a “style of leadership” survey was used in assigning students to teams. This approach has been used successfully in forming teams at Florida International University, a Gateway Coalition partner [3]. This method includes a survey to help classify students into four different leadership styles. Students completing the questionnaire are categorized as to their type of leadership characteristics. Interesting results showed that most engineering students seem to be categorized as types “2” and “3”. Ideally, a team would consist of one member from each of the four leadership types. Good team dynamics develop when students are assigned to teams using the FIU questionnaire.

Students have expressed many positive thoughts about this active learning process and the project based approach:

“I didn’t know what engineering was all about until I took this course. Now I know how much more I still have to learn to be a good engineer.”

“I didn’t know exactly what type of engineer I wanted to be, but this course has helped me decide on what field of engineering I want to go into.”

“I didn’t like it when my professor didn’t answer my question with what I wanted to know, but that’s okay, because I learned a lot more on my own anyhow.”

“I guess I should have paid more attention in high school, because now I have to know all this stuff.”

“Now I know what concurrent engineering is all about and I’m ready to be an engineer.”

And a recent conclusion presented during an oral presentation,

“... about the class ... At the start of the semester we were all presented with a task to accomplish. None of us had any experience with product development. No one had any knowledge of stereolithography or solid modeling CAD. Yet here we are. We accomplished the goal at hand. That, perhaps, is the most important lesson we learned, to succeed.”

Herein lies the motivation: the need to succeed. This course presents the students with an opportunity to be successful because there is always a conclusion or a final product at the end of the term. This ‘goal ‘presents the students with an objective” and a challenge. They can find their own ways to be successful and to accomplish the end results expected of them. They learn to work together as a team. They learn to research and obtain information necessary to meet their objective. They learn to be resourceful. They learn to challenge each other in competitive ways to out do the other teams. The motivation is there. The result is always a good feeling of what they have accomplished.

A unique experience occurred this past semester with an entire class of five teams of students that was ready to throw in the towel and forfeit a higher grade. They did not budget their time well and had great difficulty in completing all the required work in all courses. Therefore they “stole from Peter to give



to Paul.” In other words, they were selectively choosing which work to do and which they thought they could bypass. They were frustrated when they realized they had fallen so far behind in this course. By the last week of the semester, they were fighting with each other but nevertheless spent many hours stretched over several days working together in the library, in the CAD lab and in the dormitories to pull it off - AND THEY DID!

EVALUATION AND ASSESSMENT

Evaluation and Assessment are important parts of the Gateway Engineering Education Project and the Fundamentals of Engineering Design course at NJIT. At the conclusion of each semester, input is sought from students in FED 101 using course evaluation forms. Eight sections were evaluated in the spring 1995 and included 115 students completing the evaluation form. The possible responses range from strongly agree to strongly disagree. Results are shown in Table 1.

	AS	A	N/U	D	SD
1. My experiences in this course have helped me to see myself as an engineer.	26%	35%	28%	9%	2%
2. The teaching strategies used in this course were effective.	16%	47%	26%	10%	1%
3. This course enabled me to develop my problem solving skills.	15%	35%	28%	19%	3%
4. This course enabled me to develop my computing skills.	18%	36%	27%	16%	3%
5. This course enabled me to develop my teamwork skills.	28%	47%	15%	8%	2%
6. Overall, my experiences in this course were positive.	19%	42%	23%	9%	7%
7. This course enabled me to develop my design skills.	30%	41%	21%	6%	2%
8. Highlights of engineering principles have been central to this course.	30%	49%	17%	3%	0%
9. This course enabled me to develop my communication skills.	23%	47%	21%	8%	1%
10. Overall evaluation of program.	22%	42%	24%	10%	2%

Table 1. FED 101 course evaluation results. The possible responses are: AS = strongly agree; A = agree; N/U = neutral/undecided; D = disagree; SD = strongly disagree.



It is observed by the responses to Question 1 that a majority of the students reported they had developed a concept of themselves as engineers. Only a total of 11% were in the disagree or strongly disagree category. When asked what they liked best about FED, one student stated that the course “prepared me for what is to come as an engineer,” another claimed that it “gives you a chance to interact and to think of your future as engineers,” and another said it gave me “the feeling of being an engineer.”

A majority of the students responding to Question 2 had positive feelings about the effectiveness of the teaching strategies. One student appreciated “the opportunity to use our creativity,” and another liked being able to “interact with the material being taught.” However, there were numerous comments about the amount of work expected for the credits earned. Referring to the two credits for the six contact hours course, one student stated “too few credits for the hard work accomplished; if there were more credits, I would be more enthusiastic.”

Questions 3, 4 and 5 assessed the students’ feelings of growth and development in problem-solving skills, computing skills, and teamwork skills. Results indicate about half of the students were satisfied with the improvement of their problem solving and computing skills. Many students stated that learning to use Pro/ENGINEER solid modelling software was one of the most important and enjoyable aspects of FED. An overwhelmingly large majority, 75%, were satisfied with their accomplishment in building their teamwork skills, while only 8% disagreed and 2% strongly disagreed. One student claimed s/he enjoyed “working in groups to solve problems,” while another enjoyed “working as a team as in the real world of engineering.”

In responding to Question 7, a substantial majority of the students, 71%, believed that the course provided them with opportunities to develop their design skills; 6% disagreed and only 2% strongly disagreed. The comment of one student summed up the feelings of many: what I liked best about the course “was learning the detail and getting a feeling of the design process.”

Commenting to Question 9, the effort to develop communicative skills was very much appreciated by the students. 23% strongly agreed and 47% agreed that the course helped to develop such skills; only 9% were in the disagree category. A number of students mentioned that one of the things they liked best about FED was the (oral) presentations and another felt that the course “greatly strengthened my speaking skills.”

As for the students’ feelings that the highlights of engineering principles were central to the course (Question 8), more than three quarters of them agreed or strongly agreed; only 3% disagreed and no one strongly disagreed. Students appreciated getting a “deeper insight into what engineering is about” and learning about “new technologies and techniques in the engineering field.” One summed up the feelings of many stating we were “allowed to be creative and experience real engineering work.”

Overall, the students were very positive about the course. More than half, 64%, described their experience as positive; 9% disagreed and only 7% strongly disagreed. On the evaluations, almost every student had at least one positive comment about the course. In addition to positive feelings about the teachers, and about learning computer skills, students liked “working with my group, improving my group skills, and having a chance to learn about other fields in engineering.” Many were happy “to be able to work closely with others.”

In summary, students taking FED 101 felt positively about their experiences and identified benefits derived from the course. This can be attributed to the observed increase in student retention rates at NJIT. On the negative side, many students expressed concerns regarding the amount of work required in the program in relation to the number of credits received. An analysis of the work load is to be conducted to determine if additional credit hours are necessary or if curriculum modifications need to be made. Another comment made by some students, “I would like to choose my own module”, or “the module should be related to my choice of major.” This would be an administrative nightmare for the number of students involved and also contrary to one of the main purposes of the course, to give students the opportunity to sample different fields of engineering.



RETENTION

Retention data have been very positive to date. The administration has reported that retention of students from the freshman to sophomore year for students who have been through the FED 101 course is 93% for the 93/94 to 94/95 academic year. This is in comparison to an 88% average retention rate overall. Of the 136 students enrolled in the first year FED 101 course, nine students failed to return; five had overall poor academic performance, one was an A student who transferred into an engineering program in another state (family move), and the others apparently decided that engineering was not for them and transferred to other colleges. Although these numbers are encouraging, they are preliminary and further data are required to validate these early results. Additional studies are required to determine the effect of FED 101 on retention rates from the sophomore to the junior year. One complicating factor is a rather large influx of transfer students into the junior year from the community colleges.

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BIOGRAPHICAL INFORMATION

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