A Multidisciplinary Course Sequence for First-Year Engineering Students

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Abstract

The University of Notre Dame has developed a new first year engineering program, and central to that program is a two-course sequence entitled "Introduction to Engineering Systems." These courses use a sequence of team-based, multidisciplinary projects to introduce students to the engineering profession and to assist them in developing fundamental problem-solving skills common to all engineering disciplines. This paper describes how these new courses were developed and outlines the learning objectives for the courses. It includes details on the implementation of the courses and the four projects that are central to these two courses. The paper details the ongoing assessment activities and the progress toward achieving the various desired outcomes set-forth for the courses.

I. Introduction

In 1998, the College of Engineering at the University of Notre Dame embarked on an intensive self-study of its undergraduate engineering programs. This was done in response to the challenges and opportunities resulting from ongoing changes in both engineering education and the engineering profession. This self-assessment led to a strategic plan that identified those areas in which the College of Engineering should invest time and resources. This study emphasized the importance of moving from an education process that was faculty and lecture centered to one that contains significant elements that are student-centered. A student-centered activity is one that actively engages the student in the learning process, thus enhancing their understanding and ability to use the knowledge gained. This student-centered emphasis better prepares students to be effective engineers, lifelong learners and leaders in new technology developments by stressing the importance of student participation in the discovery of knowledge. Particular importance was also placed upon increasing interdisciplinary breath in all fields of study to complement the existing emphasis on disciplinary depth.

To this end, the College of Engineering began efforts to integrate the student-centered activities in those parts of the curriculum where they could provide the greatest benefit. The first major effort was to restructure the first year curriculum for all students who intend to enter the College of Engineering in their second year. This included the development of a new two-course sequence entitled "Introduction to Engineering Systems." (These courses are designated as EG111/112 and will be referred to as such in this paper.) These multidisciplinary courses introduce engineering students to the role of engineers in society, and illustrate how engineers design systems and solve problems. This is done in the context of how engineering systems influence, and are influenced, by the world around them. The courses introduce basic

engineering skills including how to identify, formulate and solve problems, how to verify and communicate results, and how to use computers to aid in this process. The goal is to actively engage the students in applying engineering analysis and design methods to solve practical problems. This involves working collabortively within a team to plan, design, analyze, implement, evaluate and report engineering activities.

To better appreciate the approach taken, one must consider the boundary conditions of the problem. Notre Dame is a private, research university with an undergraduate enrollment of about 8000. Admission to the University is "intent blind," in that is there is no consideration given to the intended field of study during the admission process. Students are not enrolled in discipline-specific colleges during their first year at Notre Dame but rather in a college called First Year of Studies. Prior to 2000, those students with an interest in pursuing degree programs in the College of Engineering typically took two-semester course sequences each in calculus, chemistry and physics and a single course in computer programming, along with the other humanities and social science requirements. Based upon these experiences, they were required to select a college and a degree program. This proved to be unsatisfactory for engineering students, who were not exposed to the modes of thought and practice specific to the study of engineering until well into their second year. In taking EG111/112, students begin to see the engineering "world view" and experience the engineering "way of life" from the start. Working through a series of in-depth, multidisciplinary projects, students start to participate in the engineering of complex systems, and through this experience begin to learn about the relationships and differences between the engineering disciplines, as well as the relationships between engineering, mathematics, and the physical and natural sciences.

The paper is organized as follows. The first two sections of the paper briefly describe the process by which the EG111/112 courses were developed, and the institutional and learning objectives for these courses. The next section outlines the basic pedagogy of these courses, namely, the use of multidisciplinary projects as a framework for teaching basic principles of engineering systems, and briefly describes the current projects. This section also discusses how major topical threads, such as modeling and simulation, process control, and the societal context of engineering are woven through the courses and the projects. Following the discussion on pedagogy, some of the specific organization and implementation issues surrounding EG111/112, including faculty participation, student peer mentors, scheduling, and communications are presented. Next, the approaches used to assess the progress toward achieving the goals for the courses are presented. Finally, the conclusion provides some additional comments on future plans and how these experiences might prove useful at other institutions.

II. Developing the Courses: A Multidisciplinary, Collaborative Enterprise

As indicated above, the College embarked upon the task of developing a new, two-course sequence that would build the foundation for the departmental degree programs, generate interest and excitement in engineering, and provide the students with information and experiences that would assist in them in choosing a program of study. The committee that developed the College's strategic plan proposed that these courses contain elements that provide: historical perspective on the engineering profession, exposure to engineering professionals, collaborative team-based design activities, and an introduction to engineering analysis, modeling, and simulation. The courses were to be used to establish the perspective of the engineer as a decision

maker and communicator. These courses were to have significant experiential learning content as well as involve collaborative efforts of teams of students on projects and activities that span all of the engineering disciplines.

These generally defined objectives served as a starting point for the course development as outlined below. The Dean of the College of Engineering assumed the responsibility for the development, content and staffing of EG 111/112. In the Spring 1999 he established a faculty committee with a single representative from each of the College's five departments. This committee was chaired by the Associate Dean and tasked with developing and implementing the new first year courses. The strategic plan mentioned above had indicated that the new courses should be in place by Fall 2000 and that a prototype implementation should take place during the 1999-2000 academic year. The activities of the committee were initially focussed on identifying in detail the "what" for the courses while intentionally delaying the discussions to determine the "how". The "whats" were summarized in the learning objectives for the two courses that are outlined in the following section of this paper.

With the objectives defined in more detail, two faculty members were tasked with developing the basic framework for achieving these objectives. A single section of 25 first year students was recruited from the class that matriculated in Fall 1999. These students were selected at random from those who had indicated an interest in studying engineering. The two instructors co-taught this small cadre for both semesters. Of the 25 who began that Fall, 22 continued into the spring semester. Three students were added in the spring to fill out the 25, as well as to determine if a student could effectively participate in the second course if they had missed the first. All 25 students completed the second semester. Currently 21 of the 28 who participated in this prototype offering are enrolled in the College and are expected to graduate next year. One of the other major efforts during the `99-`00 academic year was to establish a framework whereby the same experience that was being presented to a small group of 25 students, with two instructors and a graduate assistant, could be scaled to the entire first year class of 400 students for the Fall 2000 offering.

During this development process an attempt was made to benchmark these courses against those offered at other institutions. At that time we were uable to identify any other institutions of comparable size that were teaching two, three-credit courses that were multidisciplinary in presentation and content to all students in their first year of college. The College of Engineering at the University of Kentucky had experimented with such a program a few years earlier but had subsequently abandoned a two-semester program. Thus as is the case with most first year programs, the local constraints and goals often result in institutionally specific programs.

Some of the most difficult issues addressed during this development process were related to the real and perceived cost in faculty resources associated with presenting these courses. From the onset it was determined that all of the teaching responsibilities in these courses would be conducted by full-time faculty. The resulting framework, detailed below, was a compromise between efficiency in presentation and providing adequate student-faculty interaction. There were numerous college-wide and departmental meetings conducted to discuss the development process and significant effort was expended to develop faculty buy-in and support. Some of the faculty involved in the initial planning process were part of the first cadre (10 faculty members)

to present these courses but half of the instructors during the first offering were not part of the planning process. The Dean of the College, working in conjunction with the department heads, identified instructors to teach in these courses. At least one person from each of the five departments is involved each semester and this mix has provided a truly multidisciplinary perspective as the courses have evolved.

Parallel to this effort was the development of the infrastructure and facilities to support the hands-on activities being planned for these courses. The College of Engineering Learning Center[1], a 4000 sq.ft. facility was designed and built during this period. There were numerous other considerations that had to be addressed during this planning process. A number of course scheduling options were considered and, as this affected the academic schedules of about 20% of the first year class at the University and a signficiant number of classrooms, extensive coordination with the Dean and staff of the First Year of Studies program and the Registrar were required.

In order to institute this new program in a single year, the support of many individuals and organizations within and outside the College of Engineering was necessary. The development itself was truly a collaborative, multidisciplinary enterprise.

III. Institutional and Learning Objectives

There were two basic goals for these courses. The first was to provide the students with experiences and information that would allow them to make an informed selection of academic major. The second was to begin to develop understanding and skills common to all engineering disciplines in order to provide a solid foundation for the academic programs within those disciplines.

In order to achieve these basic objectives an initial set of learning objectives was developed. These were established prior to any discussion of structure, organization or content of the courses. The faculty committee mentioned above developed and agreed upon the suitability of these as basic, desired learning outcomes and they were used as benchmarks throughout the planning process. These objectives were also used to describe the proposed courses to faculty within the College, so that though one might eventually take issue with the methods used in achieving the objectives, there was general consensus that these were the appropriate objectives for the first year engineering program at Notre Dame. The primary objectives are to assist the students to begin to:

- understand engineering education and the engineering profession,
- develop and apply fundamental engineering skills, and
- gain practical design experience.

For each of these “high-level” objectives, sub-objectives were identified that provide additional, as well as assessable, details on each objective.

Understand Engineering and the Engineering Profession:

Rationale: Engineering students first need to understand what engineers do, the importance of their role in society, and how they design systems and solve problems. Further, they need to learn about the similarities and distinctions among the engineering disciplines and specifically what will follow in their studies.
Sub-Objectives: The engineering student must be able to:

- describe what an engineer is,
- explain the role of engineering in society,
- give examples of how engineers have designed systems and solved problems (as evidenced through case studies),
- differentiate between the various engineering disciplines,
- describe their discipline's major subject areas and why they are needed.

Develop and Apply Fundamental Engineering Skills:

Rationale: Engineering students need to acquire basic engineering skills including how to identify, formulate and solve problems, how to verify and communicate results, and how to use computers to aid in this process.
Sub-Objectives:
[a] In addressing a problem, the engineering student must know how to:

- identify, define and formulate a problem,
- apply simple analytical and empirical methods to solve a problem,
- identify and utilize physical principles and laws appropriate to the problem,
- use proper dimensional analysis, statistics, units and uncertainty,
- synthesize analytical and empirical information,
- express results in the proper context.

[b] In communicating results, the engineering student must know how to:

- communicate engineering concepts in both technical and lay language,
- formulate and present a convincing technical argument,
- write a technical memo or brief report,
- give an oral presentation.

[c] In using the computer, the engineering student must know how to:

- describe the basic components and operation of a computer,
- operate in the University's UNIX environment,
- write a program using identified software to solve a problem,
- present the results graphically,
- merge the results into a written document,
- prepare a professional-looking document.

Gain Practical Design Experience:

Rationale: Engineering students need to become actively engaged in applying engineering design methods to solve a practical problem. This involves a team approach to plan, design, analyze, implement, evaluate and document their activities.
Sub-Objectives: The engineering student must be able to:

- work as a member of a team,
- develop a plan to meet design objectives,
- design, build, complete and demonstrate an artifact made to accomplish a task,
- participate in preliminary and final design project group presentations.

These objectives provided the basis for the development of the pedagogy as discussed below.

IV. Pedagogy

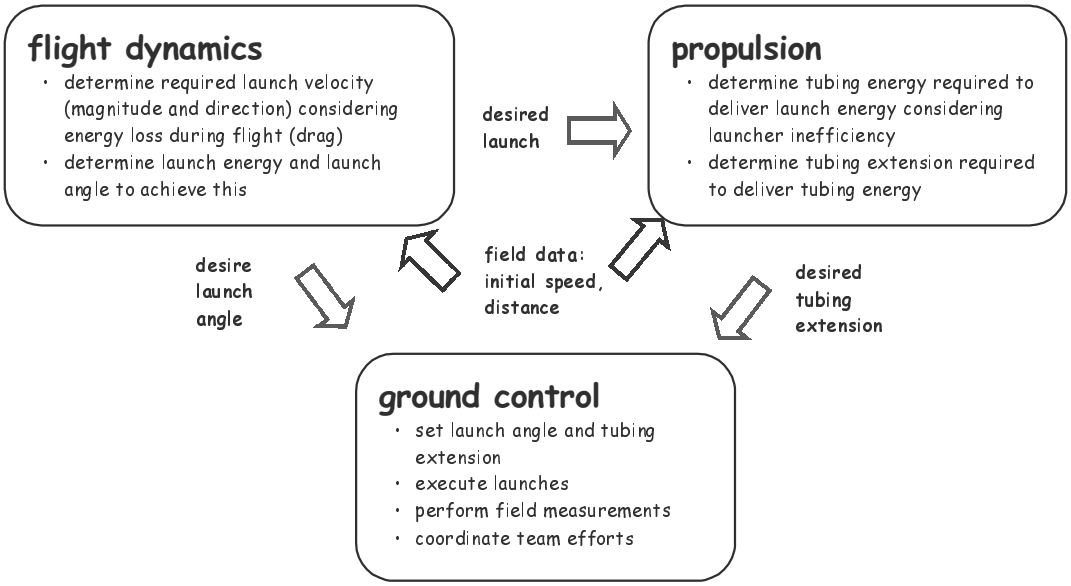
Importance of Multidisciplinary Systems

Central to the pedagogy of this course is the philosophy that much of engineering focuses on the development of systems, and that these systems are largely multidisciplinary in nature. As fundamental as the design and analysis of systems are to engineering, understanding how and why the various components of a system fit together is a difficult concept to learn. EG 111/112 emphasizes these connections, and introduces students to the modeling, design, and control of systems composed of interacting parts.

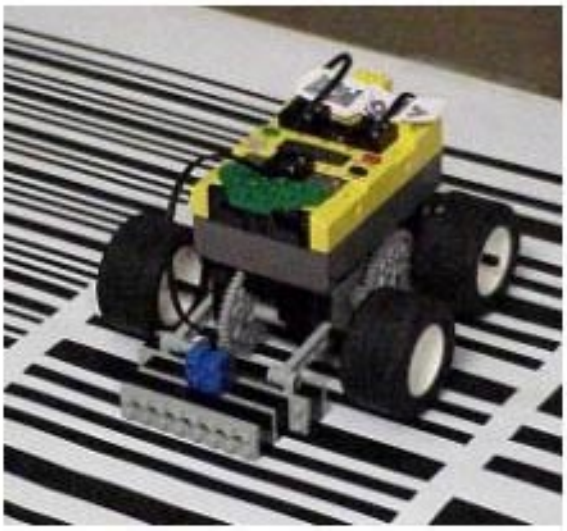
To introduce this difficult topic in a manner that provides some depth as well as breadth, EG 111/112 is organized as a series of projects, each focusing on the design, implementation, and analysis of a different multidisciplinary engineering system. Each of the four projects share a common structure, that begins with introducing the requirements for the project and showing how the system can be decomposed into components. Next, each project develops appropriate techniques for modeling the behavior of the system and shows how to use those models to make design decisions. Finally, the students implement and demonstrate their designs, document the results and make recommendations for future changes. The four projects adopted for the 2000-01 and 2001-02 academic years are briefly described below.

The Projects

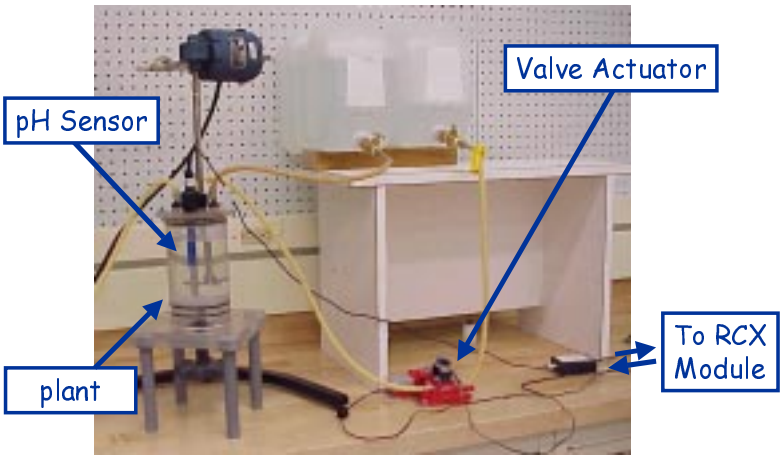
The first project in EG 111 serves as an introduction to model-based system design. It requires each team of students to use analytic and numerical models to develop a procedure by which a large slingshot-type device (provided) could accurately launch a softball to hit a series of targets placed 75 to 200 feet away. The launch process is partitioned into three parts: transfer of energy from a stored-mechanical-energy device to the ball, the dynamics of the flight of the ball with drag, and the planning and coordination of activities on the ground, as illustrated in the following schematic. The students are tasked with developing a numerical simulation based upon an analytic model for the propulsion and flight dynamics, and then use the simulation results to develop range tables for use in the field.



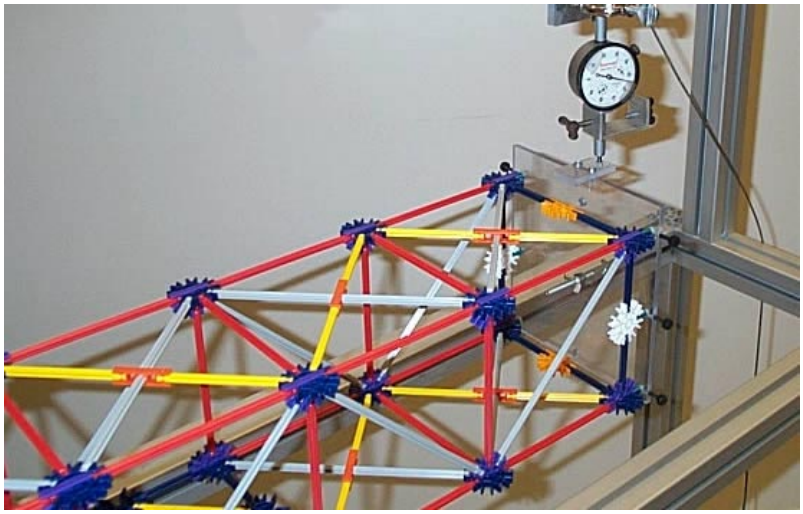
The second project in EG 111 addresses information processing in engineering systems and requires each team to design and build a data scanner capable of reading and carrying out a series of commands that were encoded into a binary format and then represented as a sequence of light and dark stripes on a sheet of paper. The students use the "Not Quite C" (NQC) programming language on the Lego RCX computer equipped with various sensors to implement this project.



The themes of the first project in EG 112 are dynamic processes and control. It requires each team to design and implement a microprocessor-based controller to continuously adjust the flow of base into a constant-flow, stirred tank reactor being feed by a "variable" acid stream so that the outflow mixture maintaines a specified pH. An analytic model is first developed for this process and then a numerical simulation of the process and control operation developed. This simulation is used to evaluate and "tune" the controller that was implemented on an actual system. Once again, the computing engine was Lego Mindstorms RCX processor unit running NQC.



Finally, the second project in EG 112 addresses concurrent engineering of complex systems and requires each team to design and build a lightweight, truss-like structure to meet a particular set of design load/deflection specification, spatial and cost objectives. The bridges were built using the K'NEX fabrication system, and the students were required to measure applied load by interfacing a load cell (provided) to the RCX unit and writing the appropriate data acquistion software. To help the students in the design phase, a simple computer-aided design package, based upon the finite-element method, capable of simulating two-dimensional trusses under loading was provided and the students developed their own software to predict system cost.



The Snowball Effect

In working in a cyclic fashion through several complete projects over the course of a year, EG 111/112 reinforces a problem-solving process and a way of thinking about systems, decomposing problems in a "top-down" fashion, and implementing and testing solutions from the "bottom up". Students experience how this approach works in a variety of contexts that combine phenomena from each of the engineering disciplines that they are considering. Working through multiple project cycles has a "snowball effect" on student learning. With each pass through a project, students learn some new techniques, reapply techniques first covered in

earlier projects, and gain both autonomy and responsibility in making design decisions on their own. The following table tracks the development of several key ideas that span the projects.

	Engineering in a Societal Context	*Principles of Balance, Conservation, and Equilibrium*	*Modeling, Simulation, and Analysis Tools and Techniques*	*Process Management and Control*	*Media, Materials and Discipline Specific Phenomena*
Launch Process	• Establish a framework to solve a problem	• Newton's Laws, • Conservation of Energy	• Euler's method for simulating dynamic systems using Matlab	• coordinated team effort following a detailed "algorithm"	• elastomer spring • Hooke's Law • drag forces
Pathfinder	• reading, report, and discussion on history of technology	• encoding and compression • information entropy	• collection and simple analysis of real-time experimental data	• introduction to automatic feedback control • state diagrams • concurrency	• symbolic information
Acid Neutralization Reactor	• project presented as prototypical of projects such as mine waste removal, biosystems	• Conservation of Mass • Mass Action Law • balance in ecosystems	• Euler's method with Matlab • characterizing performance of a control system	• PID control	• acid-base chemistry • electronic sensor technology
Lightweight Structure	• reading, report, and discussion on related issues in engineering ethics • economics	• Newton's Laws, statics • cost modeling and control	• solving simultaneous systems of equations in Matlab • finite elements	• concurrent engineering • satisfying conflicting constraints	• spring constants • indetermin-ate strutures

As the table illustrates, a number of fundamental ideas introduced early in the course are repeated and reinforced in later projects. While the applications addressed by the projects span a broad range of areas, a deliberate effort was made to keep the total set of fundamental concepts and techniques as compact as possible, and to try encourage the students to develop a level of comfort with each. For example, in the first project, the launch process, students use an elastomer spring (rubber tubing) to store energy for launching the projectile and learn about the relationship between the applied force and displacement. The fourth project, lightweight structure design, looks at a truss structure as a system of elastic spring-like elements. While the finite element method is typically treated as an advanced undergraduate topic, in the context of EG111/112 it fits naturally, appealing to the intution that the students have developed over the course of the year.

Approach to Mathematical Modeling

Mathematical modeling is of central importance to engineering, and these models are often described most naturally in terms of differential equations. Most first-year students, however, do not yet have the background to solve continuously-varying problems symbolically; that's what their later courses in calculus and differential equations are for. First-year students can, however, intuitively grasp how the "state" of a system changes from one point in time to the next and can make use of simple approximations to predict its state at a particular time, given the state an instant earlier and the input to the system. With the widespread availability of high-performance computers, a numerical/simulation-based approach to modeling system behavior has become a tool that is as valuable to engineers as the analytic approach. Specifically, two of the projects, the launch process and the acid neutralization reactor use Euler's method to simulate the behavior of dynamic systems.

By adopting Euler's method at the beginning of EG111 as a valid approach to solving differential equations, non-linear systems are no more difficult to model than linear ones. This is important in EG111/112, as the goals is to have the students discover that they can build models that they understand that are also accurate enough to use in making good design decisions. For example, in the launch process project, were the students to neglect drag and use vacuum conditions for the model of the trajectory of a projectile—as they do in their physics homework—they would fall short of the target by a substantial distance. Using a discrete simulation of the more complex model with drag, with careful programming and a little luck, students can hit the target dead-on, a much more rewarding experience!

V. Organization and Implementation Issues

The courses are in their second full year of implementation. The fundamental framework was established during the 2000/2001 academic year and a series of changes were implemented for the 2001/2002 year. This section overviews a number of issues pertinent to the presentation of EG 111/112 during the 2001/2002 academic year. The changes that were made in the evolution of EG 111/112 were based on feedback from students and faculty. This section addresses a variety of practical issues that were addressed as the courses were presented to the full complement of first year students.

Course Scheduling

The course was presented in a rather unconventional fashion. Students were assigned to small sections with a limit of 30 students per section. Each section was assigned to a faculty member and most participating faculty were responsible for two sections. The course was scheduled using a "two-week cycle" with six class meetings every two weeks. Each student attended 6 50-minutes sessions every two weeks. These six class meetings were carried out in both large-group (the entire enrollment in the course) and small-section (30 student) settings in a variety of different environments.

Three times every two weeks all the EG 111/112 sections met together in a large lecture hall for 50 minute lectures. Most lectures addressed the fundamental concepts and principles behind the

projects – i.e., they provided the mathematics, physics, engineering analysis, and computing background to understand the tasks at hand. Seven lectures, over the course of both semesters, were used for either presentations by prominent, practicing engineers or to give the departments in the College an opportunity to introduce their degree programs to the first-year students.

Once a week each small section met individually in the Engineering Learning Center. This time was spent making use of the Center's "hands on" resources – i.e., computer instruction, demonstrations, project fabrication, etc. Once every two weeks each section met individually in a "recitation" held in a regular classroom. This meeting was student-driven and it provided the students a chance to ask questions, see homework problems worked, and discuss progress on the projects.

Faculty Participation

Faculty members were recruited from every department in the College of Engineering to teach EG 111/112. They were assigned to one or more of the EG 111/112 sections; there were fourteen sections of EG 111 and twelve sections of EG 112. A course director was assigned from among regular teaching and research faculty to oversee course content and to teach at least one section per semester.

A full-time course coordinator was added to the program in the summer of 2001. Due to the heavy administrative burden associated with these courses, it became obvious there was a need for a full-time professional to provide administrative support for these course. The person hired holds a PhD in electrical engineering and has extensive industry experience. This individual was added to the College's special professional faculty. In order to be fully engaged in the course, the course coordinator also teaches two sections of EG 111/112 per semester. The course coordinator is responsible for course administration, logistics, coordination, and works with the course director and regular faculty instructors in formulating content. In addition to the course director and course coordinator, six other regular College of Engineering faculty members were assigned to teach (typically) two sections of EG 111/112 each.

Peer Mentors

To provide additional support in the Learning Center and during recitations, each section of EG 111/112 was assigned a "peer mentor" – an undergraduate student tasked with providing hands-on guidance during the project design/fabrication process as well as "typical" teaching assistant duties – e.g., grading homework, answering questions, etc. This new program serves two purposes. It provides each small section and instructor in EG111/112 with a resource person to assist in a variety of support functions but it also gives an opportunity to 12-14 undergraduate students to act as role models and gather important experience in providing tutoring and instruction.

Student Learning Assessment

Student's performance was assessed with a variety of methods; the first three components, projects, exams, and homework, were weighted approximately the same in determining course grades.

- Projects: Each project required that a "preliminary report" describing the design process and preliminary analysis be submitted prior to project testing; after testing, a short "post mortem" report or oral presentation was also required. Project grades were based on these two reports, together with an objective measure of actual project performance – e.g., points assigned based on how close the launched projectiles landed to the targets.
- Exams: There were two exams in each course. Each exam covered the material from one project. Most of the exams consisted of 30 multiple-choice questions and were completed in two hours. (The one exception: The first offering of EG 111(Fall 2000) used a one-hour exam with ten multiple-choice questions. It was subsequently decided that longer exams and more detailed examinations were necessary.) The questions on the examinations primarily involved solving problems, in contrast to recalling facts, and each problem was designed to assess competency with a particular topic. There were no comprehensive final exams.
- Homework: Individual homework was assigned each week and was due the following week. The homework was graded by the peer mentors and often associated with selected elements of the project, such as developing one part of the trajectory simulation program (e.g. the projectile trajectory without aerodynamic drag).
- Other: Each EG 111/112 instructor was given 5% of the final course grade to assess as she/he saw fit. The means by which these points were distributed included participation grades, section quizzes, and evaluations by the faculty and peer mentor on the quality of student contribution to the projects.

Computing in EG 111/112

As indicated in the course objectives in Section III, gaining familiarity with computers and programming is an important part of EG 111/112. A variety of computing environments and programming languages were used.

- MATLAB was introduced in Project 1 as an accessible but powerful programming environment that students could use in that project (to do calculations, numerical integration and graphing) as well as the subsequent projects. In the launch project the emphasis was on the application to scalar calculations and data presentation. In the lightweight structure project, matrix methods were introduced. A student version of MATLAB was accessible from every PC in every cluster on campus, and students with PC's were encouraged to purchase their own copy. MATLAB was also available via the university's UNIX workstation network.
- Not Quite C (NQC) is a high-level structured programming language used in three of the projects. NQC is a C-like language developed for the Lego Mindstorm RCX microprocessor. It is less powerful than standard C in that NQC permits only integer data types and does not use arrays or pointers; however, it has built-in multi-tasking capabilities that standard C does not offer. These multi-tasking capabilities are crucial in

implementing the real-time programming constructs required for the data scanner and the pH controller.

- The Lego Mindstorm RCX computer is built around a Hitachi H8 microcontroller with 32K of external RAM. The microcontroller is used to control motors and sensors. NQC programs are written and compiled on a PC and the machine (or "byte") code is downloaded to the RCX via an infrared serial link.

The Engineering Learning Center

The University of Notre Dame Engineering Learning Center occupies 4,000 square feet of space in Cushing Hall; it is a prototype for a much larger learning center planned for a new engineering building. The purpose of the Learning Center is to provide space and equipment needed to carry out a wide range of student learning activities throughout the College of Engineering. The facility includes a PC-based "computer classroom" (i.e., space for up to 45 students in stations built around 15 personal computers and projection equipment) specialized equipment such as fume hoods, and simple mechanical and electronic fabrication equipment. The Learning Center also contains work tables and storage lockers. The Learning Center is open approximately 90 hours per week, and most evenings until midnight. It is staffed by student support staff and peer mentors, thus much of the time each evening there are individuals in Learning Center available for questions concerning EG111/112.

As noted above, each section of EG 111/112 meets once a week in the Engineering Learning Center. EG 111/112 instructors take advantage of the computer classroom for instruction in MATLAB and NQC programming; they also use the Center's resources for demonstrations, and the students use the Center's workspace and storage lockers during the project design/fabrication process. The students have indicated that the Learning Center sessions are the most productive of all the course meeting formats.

Course Communications

A course with 400 students and eight faculty members organized in such a non-traditional format presents significant communication challenges. All written material provided to the students

were distributed via the course website[2]. These included homework and homework solutions, reading assignments, and lecture PowerPoint slides. The course instructors made use of WebCT to provide students with access to their grades and to course discussion groups. For the 2001-02 offering a comprehensive set of course notes have been made available to the students. These notes serve as a "textbook" for the course they have proven to be a most valuable addition. They are the primary means of providing course content to the students

VI. Assessing Progress

There are various means available to assess the effectiveness of the new first year program. These include student surveys, evaluation of the student's performance on tests and projects, enrollment and retention, and evaluation of the student's performance after completing the courses. The following highlights some of the measures that have been used during the first year and one half of the full implementation, thus the assessment, particularly based upon longitudinal data, is limited.

Student Surveys

In order to provide a baseline to assist in evaluating the development of the students in EG111/112 surveys of student experiences and opinions was prepared and administered at the beginning and end of this two-course sequence. The first survey was administered during the first week of class and contained 50 multiple-choice questions primarily related to interests, understanding of the engineering profession and experiences in high school. The second survey was executed at the end of EG112 and contained 100 multiple-choice questions. These questions focused on their experiences in first year, their evolving interests and their understanding of engineering as a profession. Obviously these surveys have produced significant amounts of information have provided some quantitative insight where only anecdotal and qualitative information had existed in the past. These surveys along with the regularly administered Teacher and Course Evaluation conducted the University are being used to evaluate the effectiveness of these new courses. This information is shared with the individual departments in the College in order to assist them in understanding the attributes and attitudes of their incoming students.

The exit surveys indicated that there were various changes in perception and attitudes about studying engineering and the engineering profession. There were also a significant number of issues brought forth in the exit survey that were directly related to the presentation of the courses for the first full offering of the sequence, 2001-01. These comments were related to differences in faculty and student expections, communication of information - particularly during the lectures - and the perceived value of the different learning environments. Efforts have been taken to attempt to address them in the current course offerings.

Enrollment

Enrollment at Notre Dame is intent-blind and students are admitted into the First Year of Studies when entering the University, thus no students are enrolled in the College of Engineering while taking EG111/112. In the four years beginning in 1998, the number of students indicating on their applications an interest in studying engineering were:

Year	1998	1999	2000	2001
Students indicating EG as their intent	340	322	323	352

The Fall 2000 enrollment in EG111 was 375 students. Through a variety of means it was determined that a significant number of students who might not have considered studying engineering were attracted to this first course as a way of determining if engineering was an appropriate field of study for them. For the Fall 2000 offering of EG111, 359 students completed the course thus the attrition was only 4.3%. Then in the Spring 2001, 295 students enrolled in EG112.

In time it will be possible to track the retention of students through the program. One of the primary goals associated with the courses was providing the students the insight necessary to make an informed decision regarding a choice of major. All the students who took EG111 but did not continue into EG112, thus deciding not pursue studies in the College of Engineering, were requested to complete a brief survey. Considering just two "typical" responses,

> "I decided that EG just wasn't the right thing for me. It was kind of fun but not something I would want to do everyday."
>
> "I found that I dreaded the projects and problems in EG111 ... I realized that I'd be much happier writing papers, so I figured I was in the wrong major, and there was no reason to continue in engineering."

One might assume that in some ways that goal had been achieved for some students.

Influence on other Courses in the Curriculum

As mentioned above, one of the other changes associated with the revision of the first year curriculum was that only a single physics course is required in first year. That course is nominally taken in the second semester and thus after students have completed EG111. This is a new physics course (Physics131) and there was useful, anecdotal and quantitative evidence provided by the course director regarding the student's performance in this course. There were approximately 270 students enrolled in physics during the Spring 2001 semester, effectively all were engineering intents who had taken EG111 the prior semester and were concurrently enrolled in EG112. Only 2% (6) of the students dropped the course in contrast to 12-15% in prior years for the first physics experience for engineers. The Physics Department also indicated that "fewer" students received low grades and the students were not "shocked" to see and use integral calculus. The students required less "hand holding" and appeared to be "better prepared" for college physics. Obviously there were numerous factors that brought about these observed changes. The students had acquired a semester of college-level classes including calculus and EG111 but the influence on the first physics course was positive.

Examinations

Two examinations were administered each semester. Along with the project reports, the examinations provide the most direct, quantitative assessment of the student's progress toward

the learning objectives related to fundamental skill acquisition. The examinations were multiple choice and thus the grading was automated. Preparing effective multiple choice examinations that were primarily problem-based proved to be a challenge. Once completed each problem on the exams were classified and related to one of the project's learning objectives. This helped determine if the distribution of topics, and thus "points" on the exams, was consistent with the emphasis placed on various topics during the project.. The following table illustrates this type of information for questions related to MATLAB on the Spring 2001 midterm examination. As indicated in the table, the concept of "systems of equations" was associated with five questions, "matrix multiplication" was an aspect of three question, etc. Also, some questions involved multiple concepts. This information has proven useful in identifying questions or question types that are ineffective. Attempts are made to provide questions that range across the spectrum of difficulty. The overall test performance has been good with averages in the 75% - 83% range. Some students have achieved grades of 100% but it has been an objective to provide some questions on the examinations that are challenging even to the very best students. As engineering faculty at Notre Dame are not accustomed to the multiple-choice format for problem-based engineering examinations, this information should prove helpful in developing that expertise.

Subject	% correct	% correct	% correct	% correct	% correct
Systems of Equations	96.8%	97.2%	93.6%	95.4%	78.8%
Syntax	27.4%	92.5%	96.8%	87.4%	78.8%
Matrix Terminology	65.9%				
Matrix Multiplication	97.2%	95.4%	92.5%		
Loops	27.4%	56.9%			
Conditionals	27.4%				
Gaussian Elimination	64.0%				

Examination Questions Related to MATLAB - Mid-term, Spring 2001

Performance on Projects

Aggregate student performance on the projects themselves constitutes an important dimension of course assessment. Each project in the course has a *Statement of Work and Technical Specifications* that clearly specifies quantitative figures of merit and that sets goals or constraints on these. Examining the distribution of the values for the figures of merit across the course, provides important statistics on the performance of the class as a whole. As an example, in the launch process project, the technical specifications list the evaluation criteria as follows:

The objective of the Launch System is to hit all of the targets within a 15 minute window. Accuracy will be evaluated by the Range Error Function which is defined as follows:

Range Error = |(Impact Distance – Specified Target Distance)|/Specified Target Distance * 100

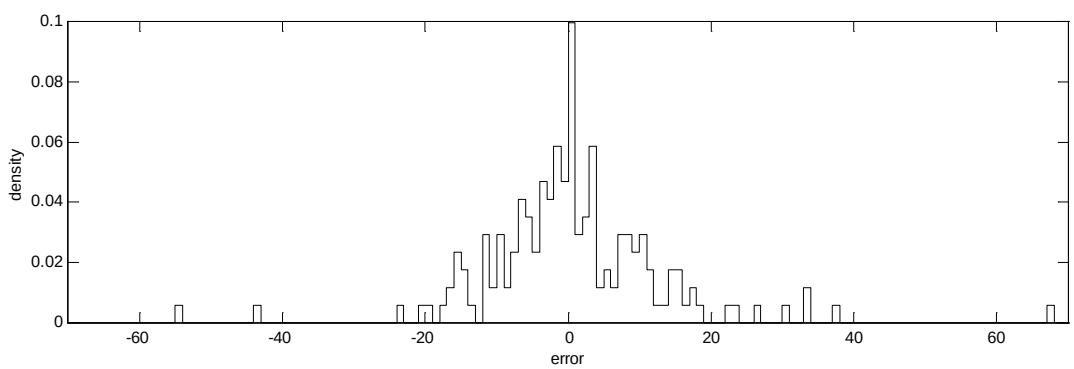
The Specified Target Distance is defined as the distance from the launcher to the target and the Impact Distance is defined as the distance from the Launcher to the impact point of the projectile.

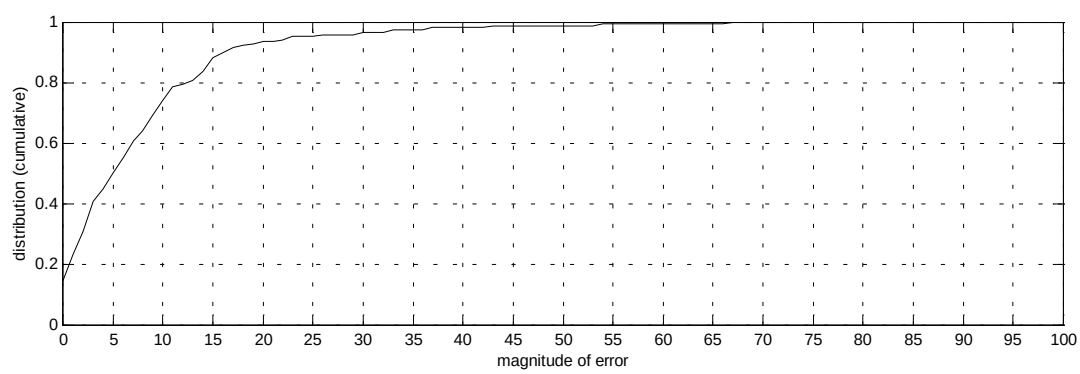
Each target launch will be awarded points for accuracy as follows:

Error Range	**Points**
0% < Range Error ≤ 5 %	5
5% < Range Error ≤ 10%	4
10% < Range Error ≤ 15%	3
15% < Range Error ≤ 20%	2
20% < Range Error ≤ 25%	1
25% < Range Error	0

Only the launches which occur within the 15 minute window will be awarded points. All launches not completed within the 15 minute window will receive 0 points. The points from each of the three target launches will be averaged to arrive at the final point total.

The following plots show the distribution of range error (positive and negative) for all launches performed in the final testing of the launch processes:





As the data shows, 75 percent of all the launches were within 10 percent of the target and 50 percent were within 5 percent of the target. By tracking statistics such as these for each of the projects, we not only have a basis for comparing groups within the course, but also have a very

concrete indicator of how well the students have learned the material. Comparing project statistics across different years provides one way for tracking improvements in the course over time.

VII. Final Comments and Future Plans

At Notre Dame

As this program is completing its second full-year of implementation, there are still a number of issues that need to be addressed. Since these courses are unconventional in content and presentation there was no textbook available to provide the students with an information source and "examples." During the first offering an attempt was made to provide this information solely in the form of the lecture notes and visuals. This was less than successful and a text has been drafted for the course and is being used in the second offering. This has proven to be much more effective and though this text will undergo significant revision in the next year, the students felt it provided the additional information source needed to augment the lectures, their notes and the small class session discussions.

The longitudinal assessment of the influence of these new courses on the individual degree programs is being developed. Individual departments are attempting to determine how the curriculum changes have influenced their curriculum and students within their own programs. New curriculum elements are being added within the various degree programs that build upon experiences develop in First Year. Continued attention is being paid to the computing experiences and assuring that each student leaves the first year with a solid foundation in computing and can effectively apply that tool, in its many forms, in later courses.

Issues of recruitment and retention are being addressed. Based upon the student response for "Time spent in the course" on the university-wide, teacher-course evaluation survey, EG112 was rated at 3.05. This ranked above the 90th percentile which was 2.95 and the mean for all first year courses was 2.27. It is realized that this course presents a time consuming introduction to their engineering education. How does this influence enrollment in the College? To date enrollment and retention figures have indicated increased enrollment in second year, but correlating this information with the many factors that influence the student's decisions is a difficult. It has also been encouraging that there are improvements in the current sophomore retention implying that those students who have selected degree programs in the College are more committed and prepared to do so.

It is recognized that this is an ongoing process and that continuous changes will be made based upon the ongoing assessment activities. To date the changes appear to be well received by students, faculty, parents and the future employers of the students, the engineering industry.

Applicability of the Notre Dame experience to other institutions

One issue that does arise is the degree to which the Notre Dame EG111/112 approach can be applied to other programs and institutions that have different boundary conditions. While EG111/112 was designed as a college-wide course, it appears that one of the most important

feature of the course—the emphasis on multidisciplinary systems—could be taught using this basic approach, even if only a single department was to use this framework to provide their introduction to engineering. As EG111/112 was first being developed, there was an inclination on the part of some engineering faculty to view a given project as a "chemical engineering project" or the "civil engineering project". By the third year that the course was taught, this viewpoint had largely disappeared, and has been replaced by faculty telling students about the wide variety of options available within each major. At Notre Dame, EG111/112 is a full-year course, which provides enough time to complete four half-semester project cycles. This schedule could be modified, depending upon what other courses are taken concurrently, and the extent to which they are integrated. Finally, the current EG111/112 projects are undertaken in the Engineering Learning Center, which was designed largely to support these courses. While it is our experience that it is important to have some dedicated space for the projects, we firmly believe that many creative approaches to the challenges of space and equipment are possible that would not sacrifice the basic effectiveness of this approach. Thus it is felt that the fundamental multidisciplinary, project-focused pedagogy does not depend upon the involvement of all departments in a college, it need not be a full-year experience and an instituion would not be required to develop a dedicated learning center in order to benefit from many of the features of the introduction to engineering courses discussed herein.

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References

1. Batill, S.M,. Gedde, N., "Development of a Multidisciplinary Engineering Learning Center," 2001 ASEE Annual Conference and Exposition, Albuquerque, New Mexico, June 2001.
2. http://www.nd.edu/~engintro (Last accessed Jan. 2002)

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