Developing and Implementing Hands-on Laboratory Exercises and Design Projects for First Year Engineering Students

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Abstract

During the past ten years, The Ohio State University's College of Engineering has moved from a series of separate freshman courses for engineering orientation, engineering graphics, and engineering problem solving with computer programming to a dual offering of course sequences in the Introduction to Engineering Program (IEP) and the Freshman Engineering Honors (FEH) Program. These new programs retain part of the traditional material but add in hands-on laboratory experiences that lead to design/build projects. Teamwork, project management, report writing and oral presentations have assumed important roles in this program. This paper describes the range of laboratory exercises employed, the design projects with the written reports and oral reports required, and the lessons learned in the transition to this dual offering freshman programs.

1. Introduction

In the past ten years, learning experiences for first year engineering students at Ohio State have notably evolved in a number of ways. Some of this evolution has been partially documented in previous works,[1-5] and it is now further described in new, up-to-date detail both in the present work and in companion papers[6-8] presented elsewhere in these proceedings.

In response to a national concern in the early 1990s about poor retention of students in engineering combined with a real, or some would say critical, need for more engineers, Ohio State worked with nine other schools to form the Gateway Engineering Education Coalition. This need for engineers was and currently is driven by society's ever-increasing consumption of technology. The Coalition, led by Drexel University, was established as a result of the creation of an Engineering Education Coalitions program by the National Science Foundation. These schools agreed to adopt or adapt Drexel's E4 program[9-12] for freshmen and sophomores which put engineering "up-front" and specifically included hands-on labs and incorporated design projects. Introducing design in the freshman year[13-17] of engineering course work was a mark of change for a number of engineering programs in the last decade.

Putting engineering up front and incorporating the hands-on laboratory experiences was intended to attack the problems of poor retention by getting students involved and excited about engineering right from the beginning of their first term. An important element here was (and is) the use of regular faculty from across the departments of the College in the freshman courses to

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provide significantly more interaction between first-year student and engineering faculty, establishing a sense of identity with or belonging to engineering. It provided and continues to offer the additional benefits of advancing toward the goals of increasing diversity, developing a dynamic curriculum able to respond and adapt to the changing needs of the engineering workforce, and using technology.

One might be tempted to remark that incorporating design in the freshman year is mostly just a very logical extension of engineering up front. Certainly on the whole this may be true. But at Ohio State the results of a College of Engineering survey in 1992 of 20% of the most recent five year graduates[18-19] revealed a strong reason to introduce team-oriented design/build projects. The survey of the graduates (and also of their employers) gathered information about both the importance of and their preparation in skills grouped in four broad areas: a) basic engineering skills, b) basic graphics skills, c) computer skills, and d) communication and problem solving skills. Without exception, the graduates from the years 1987 to 1991 and their employers indicated that the level of preparation was noticeably below the level of importance for writing skills, oral communication skills, problem solving skills, and teamwork. Clearly, design/build projects completed by small teams of students and which include both written reporting assignments and oral presentation requirements could help address the preparation shortfalls revealed by the survey. With engineering up front, it was logical to put some of these design projects into the freshman programs in addition to such projects traditionally positioned in the junior and senior years of the curriculum. As a side note, one of the surveyed graduates remarked, "without these people skills many of an engineer's technical skills will go unnoticed".[18]

2. The Early Efforts

For several years, the Ohio State engineering faculty and academic advisers had observed that many students dropped out of engineering before completing the pre-major core curriculum. Stark reality was brought home somewhat later by a careful study of 1988 first year engineering students that was completed in 1996. This study revealed the overall retention rate for freshman students who expressed an intention to study engineering was less than 40%, with most attrition occurring during the first and second years.[20] Against this backdrop of poor retention of engineering students and preparation shortfalls in those that did graduate, the Ohio State a small group of engineering graphics and engineering mechanics faculty worked together with a few select, cooperative faculty from the mathematics and physics departments to create an adaptation of Drexel's E4.

The Gateway pilot program, as OSU's adaptation was then called, consisted of three 3-course sequences taken concurrently, one in engineering graphics and fundamentals, one in physics & engineering mechanics, and one in mathematics. The "Gateway" pilot was first offered in the 1993-94 school year to new first quarter freshmen who had calculus in high school and who placed into advanced calculus by the University's math placement test. Key components of the program were the engineering graphics (EG) courses, EG 166 and EG 167. The former was a traditional introductory engineering graphics course and the latter a beginning computer

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programming course with emphasis on engineering problem solving. Both of these courses were heavily augmented with a series of weekly hands-on laboratories, and a new EG course consisting of a quarter-long team design/build/test/document project was added to complete the three course sequence. Longitudinal tracking showed that 85 to 90% of the students in the first pilot were being retained compared to 70% retention for a matched control group of accelerated math students taking the standard EG 166 - EG 167 sequence which had no physics and math coordination.

Over the course of the first few Gateway pilots, both the course content and range of offerings were varied to determine which of several approaches might prove most effective in meeting the goals outlined by the Gateway Coalition. By 1996 the course content and offerings had optimally stabilized to the point where it was proposed to the College to approve "Gateway" for all students. The proposal was approved "for honors students only" beginning with the 1997-98 school year, and the program became the Freshman Engineering Honors (FEH) Program. Since 1997-98 the FEH Program has grown in demand by honors students from about one-fifth of those eligible (or about 70 students) to three-quarters of those eligible (or approximately 250 students expected in Autumn 2001).

But the improvement in retention measured in this program did not go unnoticed. With some results from early Gateway pilots, and after the study of retention of OSU engineering students,[18] in 1996 the Dean formed a Task Force charged "to formulate a plan for a new Lower Division Program to be taken by all engineering undergraduates in the College which both addresses the needs of all our stake holders and provides an open framework for continuous improvement; and to develop proposals for the implementation of that plan." The Task Force originally suggested the development of a 3-course sequence for all freshman entitled Engineering Fundamentals which would incorporate a series of hands-on laboratory exercises in a variety of engineering disciplines. This would have been modeled directly after the Gateway pilots (or FEH Program).

Indeed a plan was developed to implement Engineering Fundamentals but it was substantially modified according to much input from over half of the members of the College faculty. Rather than offering a series of modules, each dealing with a different engineering discipline and stretching over three quarters, the faculty was in favor of a two-quarter sequence consisting of instruction in basic skills and hands-on laboratory experiences involving product dissection and real time data acquisition and centered around one or two engineered products. This approach, the Introduction to Engineering Program (IEP), was piloted in small scale in 1998-99 with 100 students and again in 1999-2000 on a somewhat larger scale with 300 students. Full-scale implementation of IEP for approximately 850 freshman engineering students (i.e., all those not in the FEH Program) occurred in 2000-01.

3. The Current Program State

The Ohio State University's College of Engineering has moved from a series of separate freshman courses for engineering orientation, engineering graphics, and engineering problem solving with computer programming to a dual offering of course sequences in the Introduction to

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Engineering Program and the Freshman Engineering Honors Program.[6-8] The IEP has been scaled to handle approximately 850 first year students per year while the FEH Program has planned to accommodate approximately 250 students in 2001-2002, or roughly three-quarters of those incoming freshmen who are designated as honors.

These new programs retain essential parts of the traditional first-year engineering course material but add in hands-on laboratory experiences that lead to design/build projects. Although different laboratory exercises are used in the course sequences of the two programs, both have the goal of hands-on experimentation, reverse engineering projects in small groups, and doing small-team design projects. Teamwork, project management, report writing and oral presentations have assumed important roles in these programs. ABET criteria are introduced early as part of the course syllabi as to which will be addressed in each particular course of the sequence. The range of laboratory exercises and the design projects with the written reports and oral presentations required that are currently a part of the IEP and the FEH Program are described in the next sections.

4. Hands-on Laboratory Exercises

The intent of the laboratory exercises that are a part of the two freshman engineering programs is to provide significant opportunities for hands-on learning combined with a broad interdisciplinary outlook. Underlying these opportunities is a goal of making the students aware of the invasiveness of engineering into their daily lives and to cause them to begin to look at common, everyday objects with an engineering mindset or viewpoint. A second goal is to introduce incoming students to various engineering disciplines they might not have previously considered or known about, or in some cases to reinforce their choice of intended major. Note that an equally helpful outcome possible here in programs of study with engineering up front is a student discovering that he or she really does not want to become an engineer after all. When this is determined early in one's college experience, both the student and the University benefit.

In either of the two programs, hands-on lab sessions are nominally two hours long with an introductory lecture given by the lab instructor followed by a structured exercise. Copies of the presentation slides used in the lecture are made available to the students on the course web page, and all assignments and other lab exercise reference material is handed out to the students either a few days ahead of time or in lab, made available on the web, or is part of the course packet purchased at the beginning of the quarter. While there is some variation, the instructional staff present with the students in lab includes a regular faculty member, one or two graduate teaching assistants, and/or two or three undergraduate "peer mentors" for a total of three to five instructional staff. A full lab section would consist of 36 students arranged on teams of four students each with each team assigned to one workbench. As was noted earlier, the involvement of regular faculty from across all departments in the College in the freshman programs is a critical element.

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4.1 FEH Hands-on Labs

The FEH Program incorporates 18 engineering hands-on lab exercises in the 3-course engineering graphics sequence. All but three of these exercises occur with the first two courses of the sequence, and thus they occur at a rate of almost one per week. In some cases the lab exercises are closely related to the current topic being covered in the classroom. In other cases, the lab is unrelated to the current classroom topic, and it may either be a preview of a topic to be covered later in a classroom setting or it may only be presented in the lab. Many of these help the students learn about devices that will be used in the third quarter design project.

The current line-up of FEH lab experiences in the first two quarters includes:

Autumn Quarter	Winter Quarter
Marble transporter design/build	Data acquisition basics and intro to Labview
Spring and levers	Material joining and material properties
Gears, sprockets, and chains	Aerodynamics and rocket thrust measurement
DC motors	Stress and strain in bicycle frames
DC power supply	Programming a controller for a traffic light
AC electricity	Traffic analysis with spot speeds
Digital electronics (And, Nand, Nor, Not)	PID controllers and intro to Simulink
Engineering measurements	

The remaining three lab exercises involve the use of a Motorola 68HC11-based controller used in the design/build project in the Spring quarter of the FEH Program. These labs are focused on understanding the basics of the microcontroller and becoming familiar with the various types of sensors and motor systems available for use in the design/build project

4.2 IEP Hands-on Labs

Unlike the laboratory exercises in the FEH Program, the IEP uses two engineered products as focal points in the first course of the 2-course IEP sequence. In this first ten-week course, the emphasis is on "take apart" which requires students to get their hands on familiar but rather complex engineered products immediately. In this process, students are exposed to the engineering tools and techniques needed to analyze and investigate these devices.

Each engineered product serves as the foundation for five lab exercises. The first product taken apart is the Kodak Max Flash© camera, an ideal device for use in this kind of lab because it is relatively inexpensive, easy to use, and familiar to the students.[21] In spite of its simple outward appearance, the camera contains a high level of sophisticated engineering design and is the platform on which are based lab exercises on introduction to engineering design, shutter design and shutter speed estimation, optical and information systems, electronics, and manufacturing processes and materials.

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The second product dissected is a commonly available mountain bike.[22] Like the camera, the bicycle is familiar to nearly all students, but the exercises provide students with insight into how something like a bicycle is designed. According to Walter et.al., [22] the bicycle labs show how engineering involves practical application of problem solving skills and how various engineering disciplines enter into the design process. Upon completion of the five bicycles lab exercises, it is hoped that the students have developed some forward thinking (i.e., design) skills as a result of the analyses.

5. Design/Build Projects

5.1 FEH Design Projects

As a sort of "capstone" course in the FEH Program, the third course in the EG sequence (EG H168) focuses primarily on the planning, management, documentation, and presentation of a quarter-long engineering design/build project. In many respects, this design project course is comparable to a junior or senior level design course in which a student might participate as a part of the requirements for his chosen engineering discipline. A major difference is that the freshman year course teaches the various planning, management,[23] documentation,[24] and presentation aspects of a design project, whereas many senior level design projects focus on the specific design problem alone, assuming some prior instruction in or knowledge of what is needed for a complete and successful engineering project.

This design project involves all aspects of designing, building, testing, and demonstrating an autonomous robot which has to perform prescribed tasks within a specified time limit while operating over a specially constructed course or track. The format of the demonstration is a competition or tournament in which a champion robot is determined. In designing and building the robots in this third course, the students have to make use of the graphics, the programming, the hands-on labs, the physics, and the mathematics of the previous quarters. Working in teams of three or four, the students are required to learn how to plan and manage a team project, present analyses of their results, submit a progress report, write a formal project report, demonstrate the results of their efforts, and make an oral presentation on the work. The course format includes lectures on the technical approach to design, mathematical calculations required, documentation methods by way of progress reports and a formal written report, requirements for an oral presentation, and various laboratory tools and techniques that are useful in completing the design. Much of the scheduled class time is set aside for open lab time where students are able to work on their robot projects with instructors and teaching assistants available to answer questions.

The controller used for the traffic lights hands-on laboratory experience of the Winter quarter EG course and for this robot design project is the Handy Board controller developed at the MIT Media Labs by Fred G. Martin.[25] Designed for experimental mobile robotics work, this popular Motorola 68HC11-based controller board is supported with a nearly complete subset of the C programming language in an interactive Windows-based environment. It has a variety of

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digital and analog input ports for interfacing with various sensors and special ports for controlling infrared transmission and reception, DC motors, and servos.

5.2 IEP Design Projects

In the second course of the 2-course IEP sequence, the ten "lab sessions" are used by the students to design and build a conveyor system which must automatically sort three different types of recyclable objects. In addition, after instruction on breadboard electronics, they have to build an electronic counting device to count at least one of the objects. In order to avoid some of the storage problems, students from one section to the next share the conveyor once it has been constructed and taken apart by each group at the beginning of the quarter. It was felt that doing the construction of the conveyor provides important experience in reading drawings and following the instructions for assembly. The construction also provides the student teams with the need to understand alignment of the belt with the shape of the conveyor frame.

6. Personnel

6.1 Program Development

During the development phase of both the IEP and FEH programs, the creation, testing and documentation of the hands-on labs and design projects were done by a combination of faculty and graduate students. In the FEH program, the robot design project came during the second year of the implementation at the urging of one of the electrical engineering juniors who had participated in an MIT Robot Competition. The laboratory exercises in the FEH program came from an industrial engineering professor and his graduate student and from an education graduate student whose background was chemical engineering and seven years in industry. These experiments were set up to cover the broad range of engineering disciplines and to prepare the students for the robot design/build project.

For the IEP program, the laboratory experiments and design project were chosen after extensive discussion about what the students were supposed to learn and what product dissection projects would provide all or most of the engineering disciplines to be studied.

In the pilot phase, the faculty and graduate students not only were involved in the development but also had to set up and tear down experiments and figure out how to store experiments when they were not being used.

6.2 Implementation

Now that the programs are established as the required program for all engineering students, two instructional laboratory supervisors have been hired to inventory the equipment, maintain the equipment, document the experiments, set up and tear down experiments, and help faculty and graduate students develop new experiments. The current staff holding these positions are also capable of developing experiments themselves. These two staff members are critical to the first

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year engineering programs so that the faculty and graduate students can concentrate on the teaching. Faculty input from across the College will continue to be sought so that the College has 'ownership' of these courses.

As the programs were being prepared to be offered each Autumn quarter, the members of the instructional teams participated in a two-day orientation. This orientation has proved extremely valuable. While piloting the IEP program, it was noted that very few of the faculty and none of the graduate teaching assistants of undergraduate peer mentors had taught freshman before. Presentations by the staff of the OSU Office of Faculty and TA Development gave some team members insights into what behavior to expect for freshmen. Going through each hands-on laboratory exercise, even if the exercise was not yet polished, helped the team to understand what was to be taught and allowed instructors to refine their presentations and assignments.

7. Lessons Learned

Assessment and feedback are critical parts of the laboratory and design projects both for the students to reflect on what they have been doing and how it might be improved upon and for the faculty to understand how the students view the experiences.

7.1 Observed Successes

Early assessment of the programs[4,8] clearly demonstrated that students in the program were better retained in engineering, had higher grade averages than their control group peers, were much more likely to enter the workforce with co-op experience, possessed more teamwork and communications skills, and were more proficient in both ABET 2000 core and technical competencies. The students who participated in the FEH Program have also become the leaders in the Engineering College organizations and SAE Design teams.

The attitudes of the faculty and students are generally very positive about the IEP or FEH hands-on lab and design/build portion of the first year engineering experience. It is worth noting that the some people who have been most enthusiastic about the IEP or FEH experience and perhaps benefited the most from it have been the student peer mentors. They often acknowledge how much they learned by reviewing material from past classes and by thinking about how to help others learn it. They expressed joy at watching the new engineering students grasp a concept. Industry visitors have also been very positive about the need for the engineering foundations and educational experiences provided by the IEP and FEH programs.

The College faculty formerly held the view that the College's programs were in place to weed out the weaker students. With more faculty involved in the freshman programs, the attitudes are changing. Student retention is a 'good' thing now. As a result of the data that has been and continues to be gathered, the College is piloting its own admission process that occurs after students are admitted to the university.

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7.2 Opportunities for Improvement

Now that both the FEH and IEP programs have been running full scale for a year, there are a number of items needing attention. The staff who work in the hands-on labs must be very good at doing the laboratory exercises so that they can help trouble shoot the problems and help the students finish within the allotted time. This particular issue came from the students' weekly electronic journals and from the end of the quarter course evaluation surveys.

In the IEP, the integration of the hands-on laboratory sessions among themselves and of the lab with the basic skills classroom sessions has been deemed critical, as is coordination among all the faculty teaching one section of the course. A common complaint was the confusion arising from having a team of professors teaching the course. For example, over the span of one week in the first course of the IEP two-course sequence, it is not unusual for students to be working on three assignments from three different instructors—homework from the basics instructor, a lab report from the current week's lab instructor, and a pre-lab assignment for the next week's lab instructor. Beginning students like to know exactly what will happen and what will be expected of them every day, and they want a clear connection between class sessions. A very detailed syllabus is required, as well as reminders in each session about how the various aspects of the course are related.

Even with the orientation session held at the beginning of the academic year for the instructional teams, some of the faculty have been surprised by the number of facts and concepts the freshman did not know. In future orientation sessions, examples of assignments or exams that demonstrate the level of student knowledge would be helpful.

During the piloting of the programs, students were told they would have a chance to explore several different engineering disciplines and participate in hands-on lab activities. Many students interpreted this to mean they would watch videos on different types of engineering and see demonstrations in the lab, even though that was certainly not what was said. Some students felt that learning about engineering by doing the lab exercises and writing formal lab reports was an imposition. As the course progressed, students began to understand what was expected of them. Student response to the course was better when it matched their expectations. Since most students are not accustomed to doing the type or amount of work required in a college-level engineering course, very specific descriptions of class activities, preferably illustrated with photographs, will give them more realistic expectations.

With all of the experiments and design projects there is a continuing need for storage or strategies to avoid having to provide storage. The design project for the FEH students is a 9x9x12-inch robot that can be easily carried from the dorms to class and back again. The design project for the IEP program is larger and storage bins are provided in the lab room. This is not the ultimate solution; rather it is due primarily to a shortage of suitable storage space in close proximity to the lab room.

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A number of the laboratory exercises need to be fine-tuned or incrementally improved, and alternatives for some lab exercises and for the design/build projects to be alternately used in future quarters or years are needed. All of this requires piloting and documentation.

In both the FEH and IEP design/build projects, there is an unintended emphasis on the electromechanical side of engineering. A number of students in both programs have indicated that they would like to have something more directly related to civil, environmental, or chemical engineering. An alternate FEH project has been offered during the Spring Quarter of 2001 that looked at campus structures, building use (air quality), and water quality. This project appeals to the civil and environmental engineers.

8. Summary

Ohio State's use of hands-on laboratory exercises and incorporation of design/build projects requiring written reports and oral presentations in the Introduction to Engineering Program and the Freshman Engineering Honors Program has been described. Putting engineering up front in the first year and incorporating the hands-on laboratory experiences has attacked the problems of poor retention by getting students involved and excited about engineering right from the outset of the college career. Retention is up. The design/build projects completed by small teams of students which included both written reporting assignments and oral presentation requirements have helped address the shortfalls in the skill areas of written communications, oral speaking and presentations, teamwork, and problem solving.

An important element here was (and is) the use of regular faculty in the freshman courses to provide significantly more interaction between first-year student and engineering faculty, establishing a sense of identity with or belonging to engineering. ABET criteria are introduced early as part of the course syllabi as to which will be addressed in that particular course. Assessment and feedback are critical parts of the laboratory and design projects both for the students to assess what they have been doing and how it might be improved and for the faculty to understand how the students view the experiences. The attitudes of the faculty and students are positive about the hands-on lab and design/build portions of the first year engineering experience. Industry visitors have also been very positive about the need for this type of engineering instruction and educational experience.

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