Session 1353

Experiences with a Comprehensive Freshman Hands-On Course – Designing, Building, and Testing Small Autonomous Robots

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Abstract

During the past ten years, The Ohio State University's College of Engineering has been aggressively addressing the issue of student retention. A major element in this effort is the development of a first-year engineering program that has moved from a series of related but separate courses for first-year engineering fundamentals to a framework that involves two course sequences with tightly coupled courses. Engineering orientation, engineering graphics, and engineering problem solving with computer programming are now offered in each of two course sequences,[1] one called the Fundamentals of Engineering and the other the Fundamentals of Engineering for Honors. These course sequences retain part of the traditional material but now include hands-on laboratory experiences that lead to design/build projects.[2] Teamwork, project management, report writing, and oral presentations have assumed important roles in both sequences. This paper describes the administrative and teaching experiences with a design/build project course in the Fundamentals of Engineering for Honors sequence that serves as a capstone-like culmination to the engineering honor students' first academic year.

1. Introduction and Background

During the past ten years, The Ohio State University's College of Engineering has been aggressively addressing the issue of student retention. A major element in this effort is the development of a first-year engineering program with a track for honors students. The Fundamentals of Engineering for Honors (FEH) sequence is a tightly coupled three-course sequence with each course lasting the full 10 weeks of an academic quarter. The first course is labeled ENG H191 and offers each student a solid foundation in the fundamentals of engineering graphics and CAD, and it also incorporates a number of hands-on laboratory exercises designed to introduce the engineering disciplines. The second course, ENG H192, presents an introduction to computer programming with the C and MATLAB languages, and engineering problem solving involving computer programs and computer tools. The hands-on lab experiences continue and are designed to further explore the engineering disciplines as well as reinforce the problem solving techniques acquired in the classroom. Both courses have a mini-design/build project usually carried out by 2-person teams over a one-week period at the end of the academic quarter.

The last course in the FEH sequence is the Engineering Fundamentals and Laboratory 3, now called Engineering H193 (or ENG H193). Prior to taking this course, the students will also have completed as a part of the FEH program two math courses and two physics courses, all of which are coordinated with the engineering courses. The physics courses cover particle motion and electricity and magnetism. As a culminating course for first-year engineering honors students, the ENG H193 course focuses primarily on the planning, execution, management, documentation, and presentation of an engineering design/build project. It is this third course of the FEH engineering sequence that is described in the present work.

2. The Comprehensive Freshman Hands-On Course

The ENG H193 design project is a focal point for the FEH program. In many respects, this freshman design project course is comparable to a junior level or senior "capstone" design course in which a student might participate as part of the requirements for his chosen engineering discipline. A major difference is that the first-year ENG H193 course teaches the various planning, management,[3] documentation,[4] 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 planning, designing, building, testing, documenting, and demonstrating an autonomous robot that 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. This is intended to represent a real process of choosing a potential prototype for a real solution to a problem presented to a number of different competing engineering groups. In designing and building the robots, the students have to make use of the graphics, the computer programming, the engineering problem solving, the hands-on labs, the physics, and the mathematics of the previous academic quarters. Working in teams of three or four, the students are required to demonstrate and present the results of their efforts by submitting progress reports, participating in performance reviews, writing a formal project report, and making an oral presentation about their project.

The course format includes lectures on the technical approach to design, useful mathematical calculations needed, documentation methods by utilizing 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. These lectures, delivered on a "just-in-time" basis, occupy less than a one-third fraction of the class meeting time. 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, provide suggestions, and supply encouragement.

Student concerns are quickly and effectively addressed by using a team-teaching approach with the team being composed of faculty members and teaching assistants (TAs). A key to the strength and success of the FEH teaching team is the experience brought to the classroom and lab by the graduate teaching associates (GTAs) and undergraduate teaching assistants (UTAs). In most cases, the TAs themselves have been student participants in the FEH program and, due to exceptional performance and abilities, were selected to return as teaching assistants.

3. Operational Details of the Comprehensive Freshman Hands-On Course

To guide the students in their project efforts, certain information must be provided. The scenario must be defined, the requirements and constraints for the problem must be clearly outlined, a robot competition course must be designed and constructed, a reliable robot controller must be supplied, and a method for students to obtain materials must be provided. Foundational for all of these elements are capable support systems.

3.1 The Scenario

The scenario for the autonomous robot design/build project, which is changed each year, is developed by the ENG H193 instructional team comprised of the faculty, GTAs, and UTAs. The ingenuity of the TAs guided by the experience of the faculty has produced unique and challenging scenarios. What follows in this section is a typical robot scenario, taken from the project description for the Spring 2002 offering.[5]

> You and your team of automated fruit picking and handling specialists are the very best in the industry. The owner of a popular apple orchard wishes to fully automate the process of picking and collecting apples in one of its orchards that contains different varieties of apple trees on several levels of terraces. The orchard owner has hired OSURED (Ohio State University Research and Engineering Development) Enterprises to help select from among several competing companies a robot capable of picking apples autonomously from the trees on the several levels. You and your team are trying to acquire the contract to deliver a fleet of these robots. To determine which apple-harvesting robot might best serve the needs of the orchard owner, OSURED has devised a scale model "test orchard" on which competing robots will be demonstrated. The orchard owner has specified that one tree be located on the same level on which the robot starts, another tree with a different variety of apples on a second level and a third tree of yet another variety apples on a third level. Trees on the second and third levels may be accessed by two or more robots. The "test orchard" allows up to four robots to be demonstrated at one time. The layout of the "test orchard" is relatively symmetric, with starting locations differing according to being a "left-handed" or "right-handed" geometry. Each robot will start when a signal light in the floor of designated starting area is illuminated. A robot may distinguish between the left-handed and right-handed layout by detecting the color of a small square on the floor in its starting area.

The competence of an apple-harvesting robot will be judged in part by its ability to find trees in the orchard and to pick apples from the trees. The orchard owner has specified that at least two different varieties of trees should have an apple (or apples) picked from them by a robot as it demonstrates its capabilities. The apples gathered by a robot are to be placed into a collection bin located on the same level as the robot's starting location. Robots will not be required to be able to sort or deposit apples by color. Robots collecting at least one apple from two different trees and depositing those apples in the collection bin will receive the maximum possible score as a part of the team grade in [the course], but superior performance during the competition will be judged by the number (and color) of any extra apples picked and deposited by a robot.

To assist robots in navigation, there are guidance markings on the ground around each tree. Marker beacons are installed in the tops of the trees on the upper terraces of the orchard. Finally, some ramps between levels in the orchard are a different color than the floor of the orchard. It should also be noted that the simulated trees are of the same shape and are oriented in approximately the same way throughout the orchard.

The basis for the robot design is a design and build competition or demonstration for a fictitious company, "OSURED Enterprises," which is interested in procuring several robots for the scenario described above. In this design and build competition, students will be divided into teams of three or four people. Each team will be a separate "contractor" trying to win business from OSURED Enterprises. Therefore, you must remember that this is a competition, and proprietary information should be kept secret. For instance, the details of your power train design should not be divulged to other teams, since you are trying to establish your team's technical superiority. Last, but most important, you are encouraged to HAVE FUN. Be creative, and use your ingenuity. Use the rules to your advantage; after all, this is business. However, remember that you are engineers and work within a set of ethics defined by the profession.

3.2 The Project Specifications

Probable success for the students is directly affected by the specifications. An overly specific set of constraints will block creativity and interest, while an under-specified situation will lead to decision-making problems and frustration.

3.2.1 Development of Specifications

Specifications are developed using a team approach, with the team being composed of faculty members and TAs. Due mainly to their direct experience, the input of these TAs is very important to the definition of the constraints for any scenario. The final decisions are made by faculty with significant consideration given to TA input, costs, time and space limitations, and probability for student success.

3.2.2 Typical Specifications

Students would typically be presented with detailed specifications to constrain their efforts to reasonable levels for success. A few examples are presented below; a complete set [5] of definitions, requirements, and contest rules are given to the students at the beginning of the project along with the scenario narrative.

Physical – The robot, in its starting configuration, must be able to fit within a footprint of 9x9 inches and must be no taller than 12 inches in its starting configuration.

Electrical and Control – Each team will be loaned a programmable controller board and issued a copy of the controller / language documentation during week one. Additional copies may be downloaded from the web. The specifics of the controller and programming will be addressed separately.

Each team will be issued a photocell (CdS) cell that may be used as a light sensor. The controller program should use the light sensor input to determine when the starting signal has been illuminated. Each team will also be issued an optosensor that may be used to determine whether a surface is dark (black) or light (white). The controller program may, for example, use the signal from the optosensor to determine the color of the small square on the floor in the starting area to determine which side of the course the robot is starting on. There will also be a white-colored ring around each apple tree to aid in navigation when a robot is in close proximity to a tree.

The course will be outfitted with three Infrared (IR) Beacons that may prove useful in navigation. An IR Beacon will be positioned on the apple trees located on the upper levels. Each team will be supplied with one IR receiver and may purchase additional IR receivers capable of detecting the beacon(s). UNDER NO CIRCUMSTANCE MAY A ROBOT EMIT AN IR SIGNAL at either of the two possible marker beacon frequencies of 100 Hertz or 125 Hertz. A robot may emit an IR signal as a result of using an approved sensor that incorporates an IR light emitting diode. Examples of such permitted sensors include shaft encoders, optosensors, and the Sharp Model GP2D12 IR ranging device.

Budgetary – Each team will have a discretionary budget of $150. Each team will also be loaned a programmable controller board and issued a set of basic sensors. The actual cost of purchasing parts will be borne by the Engineering Honors project. Purchases made by a team will automatically be charged to that team. All project purchases must be made through the Engineering Honors Program. NOTE: If your team feels it is necessary to obtain external parts in these areas, you MUST have pre-approval from a member of the Engineering Honors Program staff before purchasing these parts. Without prior approval, you will not be reimbursed, and the use of these parts may be disallowed in competition. The Engineering Honors Program staff will NOT spend time troubleshooting problems caused by "external" parts. Thus, if you choose to buy them, you are on your own. As described later, there will be bonus points for those robots that are constructed under-budget, and penalty points accessed for robots that are over-budget.

Time Limits – Each team will have one minute to set up their robot before each run. Each run will last 120 seconds from the time that the start light/signal is activated. One minute will be allowed for removal of the robot and any disposable parts after run completion while the next run is being set up.

Procedural – Each competing robot must be presented to the course marshal within two (2) minutes of the 'call to compete'. The course marshal is the final authority regarding operations on the competition course. If the robot is touched by a team member during a competition run, the run is immediately terminated and scored only to that point in the run. Points shall be awarded for each task successfully completed, and furthest progress on course and task completion will be used for tie breaking.

Testing – In the time period leading up to the competition, teams will have access to the course when they are ready to test their robots. Each team must keep a log of the amount of actual testing time used on the course as part of their project documentation. Entries in the log should show day and time, purpose of test, name of engineer conducting the test, and number of minutes used. This log must be included in the team's final report and the team notebook. In many real-world situations, such testing time must usually be paid for and is often limited in availability. While there will be no cost associated with testing time for this project charged to a team's budget, and while testing time will generally not be limited, a log of testing time used is required.

3.3 The Robot Course

The "Course Team", which generally is a group of UTAs, is assigned to build the course after the high-level design is determine by the instructional team. The course team spends the first two quarters of the academic year constructing, modifying, and changing the robot course into what will eventually be given to the students. The course is constructed out of a variety of materials such as lumber, PVC roofing gutter, floor carpet, linoleum, and polycarbonate sheet. As the course team decides upon materials and construction practices, some aspects of the high level design may be modified to facilitate ease of construction, or rein in the level of difficulty of the project. When building the course, it is very possible to choose materials for driving surfaces, gripping surfaces, and objects in a wide spectrum of difficulty. Therefore the course team continually updates the instructional team in its decisions, and modifies the course and materials to keep the level of difficulty constant throughout the build process. In order to build the course correctly, the course team must make production quality working drawings of the course. These drawings are then passed along to the students once they receive the design project.

After the scenario and course are unveiled, the course team continuously monitors the wear on the course to ensure that it stays as constant as possible for student use. The Course Team is also responsible for moving the course to the competition venue to ensure that its conditions are the same as the ones the students experience in lab.

3.4 The Robot Controller

The controller used for this robot design project is the Handy Board controller developed at the MIT Media Lab by Fred G. Martin.[6] Designed for experimental mobile robotics work, this popular Motorola 68HC11-based controller board has a variety of digital and analog input ports for interfacing with various sensors and special ports for controlling infrared transmission and reception, up to four DC motors, and up to two servos. More recently, an expansion board has been developed to extend the number of sensor ports and interfacing capabilities. The Handy Board includes 32K of battery-backed static RAM, a connector system that allows active sensors to be individually plugged into the board, an LCD screen, and an integrated, rechargeable battery pack.

The platform is supported with a nearly complete subset of the C programming language in an interactive Windows-based environment called Interactive C (IC).[7] A useful feature of IC is its virtual machine approach to executing programs. Most embedded systems rely on an edit-compile-link-download cycle. In contrast, IC provides a virtual machine that runs on the 68HC11 and interprets pseudo-code (called "p-code") that is produced by the compiler. This approach is similar to that employed by the Java Virtual Machine.[8] In exchange for a performance penalty because of the interpreted p-code, the virtual machine approach does provide two benefits that are especially valuable in this context:

- Interpreted execution – Allows run-time error checking. Like Java, IC performs array bounds checking, as well as trapping other errors, at run-time to protect against common programming mistakes made by beginners. Another benefit of this approach is incremental development. Students can enter single lines or blocks of code into an interaction window (or console) on the host PC. The code snippets are then compiled, sent to the Handy Board, evaluated, and results returned.

- Multi-tasking – Multi-tasking allows students to create different processes for different types of robot operations (e.g., motor control, sensing, navigation algorithms, etc.).

The Handy Board is frequently used to run robot design courses and competitions at the university and high school level, build robots for fun, and control industrial devices. Its popularity has made supporting the controller in the ENG H193 course easier because of the good availability of boards and components from vendors and the freely available contributed software from a Handy Board web site.[9]

3.5 The "Company Store"

The FEH "Company Store" serves as the students' primary outlet for parts and supplies necessary to construct their robots. Common parts include Erector™ set parts, structural materials, motors, gears, wheels, electrical components, various sensors, nuts, and bolts. Except for exotic requests, all of these parts can be purchased directly from a "company store." The store is available during all open lab times, and it maintains a stock and advertises every item available in a catalog. The catalog is distributed to the students and is also available online. If a team wishes to purchase a part found on the Internet or in a vendor catalog that it is not currently stocked in the store, the store will acquire the part. Usually, if the non-stocked part appears to be a generally useful part for a robot, the store will order a quantity of that part and absorb the shipping cost. The part is then delivered to the team that ordered it, and the extra parts are stocked by the store. This allows the store to offer an increasing inventory of useful robotic parts while also having extras of the same part on hand in case the team's original part fails.

Parts and budgets are tracked online using a web server based application written specifically for this task by one of the capable UTAs. Teams may look up parts in stock at the store, and also keep track of their budget as necessary through this online environment. The company store is managed entirely by UTAs who carry all responsibility from managing orders to maintaining budgets to monitoring inventory. Using an online database keeps the store clerks from being overburdened with paperwork as most teams complete one or more store transactions each day. This becomes especially important when competition time nears and teams are scrambling to complete their robots on time and under budget.

3.6 The Support Systems

All open labs are staffed by at least two UTAs and often at least one GTA. Adjacent to the open labs is the "Company Store" which is staffed by at least one UTA. During normal class times, students are aided by three UTAs and one GTA as well as a member of the FEH faculty. As class times often intersect open lab times, this frequently allows students to have access to the support of as many as six or more UTAs with previous FEH experience, two GTAs with previous FEH background, and at least one experienced faculty member. Also, two instructional laboratory supervisors are available to assist students as may be necessary.

Machine shop tools and related user training are available locally and through other engineering departments on campus. The use of such equipment is closely coordinated and monitored by staff. During class time one UTA will travel with teams to facilitate use of the shop area. During open lab time one UTA is in the shop area at all times.

Students can also receive assistance on-line on a message board maintained by some of the FEH instructional staff. Here they are not only able to ask questions and receive authoritative answers from the instructional staff, but they are also able to receive answers from their peers. This peer advice can be extremely beneficial to a team since the project scenario changes every year and even experienced staff may not be able to provide definite answers to questions about new unknowns. In addition, the GTAs use a shared Instant Messenger name that is kept active almost constantly which allows the students to directly contact a GTA outside of class or open lab time.

Throughout the design project, each team's individual progress is very closely monitored, and all members of the student teams are required to meet with both a GTA and a faculty member weekly to discuss the group's accomplishments and challenges. In addition to these project review meetings, students are asked to anonymously evaluate each of their other team members, share these peer evaluation results with each other, and submit them to the instructional staff for review during the third, seventh, and last week of the quarter. These tools assist the instructional staff in directing help where it is most needed.

Along with closely monitoring students in-class, the FEH faculty, staff, and GTAs meet weekly to discuss developments in the program. Topics discussed vary across a wide spectrum from individual student issues to curriculum changes. Weekly journals that students are required to anonymously generate are reviewed.[10] This meeting not only helps bring all the engineering faculty involved with the robot project together, it also includes the instructional staff of the FEH math and FEH physics classes which the students continue to take during the project. This allows for coordination of midterms and other activities so as not to overload students during the busy quarter. Students see results from these meetings very quickly in their exam schedules as well as receive in-class feedback given by faculty during their classes to particular journal entries that were of the most interest to the instructional staff.

Through active feedback and a strong support structure, the student teams are successful at producing working robots every year regardless of the change in scenario.

3.7 The Competition

Two types of competition are held during the final weeks of class. During the eighth week of class, teams are required to have their robot ready to participate in an individual competition. This individual competition is then used to seed the brackets used for head-to-head competition, which occurs a week later.

The individual competition gives teams an idea of how scoring will take place and allows teams to gauge their performance against that of their competitors. This serves as motivation for most teams to make last-week revisions and updates to their robot hardware and software, and to see other robot's strengths and weaknesses compared to their own robot. Individual competition scores give the instructors a method of determining the potential of each robot so that they may be more equally paired during a final competition.

The final head-to-head competition is held in an arena environment and is open to the public. A large crowd of family members, media, and other interested public attend the 2-hour event. Two identical courses are used to run matches in an alternating fashion to keep the action going.

Large projector screens are utilized along with video cameras and a specially designed software package for displaying the teams participating during each match. Individuals from industry judge the event and determine each robot's score. Winners of each match are then placed against fiercer opponents until finally a grand champion is announced. Prizes, which are provided by industry sponsors, for the winners and other awards such as "Best Engineered" are handed out by the judges during the closing ceremony. A photograph of the 2002 FEH Robot Competition showing one of the multi-level apple orchard test courses described earlier in Section 3.1 is shown in Figure 1 below.

Figure 1. The 2002 FEH Robot Competition.

4. Lessons Learned

The lessons learned during the offering of the robot design/build project for several years in the FEH program are summarized as observed successes and opportunities for improvement.

4.1 Observed Successes

Participants in this first year FEH program are well prepared for success in their subsequent academic career and are at a strong advantage when seeking co-op or internship job opportunities. Longitudinal tracking of FEH students has revealed a number of measures of success. When compared to a matched engineering honors control group, honors students who have completed the FEH program's robot design/build project course:

- Are more likely to stay with engineering[11] (See Figure 2)
- Often start their engineering major 1 quarter earlier (See Figure 3)
- Graduate in 4.3 years rather than 4.8 years
- Participate in a co-op or internship more (80% of FEH versus 50% of control group)
- Are more likely to become the leaders in student organizations
- Have better grades in subsequent math and physics courses
- Have higher GPAs with an upward trend after three quarters
- Are more likely to retain their University Honors status

The FEH program has become one of the important reasons for top students to choose OSU over other schools.

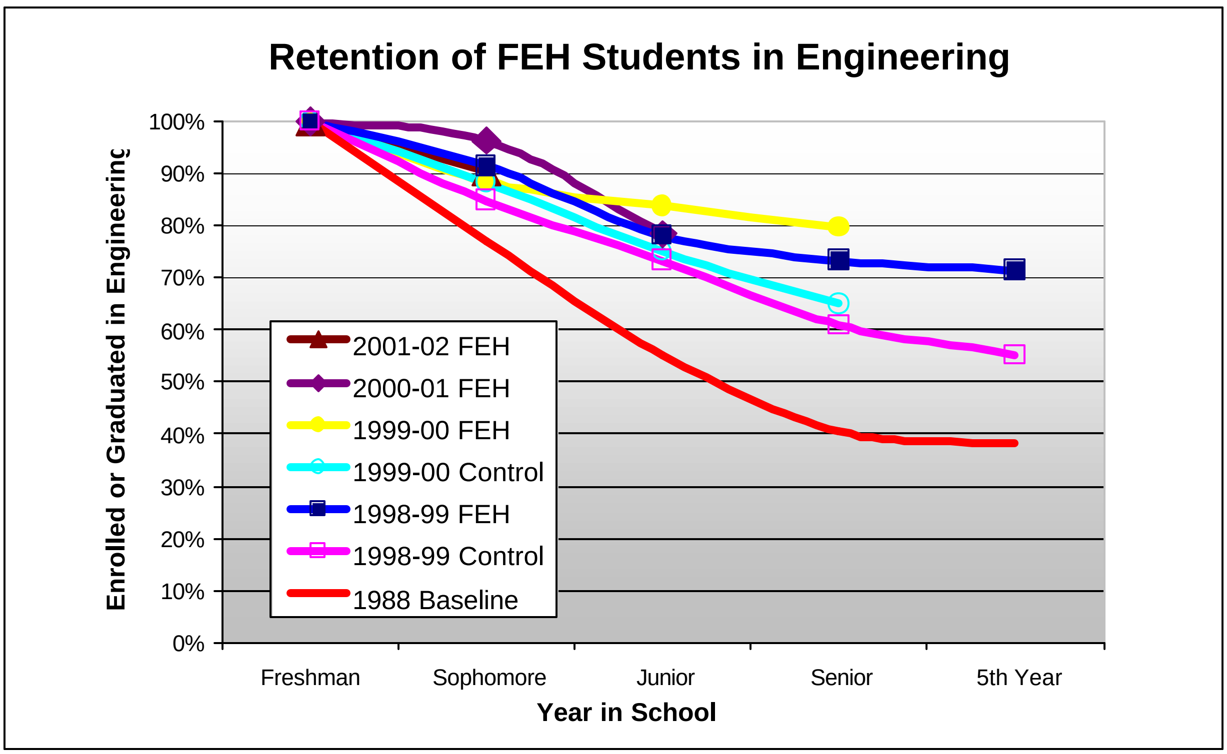

Figure 2. Retention of FEH and non-FEH honors students in Engineering to graduation compared to a College baseline for all students measured in 1988.

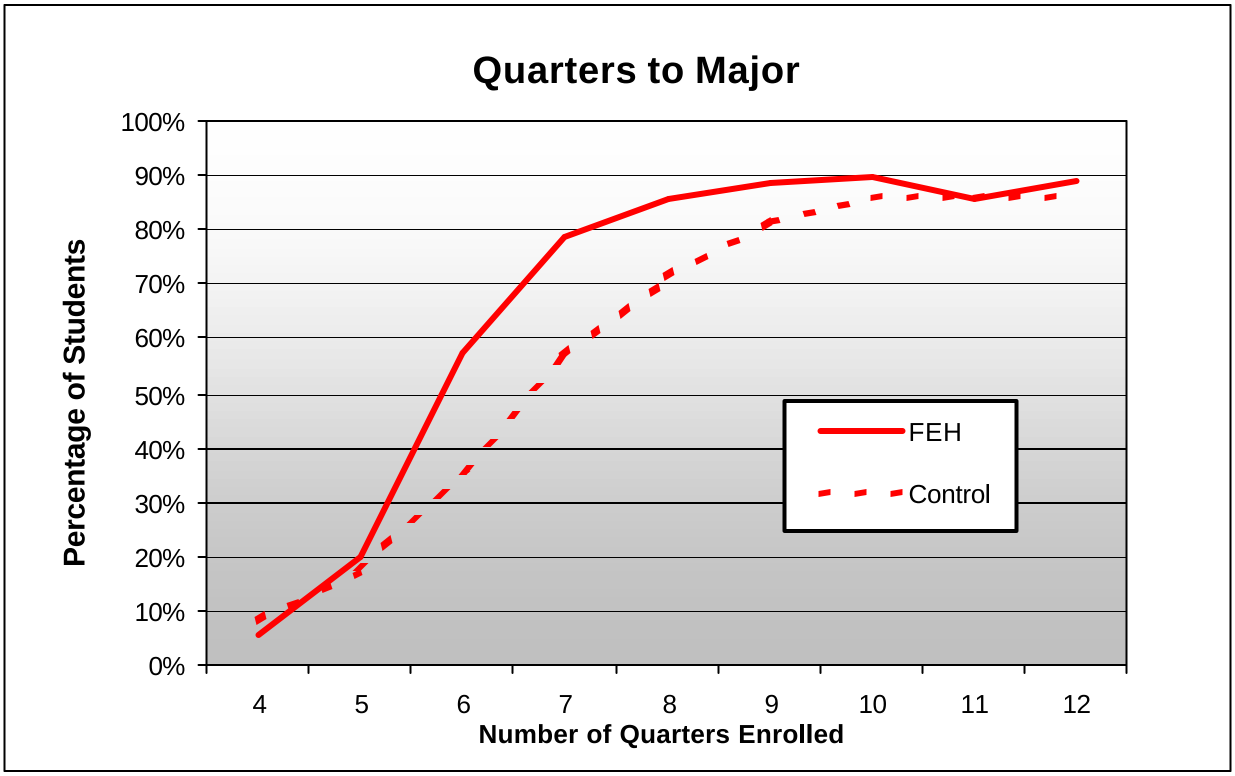

Figure 3. Comparison of academic quarters to entry to major between FEH and non-FEH honors students who entered in Autumn 1996, 1997, or 1998.

4.2 Opportunities for Improvement

As is often the case with many programs, there are opportunities for improvement.

The increasing popularity of the successful FEH program thus far has fueled a noticeable increase in the FEH student population. For example, there were about 70 honors students who started the FEH sequence in fall quarter of the 1998-99 academic year. A total of 250 honors students began the FEH sequence in fall quarter 2002. Historically, FEH was always able to provide a significant amount of instructional support to each student, but with such an increase in demand for the program, staffing at all levels—faculty, graduate teaching associates, and undergraduate teaching assistants—becomes more challenging. Several aspects of FEH, including the hands-on lab experiences, were originally designed with a smaller population in mind; population growth has strained resources of laboratory space and equipment. It is also difficult to provide a generous amount of individual feedback on each of the labs and assignments in a timely fashion when so many students participate in the program. If the growth of FEH is to continue as it has in the past few years, further thought will need to be given to the concern about how to continue providing the same high quality experience to a larger FEH population.

Also, as the number of FEH students increase, the diversity of engineering majors in the program increases as well. Whereas in the past many students were attracted to FEH primarily for the robot project as described in this document, a growing percentage of FEH students who plan to pursue fields less electrically or mechanically centered are more attracted to the enhanced instructional schedule during the first two quarters of the FEH sequence and are less interested in the robot project. Finding a design/build project that can bring the same amount of enrichment to these students is an important task. Already, alternative design projects involving designing measurement instruments for laboratories as well as designing entirely mechanical devices for other competitions have been tried. As experience is gained with these alternative design projects, they will be further developed to give engineering students more choices for enriching their first-year experience. Future additions to the list of alternative design projects may both help honors students enjoy their first year design project and facilitate growth in other areas of the FEH program.

5. Summary and Conclusions

Ohio State's use of a robotics-based design/build project as a capstone-like culmination to the first-year experience in the Fundamentals of Engineering for Honors program has been described. By retaining a significant amount of experience and spirit from previous FEH students and instructors who continue to enhance the program, and by providing a hands-on design/build project typically found in junior or senior level engineering curriculum, first-year engineering students are given an experience entirely unique and extremely beneficial to their collegiate engineering career and their futures as productive engineers. The FEH program has had notable success and continues to assess its own progress to foster change for keeping pace with changing needs and student population. Changes may be needed in the near future to keep up with the ever-increasing first-year population and diversity, but by continuing the tradition of unconventional thinking, experimentation, and frequent feedback, there is much evidence that indicates the future of the FEH program will continue to be bright.

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