An Overview of Highly Successful First-year Engineering Cornerstone Design Projects

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Abstract

The Ohio State University (OSU) Engineering Education Innovation Center's First-year Engineering Program (FEP) has focused on increasing student retention and improvement of student preparation for engineering through offering the fundamentals of engineering within the student's first academic year at OSU. The course sequences include engineering fundamentals, technical graphics, engineering problem solving with computer programming, and hands-on laboratory experiences that lead to a design-build project. There are three sequences offered to first-year engineering students: Fundamentals of Engineering available to all students; Fundamentals of Engineering for Honors designed to challenge the University-designated Honors students; and the most recent, Fundamentals of Engineering for Scholars in which the students are part of a living/learning community and are exposed to green engineering topics and sustainability issues. Several different design-build multidisciplinary projects covering topics within the 14 different engineering majors are offered to first-year students at OSU.

The four cornerstone design projects highlighted in the work presented here are: the basics of potential and kinetic energy through model roller coasters; lab-on-a-chip with a nanotechnology component; fully-functional, small, autonomous, ground-based robots; and autonomous, advanced energy vehicles.

This paper presents an overview of these cornerstone design projects offered at OSU and covers the details on how these design-build projects were developed, currently operated, and how they have been successful within FEP.

1. Introduction and Background

The Ohio State University (OSU) Engineering Education Innovation Center's First-year Engineering Program has focused on increasing student retention and improvement of student preparation for engineering through offering the fundamentals of engineering within the student's first academic year at OSU. In response to a US 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 became a part of a nine-school coalition called the Gateway Engineering Education Coalition. This need for engineers was then and currently still is driven by society's ever-increasing consumption of technology and now by grand challenges[1]. The Coalition, led by Drexel University, was established as a result of the creation of an Engineering Education Coalitions program by the US National Science Foundation. The Gateway schools agreed to adopt or adapt Drexel's E4 program[2-5] 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[6-10] of engineering coursework was a mark of change for a number of engineering programs at that time. In many respects, a truly comprehensive first-year engineering 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 or her chosen engineering discipline. Such first-year design projects are now commonly called "cornerstone" projects, and when combined with a senior capstone design project, the two experiences serve as bookends for the undergraduate engineering experience.

Putting engineering up front with design introduced early and often and incorporating the hands-on laboratory experiences were intended to attack the problems of poor retention by getting students involved and excited about engineering from the beginning of their first term. An important element at OSU was (and is) the use of faculty from across the College. The first-year courses are to provide significant interaction between first-year students and engineering faculty, which establishes 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.

2. The First-year Engineering Program Current State

The FEP course sequences include engineering fundamentals, technical graphics, engineering problem solving with computer programming, and hands-on laboratory experiences that lead to a design-build cornerstone project. There are three sequences offered to first-year engineering students: Fundamentals of Engineering available to all students; Fundamentals of Engineering for Honors designed to challenge the University-designated Honors students; and the most recent, Fundamentals of Engineering for Scholars in which the students are part of a living/learning community and are exposed to green engineering topics and sustainability issues. Students can apply to receive Honors or Scholars status when applying to the University. Their acceptance is based on standardized placement exam scores; and, in the case with Scholars, their extracurricular community involvement is also considered. Students designated with Honors or Scholars status may elect to enroll in any Fundamentals of Engineering course sequence for which they qualify and are not required to take the respective alternative course sequence.

These course sequences are one of the most innovative and successful of their kind, and have received national attention[11]. Each year, approximately 1,600 students complete one of the FEP sequences. Within these three sequences there are several different design-build multidisciplinary project choices. All of these projects run for the full 10-week academic term. The four current cornerstone design-build projects highlighted in the work presented here are:

1. the basics of potential and kinetic energy through model roller coasters,
2. a "lab-on-a-chip" done in micro-scale with a nano-scale technology elements[12],
3. fully-functional, small, autonomous, ground-based robots[13-14], and
4. autonomous, advanced energy vehicles that are suspended from and maneuver along a monorail track[15].

3. Common Elements in Each Design Project

There are a number of instructional elements common to all of these team-based cornerstone projects. The FEP has settled on a project team size of typically four students, which matches well with the project workload and typical kinds of tasks to be completed. The teams are formed, mentored, and reviewed to ensure that the students receive timely feedback on their performance.

Project management elements introduced throughout the design processes are regularly evaluated by requiring a regularly-updated project notebook. Each team tracks and manages the design-build project through notebook records that contain a team working agreement, initial concepts and sketches, brainstorming notes, team meeting agendas and minutes, scheduled performance tests, detailed CAD drawings, project schedule and budget information, and laboratory team memos and team reports.

The course format includes lectures on the technical approach to design, useful mathematical calculations needed, documentation methods for 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 one-third of the class meeting time. Much of the scheduled class meeting time is set aside as an open lab setting where students are able to work on their design-build projects with instructors and teaching assistants available to answer questions, provide suggestions, and offer 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 design project 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 students in the FEP program and, due to exceptional performance and abilities, were selected to return as teaching assistants.

Throughout the design project, each team's progress is closely monitored, and all members of the student teams are required to meet with both a GTA and a faculty member regularly 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 periodically during the term and finally at the end of the term. After each evaluation, the team members are encouraged to meet together to share these peer evaluation results with each other. All of the peer evaluation results are available to the instructional staff for review. These tools assist the instructional staff in directing help where it is most needed.

The teams' final designs are evaluated during individual competitions and scored based on the year's design criteria. At the end of the project each team develops a final report and oral team presentation. A final public competition or public exhibition, open to students and family members, industry support personnel, and the general public, brings all of the students together. In some cases, these competitions are co-judged by industry experts.

4. Four Successful First-year Engineering Cornerstone Design Projects

One important objective for cornerstone design projects is to provide a team-based experience that includes all aspects of engineering design and development. This includes student exposure to all activities within the design process from initial concepts through prototype development and testing to a final product. This objective also includes successfully providing students with awareness of and experience with the iterative nature of design throughout the design cycle. In order to assess this objective, student team-based surveys were conducted on a weekly basis throughout the design for each cornerstone project.

The surveying was anonymous and asked 72 teams, 18 teams on each design project (or approximately 288 total students), to record time spent on certain design process activities. The design process for the design projects was broken into seven activities including project management, a main objective for each design project which includes time management, task scheduling, team communications, and meetings. The additional activities were selected based on the common activities, such as brainstorming and lab specific tasks geared toward their respective design project. The activities on the survey include; identifying solution options, identifying constraints, performing research, performing analysis, evaluating analysis, and implementing design decisions. Along with the average percentage of total time spent for each activity throughout the design project, and the number of times the student team revisited the activity on a weekly basis was also recorded. This information was requested to provide insight into the students' experiences within the design cycle.

The following sections present an overview of each cornerstone design project. The overview includes project motivation, hardware components provided, design progression through hands-on labs and/or performance tests, and, if applicable, example operational objectives. Results from the student team-based surveys are included for each project description.

4.1 Roller Coaster Project

Students are presented with an introduction to the competitive amusement park industry through designing and building model roller coasters within this project. The students' creativity is challenged in developing innovative and exciting new model roller coasters while meeting configuration requirements.

The roller coaster is an open-circuit track using a one-inch nylon ball that rolls along track rails, trading potential energy for kinetic energy. The tracks are made of two 25 foot length 1/4 inch outside diameter polyethylene tubes that are connected using custom-designed snap-fits. The snap-fits can then be attached through nylon clips to a roller coaster support frame constructed of 1/2 inch plastic (CPVC) tubing of various lengths and several types of standard pipe connectors. The roller coaster must fit on the lab table, an area of five feet by four feet, and use the provided starting tower that allows for a maximum starting height of slightly more than three feet above the table surface.

Along with using the full 25 foot track section, each team's roller coaster must meet minimum required features such as a vertical loop, horizontal loop, bump, and straight horizontal section. A list of standard roller coaster features and points earned for successfully constructing and maneuvering along the track are provided to the teams. In order for the students to receive the highest possible score for the roller coaster, the teams are required to modify or add more features to the standard features listed. Teams must include eight speed sensors for measuring the ball's speed throughout the coaster.

The students develop design constraints through a series of labs, which include measurement of structural components, basic roller coaster physics with energy losses, and electronic speed sensor circuit development, which is used to collect data for determining energy losses due to g-force and track support. Based on results of the student team-based, weekly survey, Figure 1 shows the breakdown of the average percentage of total time spent and the number of weekly visits or revisits to the design process activities.

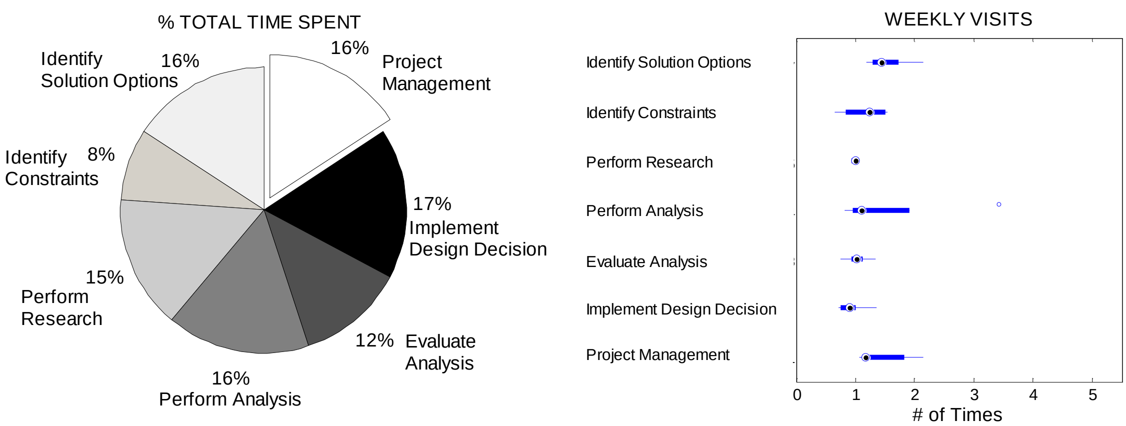

Figure 1: Roller Coaster Cornerstone Design Project – Student Team Survey Results.

The weekly visits are represented as a box plot of the survey data with the central mark as the median and with the edges of the thicker horizontal bars marking the 25^{th} and 75^{th} percentiles. The extending thin lines mark the extents of the data, not including the outliers, which are marked as open circles.

4.2 Nanotechnology Project

The nanotechnology cornerstone design project provides the students with experiences in the development of a Lab-on-a-Chip (LOC). The students are presented with a design scenario of using nanotechnology for product innovation or improvement within the biomedical field. The LOCs in the design scenario are to be used to conveniently run tests on small amounts of fluids on-demand and in the field. The project's test base uses fluorescein, a chemical that is used to detect an eye disorder known as dry eye syndrome. Current technology limits testing for dry eye syndrome to large facilities, requiring the patients to travel to a doctor's office. The project objective is design a cheap, portable LOC to measure the concentration of fluorescein, greatly reducing the cost of equipment and the capability to reach patients that may find it difficult to travel.

Each team creates two prototype LOC designs for the detection of fluorescence of a chemical solution. The entire layout of the both chips must fit with a 5.08 centimeter circle.

Students are exposed to the equipment and operational requirements necessary to design the prototypes through a series of labs. The operational requirements for the chips include the capability of passing samples of varying concentration of fluorescein solution for testing without contamination, cleaning the chip without removal from holders, and performing trials without contamination. Figure 2 shows the breakdown of the average percentage of total time spent and the number of weekly visits or revisits to the design process activities for the nanotechnology project.

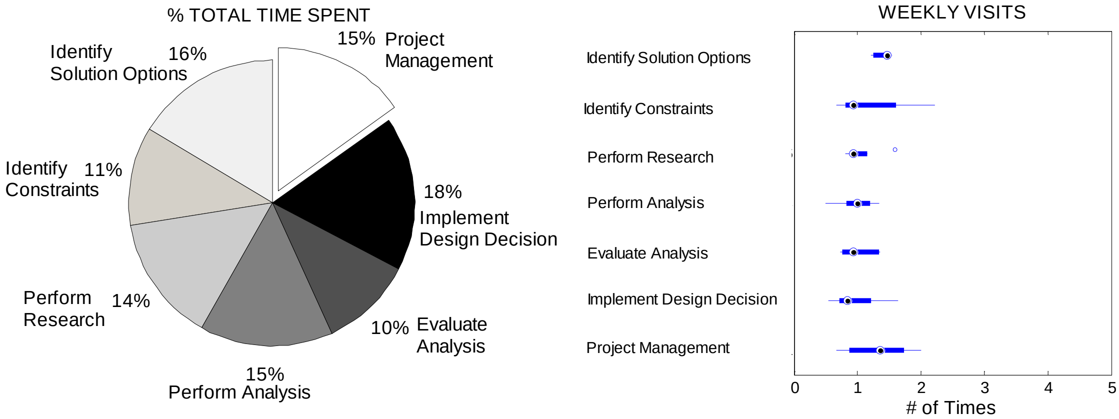

Figure 2: Nanotechnology Cornerstone Design Project – Student Team Survey Results.

4.3 Autonomous Robot Project

The most mature of the projects included here is the autonomous robot project, a project which was first introduced in 1996. It served as the original cornerstone design-build project inserted into the OSU engineering curriculum during the time the Gateway Coalition Project efforts were piloting a revamped first-year experience for honors students in what is now called the Fundamentals of Engineering for Honors (FEH) program.

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. The project 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.

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 construction materials must be provided. Foundational for all of these elements are capable support systems.

Each year the project scenario is completely changed. The Spring 2011 scenario involved an autonomous task robot performing a variety of jobs down on the Facility of Agriculture and Rural Machinery or FARM. On this small (~1/16 scale) simulation of a farm, the robot was required to properly locate and then harvest stalks of corn to be delivered to a storage bin. The robot also had to navigate to and then load a bale of hay onto an elevator used to load hay into the barn. A third task involved moving a grain wagon from the barn down to the field. The time limit for this exercise was two minutes. The task robots were limited in size to a 9 inch by 9 inch footprint. The course area that simulates the farm was approximately 12 feet by 12 feet in size. In addition to competition winners, several other teams are recognized for having the best engineered, most innovative, most consistent, and best documented robot designs.

Figure 3 shows the breakdown of the average percentage of total time spent and the number of weekly visits or revisits to the design process activities for the autonomous robot cornerstone design project.

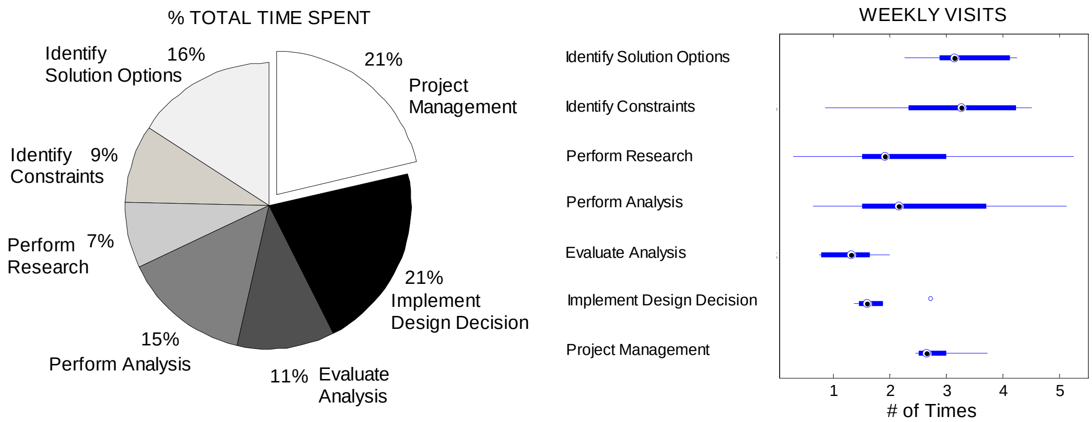

Figure 3: Autonomous Robot Cornerstone Design Project – Student Team Survey Results.

4.4 Advanced Energy Vehicle Project

The most recent cornerstone design project is a model-scaled advanced energy vehicle (AEV). It was developed specifically to focus on energy efficiency and energy management concepts for students in the Fundamentals of Engineering for Scholars course sequence.

AEVs are small (<500grams), autonomous, electric motor-powered, propeller-driven vehicles that are suspended from and maneuver along a closed-circuit monorail track hung from the laboratory ceilings. The AEV structure and monorail support arm are designed and constructed by students using two millimeter thick PVC sheets. The propulsion system includes electric motor and propeller combinations. The energy storage system is a two-cell lithium polymer battery. An in-house, custom-made automatic controller and performance recorder system featuring off-the-shelf Arduino Nano microcontroller[16] and speed controllers were developed and provided to each team. Data is collected through the autonomous control system and is used to monitor current and battery voltage during a defined vehicle run in order to determine overall energy consumption and provide the necessary information for developing energy management modeling of the AEV. Although not required, aerodynamic body components are highly encouraged to draw out a team's artistic creativity and add visual appeal to their vehicles. The AEVs must also fit within the team's storage box, approximately six inches wide, twelve inches long and five inches deep, with or without the support arm attached.

The AEVs are designed and built based on a series of labs and performance tests that utilize desktop wind tunnels and cover topics such as electric motor and air-breathing propulsion performance and evaluation, system efficiency, automatic control programming, and energy management.

Each year the operational objectives change, with the most recent AEV design scenarios focused on developing an energy-efficient alternative student transportation system for the Ohio State Campus Area Bus Service (CABS) in the year 2020 (CABS 2020). The operation required three stops, each made for a predetermined amount of time along the closed-circuit monorail track. Final competitions are conducted in order to further motivate teams. The competition is evaluated based on the most energy-efficient AEV performance in completing the operational objectives and also includes recognition for the best project documentation, most innovative design, and best engineered design.

Figure 4 shows the breakdown of the average percentage of total time spent and the number of weekly visits or revisits to the design process activities collected from student team-based weekly surveys for the design process activities for the AEV cornerstone design project.

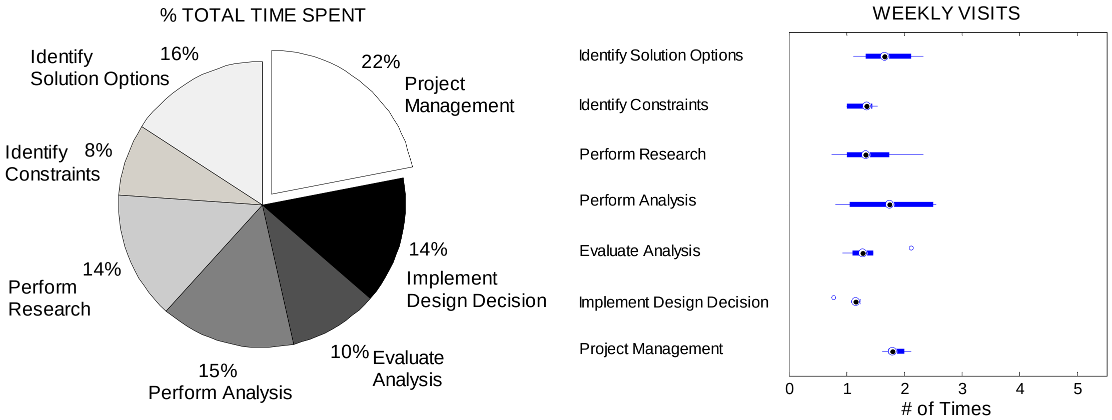

Figure 4: AEV Cornerstone Design Project – Student Team Survey Results.

5. Observations and Lessons Learned

The first observation to be made for these four projects comes directly from design process activity data collected and shown earlier in Figures 1-4. Given that the seven design and project management activities in the weekly team-based survey represent a reasonably full set of activities for most any design project. It is encouraging that all the FEP cornerstone design projects incorporate a measureable amount of time spent performing each activity. Data reveal that students are getting exposure to and experience in all of these important design activities, with no specific activity receiving less than 7% of a team's attention.

More complex design problems require and allow for more visits and revisits to specific design activities as shown by the weekly visits data for the Honors robot and Scholars AEV projects when compared to the other two projects. The greatest number of visits and revisits occurs for the robot project in the areas of identifying constraints and identifying solution options, with both areas having over three visits per week. It should be noted that the Honors robot project has approximately twice as much scheduled class meeting time available per week compared to the other three design projects. Occurrences of multiple visits to design process activities highlight and reinforce the iterative nature of design for the students.

Along with structured laboratory and classroom assignments, each design project provides time for student teams to explore the open-ended nature of design. These class sessions require the student teams to work on their designs in "free" time, or in the context of robot and AEV, when meeting performance tests. These class sessions do not require the students to complete and submit laboratory reports. The survey data demonstrates that balancing the structured laboratory experiences with the open-ended work sessions and/or performance tests provides time for the students to explore the iterative process of design within the design cycle.

Historically, the FEP has always been able to provide a significant amount of instructional support to each student. With recent increases in program enrollment of nearly 60% in the last three years from 1,000 students to 1,600 students per year, staffing at all levels—faculty, graduate teaching associates, and undergraduate teaching assistants—becomes more challenging. Several aspects of the FEP, including the hands-on lab experiences, were originally designed with a smaller student population in mind; increases in enrollment have 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.

The cornerstone design experiences have provided and continue to provide an increase in interaction between first-year students while establishing a sense of identity to engineering by placing it "up-front." These design projects have received national attention, and with the increasing enrollment rates, FEP is continuously learning from and adapting in order to provide a successful bookend for the undergraduate engineering experience.

6. Summary and Conclusion

The use of first-year cornerstone design-build projects as a "capstone-like" culmination to the first-year experience in the course sequences available to students in the First-year Engineering Program at The Ohio State University has been described. Student team-based survey results of design and project management activity utilization were shown. The surveys included seven design activities, common to all of the design-build projects. 72 teams recorded the amount of time and number of times that was spent on each activity. Data revealed that students got exposure to and experience with each important design activity, with no activity receiving less than 7% of the team's attention.

First-year engineering students at The Ohio State University are given an experience entirely unique and extremely beneficial to their collegiate engineering careers and futures as professional engineers The first-year engineering student experience is enabled through the retention of a significant amount of experience and spirit from previous FEP students serving as teaching assistants, instructors who continue to enhance the program, and by providing hands-on design-build projects typically only found in junior or senior level engineering curricula.

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