AC 2010-146: PROJECT-BASED FRESHMAN ENGINEERING EXPERIENCE: THE CORE COURSE

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Project-Based Freshmen Engineering Experience: The Core Course

Abstract

Villanova University has embarked on a new project-based approach for the required first year engineering experience. The two-semester sequence is divided into four ½ semester blocks with the first ½ semester block being the Core Course; this paper focuses on this first block. The Core Course is intended to cover material germane to the 5 engineering programs available at Villanova University (chemical, civil and environmental, computer, electrical and mechanical). This paper focuses on three major topic points:

- A discussion on the motivation for the change in the freshman engineering experience;
- Lecture details that take a geographically (and internationally) diverse set of freshman from different school systems and different learning backgrounds and provides the university-level engineering background that will enable them to successfully complete the mini-projects in the remaining three blocks in the sequence; and
- Project details (both pedagogy and logistics) used in this first block to aid in student's understanding of the engineering method, the collection and interpretation of data, and the presentation of this data

Introduction and Motivation

Villanova University has embarked on a new project-based approach for the required first year engineering experience. This project-based course sequence was deemed a practical approach to of end-of-course surveys as well as input from a number of freshmen and sophomore focus groups over the 2006-2008 time frame. These studies indicated that students felt that the previous freshmen engineering experience could provide a better introduction to the various engineering disciplines offered at Villanova University. The studies also indicated that the current previous freshmen engineering experience (a single course in each of the Fall and Spring semesters) was not as effective as it could be. In some cases, the sequence lacked relevance to current engineering problems and practice. The semester project in the fall course was either too challenging or not challenging enough for too many of our students. The previous freshman engineering courses were taught by faculty from the Mechanical Engineering department; besides a large project, the Fall course introduced the students to AutoCAD and SolidWorks, and for orientation and to stimulate interest in the engineering profession, had lectures and laboratory exercises on the five engineering programs offered at the university. The spring course focused on programming (MATLAB, Mathcad, and Excel) and problem solving. While the college enjoys an overall retention rate (freshman to sophomore year) consistently averaging over 80% (Figure 1), it was still felt that improving the freshman engineering experience would keep this rate at a high level, while at the same time providing a more relevant education for the freshman, and would also improve the slightly lower retention rate for underrepresented groups (the university has a common freshman year where student arrive undeclared and choose their major during the middle of the Spring semester).

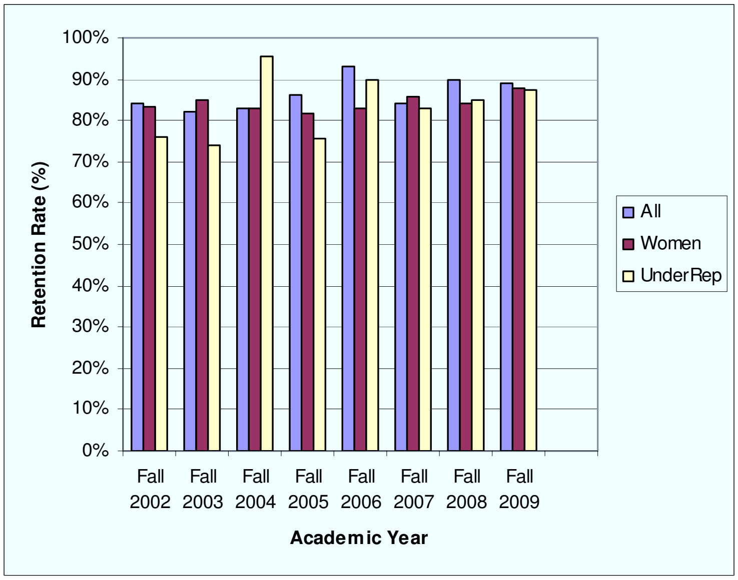

Figure 1. Engineering retention rates at Villanova University for engineering students (all, women and underrepresented groups) over an eight-year period. The Academic Year is defined as the start of the sophomore year in August.

A college-level committee (Freshman Engineering Committee, FEC) met frequently during the 2007, 2008 and 2009 academic years to create a new freshman engineering experience. The vision of the FEC was to: "… offer the most effective freshman engineering educational program in the U.S. (among schools having a common year) while fully supporting the mission and character of Villanova. Central to this vision is an emphasis on technical fundamentals in engineering including problem solving, design, data processing and interpretation, and computer programming, as well as non-technical skills including teamwork, effective communication, interactions among students and faculty, leadership, and service to society."

The initial approach was to ignore all constraints including material costs, staffing limitations and cost, and space, and formulate the best possible program for freshman engineering students. The FEC surveyed the college faculty to collect lists of desired technical and non-technical skills (Appendix A) and characteristics they wish to see in rising sophomores and beyond. The FEC also surveyed freshman and sophomore engineering students for their thoughts on positive and negative aspects of the current freshman engineering experience as well as the freshman mathematics and science courses. The FEC benchmarked against other freshman programs at several engineering schools (Notre Dame, Olin, Harvey Mudd, Lafayette, Purdue, Clemson, Rose-Hulman, Lehigh, Georgia Tech, Vanderbilt were among those studied). The FEC focused on mulit-disciplinary project-based and active-learning experiences as the best way to introduce new students to the engineering discipline. However, the FEC recognized that a transition period where engineering principles were introduced was also a requirement for those students fresh out of high school and without much engineering experience. The results of this committee's efforts were the development of a new two-semester course freshman sequence.

The resulting new freshman experience is divided into four half-semester blocks with the first half- semester block being the Core Course; the Core Course is the main focus of this paper (other papers in this conference will focus on two of the remaining three blocks that are composed of 'mini-projects'. The fourth block is department-specific and taught after the students have selected their majors.). The Core Course is intended to cover material germane to the five engineering programs available at Villanova University (chemical, civil and environmental, computer, electrical and mechanical). This paper will focus on two major topic points related to the general operation of this Core Course:

- Course material that takes an internationally diverse set of freshmen from different school systems and different learning backgrounds and provides the university-level engineering background that will enable them to successfully complete the mini-projects in the remaining three blocks in the sequence; and
- Topic selection and small project (our so-called micro-projects) details (both pedagogy and logistics) used in this first block to reinforce students' understanding of the engineering method and satisfy other course outcomes.

In this paper, we cover the details of the Core Course. Among these details are the desired Core Course outcomes, details of the lecture and micro-projects, how the Core Course fits with the overall vision for the remainder of the freshman engineering experience with more detailed multidisciplinary projects, as well as the results of assessment of a number of the desired course outcomes.

Desired Core Course Outcomes

The instructors of the course developed a set of course outcomes based on the goals outlined in the FEC course of action. Students communicate the results of assignments through formal and informal reports, because communication skills are extremely important for practicing engineers. Through the activities of this course, students learn the design process and develop useful engineering skills. This is an extremely important course for entering engineering students because, from class surveys, it was found that less than 5% had any exposure to engineering while in high school, a fact that has been noted in previous studies[1,2]. Therefore, the outcomes listed above were a necessary part of the course so that the students were well prepared for the mini-projects. The topics in this course give an overview of many engineering concepts and include: engineering mathematics; units, dimensions and conversions; the engineering design process; estimating and problem solving; engineering software packages; and an introduction to basic engineering principles. At the conclusion of this half-semester course, the student should:

General

- Understand what engineers do and know the professional organizations
- Be self-confident about studying engineering
- Understand the importance of independent learning

Professional Skills

- Understand the planning and managing of engineering projects by example
- Understand "real-life" constraints in engineering
- Understand the importance of teamwork and conflict resolution skills

Technical Skills

- Have improved logical and critical thinking skills, including organizing and documenting solutions
- Understand the process of engineering problem solving through the core course micro-projects and homework exercises
- Understand the processes of engineering modeling, analysis, and design
- Within the context of course micro-projects and other assignments:
    - Use algebra, geometry, trigonometry, and introductory calculus
    - Use mathematical concepts such as units, accuracy, precision, error analysis, and significant figures
    - Collect, organize, analyze, and present data and graphs
    - Use the PC as a data acquisition and manipulation tool

The plan was to include all of the skills appearing in Appendix A, not on this list, in other parts of new freshman program including the mini-projects and department-specific blocks.

Details of the Core Course

The course met twice a week in two 75-minute class meetings. Each lecture section contained an average of 55 students from the various engineering disciplines (recall that freshmen do not declare an engineering major until mid-spring). Electrical and mechanical engineering faculty taught the various course sections and met weekly to coordinate course activities and micro-projects. Each section was assigned two or three undergraduate teaching assistants to assist the faculty during lecture (in class problem sets or software issues) as well as assisting in the micro-projects. These teaching assistants were found to be invaluable for this class and the course faculty felt that the course really could not have been run well without them. A modified/reduced portion of the larger textbook, Introduction To Engineering by J. Brockman was used[3]. The readings shown in Table 1 are chapters from this custom textbook; also shown in Table 1 is a summary of the micro-projects and homework assignment schedule. The lecture portion of the course began with a discussion of the engineering method and common terminology used throughout the various engineering disciplines, then moved to systems definitions, creation and understanding of various engineering models (both theoretical and empirical), mathematical and computer-based methods of solving engineering problems, and an introduction to various computer tools (in this seven week course, students use Mathcad, MATLAB and Labview in addition to MS Office tools). Project-based experiences (the micro-projects) in this seven week course included having students compute their 'carbon footprint' based on an energy audit of electrical appliances in their individual dorm rooms, confirmation of conservation of momentum with a visit to the campus pool hall, thermal modeling of electric kettles, vibration analysis using tuning forks and transform analysis, and modeling of ballistic trajectory via experimentation. These experiments (micro-projects) were synchronized with the lecture material so as to reinforce student learning. In addition to the lectures and micro-projects, five homework sets were also assigned. Two one-hour long tests were given at the end of the 3rd and 6th week along with three 10-minute web-based quizzes given during the 2nd, 4th and 6th week. Student groups for the micro-projects were randomly selected by the section instructors. The micro-projects were designed to illustrate the forward engineering design process[4-6] rather than reverse engineering[7] and are described in detail in the next section.

Micro-project Details

This section presents details on four of the course micro-projects. These projects were designed to take one class session (75 minutes) and to be done using a modest amount of equipment. Each micro-project required the student groups to write an engineering report; a report template was provided to the students so that they saw from the very beginning of their engineering academic careers the proper format for an engineering laboratory report.

Carbon Footprint

In lecture, we discussed a chemistry-based as well as an energy-based approach to calculating the amount of CO_2 we produce on an annual basis; i.e., our *carbon footprint*. To obtain "ballpark values," we pointed the students to several online carbon footprint calculators that handle various pollution sources. A specific source of CO_2 generation is a dorm room, and that's what we wanted the students to investigate.

The carbon footprint assignment proceeded as follows:

- In your dorm, note all the electrical appliances (e.g. refrigerator, computer, lighting, cell phone charger, iPod, etc.). Enter each appliance name into Excel, along with its operating current, voltage, and power rating (look on the back of the device for a label indicating watts (W) or possibly current (A, mA)). For the refrigerator, since the compressor turns on and off, the faculty told the students that the power rating multiplied by the number of hours will not give an accurate measure of the total energy consumed, and to assume the compressor runs 10% of the time to estimate the energy consumption.
- List the approximate number of daily hours of usage for each appliance. Multiply its power rating by the number of hours per day. This gives the daily energy being consumed by the device.
- Assuming a 50% coal-based power / 50% nuclear-based power electric generation mix, calculate how much coal is being consumed each month for each of your appliances.
- From this value, determine your annual carbon dioxide emission.

Several key outcomes of the course were addressed in this micro-project. These included the following:

- Perform and present intermediate results and hand calculations, using proper engineering units.
- Extend and synthesize their knowledge of carbon footprints to other pollution sources. For example, compare various automobiles and their fuel efficiencies with respect to carbon dioxide output.

Conservation of Momentum

The concepts of conservation of energy and momentum as examples of Physical Laws were covered through examples of collisions between billiard balls of similar and of different masses. We went through several problems (both in class and for homework) and we showed the students how to set up and solve the equations in Mathcad. To further illustrate these two conservation laws experimentally, we designed a set of experiments for the students to perform on a pool table in the university Pool Hall. The students worked in teams of five students on these experiments.

In the first experiment, the students were asked to align two identical pool balls in a straight line and set up a digital video camera above the pool table. A tape measure and a stopwatch were also placed alongside the line of the pool balls. As the first pool ball was struck, the digital video camera started recording the motion of the two balls before and after collision and included videotaping of the tape measure and the stopwatch. In this way the students could calculate the velocity of the two balls both before and after collision. Most students used the video feature of their cell phones. The second experiment entailed the same set up but the first ball struck the second ball at an angle rather than head on. A protractor was used to calculate the angle of incidence and the angles of motion following the collision. The orthogonal components of the two balls' velocities could then be calculated from the experimental data gathered. The data analysis comprised verifying the conservation of momentum and energy laws assuming a frictionless surface and estimating the frictional losses on the pool table.

Several key outcomes of the course were addressed in this micro-project. These included the following:

- Have improved logical and critical thinking skills, including organizing and documenting solutions
- Understand the processes of engineering modeling, analysis, and design
- Within the context of course micro-projects and other assignments:
    - Use algebra and trigonometry
    - Collect, organize, analyze, and present data

Dynamic Thermal Modeling

The so-called Electric Kettle micro-project was a hands-on exercise done in teams of five. The objective of this micro-project was to introduce freshmen to the concept of modeling a physical system. A relatively simple time-varying system in the form an electric kettle filled with water was chosen for study. A lumped model was utilized with the state of the system defined by one physical variable: the temperature of the water in the kettle. The water in the kettle was heated and its temperature monitored with a thermocouple. The thermocouple was connected to the NI USB-9211A data acquisition unit and Labview was used to construct the temperature vs. time profile in real time. Both heating and cooling profiles were determined experimentally. Next, students were asked to model the heating and cooling of the water using a first-order ordinary differential equation. This equation had to be integrated using a numerical method (Euler's method) with appropriate initial conditions. These calculations, performed in Mathcad, were then compared with the experimental heating and cooling profiles to determine the effectiveness of the modeling process.

Several key outcomes of the course were addressed in this micro-project. These included the following:

- Have improved logical and critical thinking skills, including organizing and documenting solutions
- Understand the processes of engineering modeling, analysis, and design
- Within the context of course micro-projects and other assignments:
    - Use algebra and introductory calculus
    - Collect, organize, analyze, and present data and plot graphs
    - Use the PC as a data acquisition and manipulation tool

Table 1. Summary outline of Freshman Core Course

Week	Textbook Readings	Class 1	Class 2
1	Engineering and Society, Organization and Representation of Engineering Systems	Overview of course; brief discussion on the Textbook Readings done over the summer. What is Engineering?	Intro to engineering design process **Writing Assignment:** Write a single-paragraph biography of five engineers in different disciplines, outlining their contributions to the profession. *Homework*: engineering professions and professional societies
2	Learning and Problem Solving	Engineering Problem Solving and computer-based calculations	**Micro-project:** In-class: Manufacturing crayons – mass balance using Mathcad. *Homework*: Brownie mix mass balance using Mathcad
3	Learning and Problem Solving, Laws of Nature and Theoretical Models, Systems of Units	Systems and conversion of units, estimation and "ballpark" solutions, "napkin" or "back of the envelope" engineering	**Micro-project:** Carbon footprint calculations (dorm exercise) *Homework*: units and conversions (included an on-line assessment)
4	Laws of Nature and Theoretical Models	Analysis and modeling; Conservation of momentum and energy	**Micro-project:** Pool table exercise (class and homework) *Homework*: Applications of Physical Laws to Engineering
5	Modeling Change in Systems	Time-varying systems	**Micro-project:** The Electric Kettle *Homework*: Euler's Method for Solving Dynamic Systems Problems
6	Modeling Change in Systems, Introduction to MATLAB	Computer-based calculations and graphing	**Micro-project:** Launcher/ Vibration Analysis *Homework*: MATLAB programming
7	Vector Operations in MATLAB	**Micro-project:** Vibration Analysis/Launcher	Wrap up, takeaways

Vibration Analysis

The vibration analysis micro-project was a hands-on exercise done in teams of two students. The objective of this micro-project was to introduce the students to the data acquisition capabilities of their laptop computers as well as to have the students generate, analyze and present the results of their data collection and to compare their results with standard vibration theory. For this micro-project, tuning forks were used to generate a single frequency tone that was then input to the laptop via the internal microphone as a .wav file. MATLAB's signal processing capability through the Fast Fourier Transform (FFT) was then used on the .wav file to generate the frequency 'signature' (spectrum) of the vibration from the tuning fork. Students found the spectral responses of four or five tuning forks, measured the lengths of the tines, plotted frequency vs. tine length and then compared their results with the standard frequency-tine length expression.

Several key outcomes of the course were addressed in this micro-project. These included the following:

- Have improved logical and critical thinking skills, including organizing and documenting solutions
- Understand the processes of engineering modeling, analysis, and design
- Within the context of course micro-projects and other assignments:
    - Collect, organize, analyze, and present data

Linkage to Remainder of Freshman Engineering Experience

As mentioned earlier, very few of the entering freshmen have been introduced to general engineering principles while in high school. The goal of the Core Course was to prepare the students for success in engineering in general and to prepare them for more detailed project-based experiences during the remainder of their freshman year. This section of the paper describes the detailed mini-projects that follow the Core Course to show the linkage between the two distinct course experiences.

During the second half of the first semester, the students choose to work on one mini-project from among the six listed below. In the first half of the second semester, students can choose one of the other mini-projects from the list. These projects are all multidisciplinary hands-on projects taught by teams of senior research faculty selected for their teaching ability. The second half of the second semester focuses on discipline-specific mini-projects.

- In the Artificial Kidney Project[9], the students learn about how kidneys should function, what chronic kidney disease can do to them, how current dialysis systems work, and current research into improving these methods. Then they model the waste removal of the artificial kidney and its effects on a patient's overall health by using a numerical model. Next they build their own model dialysis filter unit for a haemodialysis machine. The design takes into account different variables such as the flow rate, the filter geometry and the patient's overall health. Finally, they test the filter device to see how much urea can be removed from a model "blood" solution. Mathcad is heavily used in the project and reinforces the use of Mathcad introduced in the core course.
- The Robotics project has teams of students designing, constructing, and programming (using MATLAB, reinforcing its use in the core course) LEGO-based robots in order to solve a variety of engineering problems. Some of the assignments include catapult trajectory aiming, racing path-following robots, robotic basketball, robotic art, and digital scanning.
- In the Acoustic Technologies in Object and Fault Detection and Classification[10] project, students apply acoustic and ultrasonic technologies to collect data, classify materials, detect flaws or damage, nondestructively evaluate material characteristics of products and structures, and construct and destructively evaluate reinforced concrete beams. MATLAB was heavily used in this project and was related to the vibration analysis in the core course.
- In the Aerodynamic Drag Reduction project, students investigate decreasing the drag on a vehicle, namely a recumbent bicycle, and then design and build a fairing and demonstrate the

design's effectiveness. In the process, small models are tested in the wind tunnel and mathematical models are developed to simulate the effects of drag on efficiency. The impact of drag on simple ballistic trajectories was covered in the core course as an introduction. This mini-project provided the students additional opportunities for reinforcement in using Excel.

- An Electric Car project had students designing an alternative electrical energy power system for a model car. They learn about alternatives to the internal combustion engine based on power sources that can be used to power electric motors for automotive applications. Some of the power sources are batteries, fuel cells, and solar cells. The students analyze the operation, energy density, efficiency, and available power of alternative power sources through the use of experiment and calculation. They then design and build an electric power system for a model electric car using a combination of any or all of the alternative power systems in this project and compete in a series of performance challenges. Power calculations in this mini-project provided reinforcement for the concepts used in the Carbon Footprint micro-project. This mini-project also provided further reinforcement in the use of MATLAB and Mathcad.
- In the SMARTBEAM project[10], the students identify the variables that affect the design of a structure and the load-displacement characteristics of a beam designed for reduced weight and material usage. They calculate and measure deflections, use Finite Element (ABAQUS) software to determine stresses and displacement, and design a data acquisition system (Rensselear Mobile Studio[8]) to record strain in a beam.

All of these projects require the students to understand the engineering design process and project planning, to know the approach to solving engineering problems, and to be able to work in groups. In all projects, formal written reports and oral presentations are required and it is expected that the students have some experience and expertise in these areas. Students are also expected to apply math and science in solving engineering problems and to be able to collect, organize, analyze and display data. All work must be done using proper consistent units and significant figures. These are all outcomes in which the students have developed some expertise during their experiences in the core course.

Assessment Results

A preliminary assessment of the Core Course described in this paper and the previous version of the freshmen course was performed. The preliminary assessment involved two approaches: one based on a review of the results of the university's Course and Teacher Survey (CATS) given at the end of each course, and an assessment with the follow-on course instructors regarding the preparation of the students for their respective mini-projects. The CATS provides student feedback on 23 questions pertaining to the course and instructor and the results are provided on a scale of 1 (poor) to 5 (excellent). CATS data for four questions were selected for the fall 2009 course and compared with the same questions for the previous freshman course in the fall of 2007 and 2008. While the data set was rather limited, the data did provide a means of obtaining a year-on-year comparison for each freshman cohort (Table 2 provides statistics of the three cohorts in the review, indicating similar entering freshmen credentials). As stated in the introduction, one of the major drivers in developing this new engineering experience was to provide a more rigorous and intellectually stimulating introductory course for all freshmen engineering students. Based on the year-on-year comparison between the new and prior freshman courses, the students indicated that indeed this new course required more hard work and was more intellectually stimulating than students in the earlier versions of the course indicated by a substantial margin (Assessment A and B in Figure 2). The students also felt that they learned a great deal (Assessment C) and saw substantial value (Assessment D) in the course compared with the previous freshman engineering experience. Further faculty review of these student responses indicate that there is room to provide an even more rigorous Core Course to the students; this feedback has been provided to the Core Course instructors and will be implemented in the next version of the course.

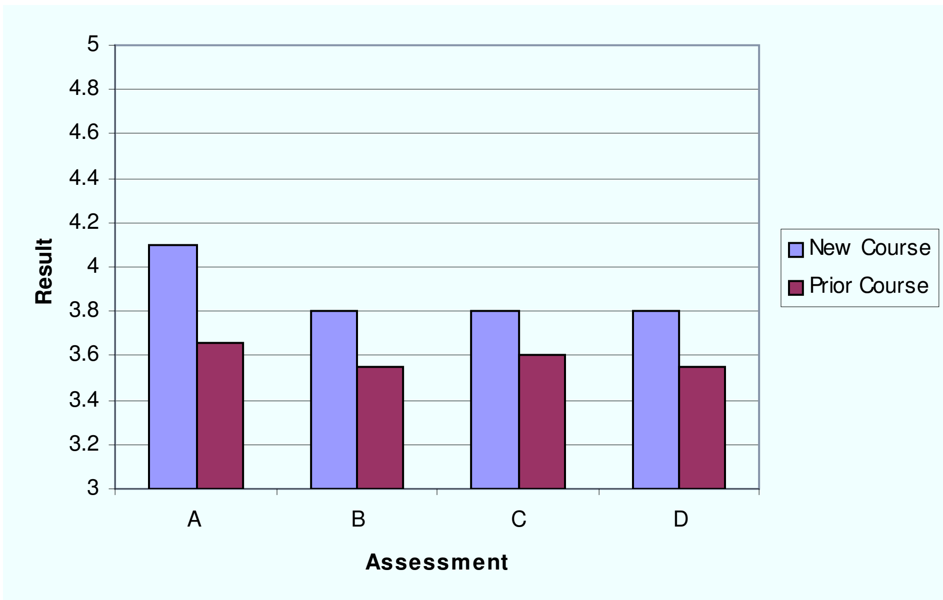

Figure 2. Comparison of Assessments between the New Freshman Engineering Experience described in this paper and the Prior Freshman Course.

Table 2. Information about the entering freshmen cohort at Villanova University

Year	SAT (combined range)	ACT (composite range)	Top 25 percentile in high school	Percentage of female students	Percentage of male students	Percentage of under represented groups
2007	1290-1400	29-32	92%	23	77	7.2
2008	1240-1390	29-32	95%	28	72	6.1
2009	1250-1390	29-32	91%	32	68	11

In addition to the results of assessment based on limited data set described above, the faculty involved in the Core Course have met with their counterparts in the follow-on mini-projects portion of the course. Among the issues involved in assessing the importance of the Core Course to helping the mini-projects was how well the Core Course prepared the students for the mini-projects in terms of the following course outcomes:

- Ability to use appropriate software for a specific engineering problem;
- Ability to solve engineering problems using a methodical approach;

- Familiarity and a high comfort level with SI units; and
- Ability to write an engineering report

The faculty in the mini-projects indicated that the students were reasonably well prepared for the follow on projects, especially given the amount of material to be covered in the seven week core course. In addition to these evaluations, this first run of the Core Course now provides a baseline for future versions of the course and forms the basis for further assessment and continuous improvement of the course as the College moves forward with the freshman engineering experience. The Core Course faculty will be developing rubrics for the assessment of student performance in the above course outcomes. These rubrics will initially be used in further assessing the fall 2009 course as well as subsequent Core Course offerings.

Conclusions

This paper presents the design and preliminary assessment results for a new freshman engineering experience at Villanova University. The new experience provides the students with a 'core' of engineering material (the major focus of this paper) that forms the foundation for further freshman-level work on a number of multidisciplinary engineering projects. The new Core Course includes both lecture-based material to aid the students in transitioning to engineering from high school as well as a series of 'micro-projects' that introduces the students to the engineering method, reinforces lecture material, and provides an introduction to proper engineering report writing. Initial assessment results indicated improvement in several areas, but also gave indications as to what areas of the Core Course might need additional attention in the future. Based on Fall 2009 to Spring 2010 retention data, more than 95% of freshman students will be returning for the second semester in the College of Engineering.

Acknowledgements

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Appendix A: Desired Skills from FEC Recommendations

1. Non-technical
    a. Teamwork
    b. Conflict resolution
    c. Communication (oral, written, graphical)
    d. Lifelong learning
    e. Project management
    f. Ethics
    g. Service to society

2. Technical
    a. Math
        i. Algebra
        ii. Trigonometry
        iii. Basic calculus
        iv. Rigor and systematic, methodical characteristics
    b. The balance concept (a transferable technical skill); flow, accumulation, and source
        i. Mass
        ii. Momentum (and Moments)
        iii. Energy
        iv. Charge
    c. Problem solving
        i. Define and understand problem
        ii. Sketching, including the general free-body diagram
        iii. Accumulate facts
        iv. Select appropriate theory, principle, equations, formulas
        v. Make appropriate simplifying assumptions

vi. Solve problem in appropriate manner (analytical methods including algebra, use of paper & pencil, modern engineering tools (FDM, FEM; see SolidWorks below, CFD), orders-of-magnitude, estimating)
vii. Understand dimensions and units (unit cancellation, consistency of use, rigor)
viii. Computer programming as a problem-solving skill (simple programming logic, assignment, loop, if/then, IO, functions, syntax commonality among packages)
ix. Present solution in appropriate form (formula, numbers, table, graph)
x. Critique and verify results (a critical thinking skill)
xi. Discuss results

d. Data
   i. Collection
   ii. Appropriate graphing
   iii. Curve fits & common representations
   iv. Errors
   v. Significant digits
   vi. Accuracy/precision

e. Introduction to design
   i. Problem finding – critical assessment of a need
   ii. Apply creativity - problem definition
   iii. Address uncertainty – accumulation of information, face constraints
   iv. Iterate on solutions – fail quickly and often (use c. above including critical thinking)
   v. Analysis, incubation, and decisions
   vi. Specifications
   vii. Communicate findings
      1. Drawing
      2. Use of drawing packages including AutoCad and SolidWorks

f. Introduction to computational tools
   i. The relevance of programming in engineering – how it helps us
   ii. Programming as problem solving
   iii. Familiarization with Mathcad, MATLAB, Excel