A Project-Based, Industry-Driven Freshman Design Sequence for Mechanical Engineers

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Abstract - **The engineering programs at York College of Pennsylvania recently undertook a comprehensive review of the two-course freshman engineering design sequence. This detailed study resulted in a complete restructuring of the sequence. This paper describes the original structure of the sequence, the shortcomings identified through assessment of its effectiveness, the structure of the new sequence, and results/observations from teaching under the new structure during the 2013-2014 academic year. York College offers three engineering programs - mechanical, electrical, and computer - all of which require three full semesters of cooperative work experience. While the redesign affects all of the engineering programs, the focus of this paper is specific to the mechanical engineering program. Originally, the three engineering programs shared a common two-course introduction to engineering sequence. The primary goals of the original sequence were to expose students to the engineering design process via hands-on projects, to develop teamwork skills in a multidisciplinary environment, to illustrate the differences in the three engineering disciplines, and to develop basic engineering skills including CAD, manufacturing methods, programming, and electronics. Assessment of the course outcomes along with an extensive, multi-year survey of the employers of the programs' co-op students revealed several shortcomings with the original structure. To address these shortcomings, the introductory engineering sequence was completely revamped. The new sequence consists of a common first course in the fall followed by a major-specific course in the spring. The common first course is split into two half-semester modules, one focused on mechanical engineering and one on electrical/computer engineering. The second course in the sequence is major specific. The mechanical engineering majors now take a course that integrates advanced CAD, CAM, and CNC machining via hands-on design projects.**

Index Terms – Freshman design, Introduction to engineering, Mechanical engineering, Design and manufacture.

INTRODUCTION & BACKGROUND

York College of Pennsylvania, a small, private, undergraduate college located in South Central Pennsylvania, offers three ABET accredited engineering programs – computer, electrical, and mechanical. Students in each of these majors complete a two-semester freshman design experience. The goals of this experience are to: expose students to the engineering design process; provide several hands-on design projects; develop teamwork skills in a multi-disciplinary environment; develop basic engineering skills including CAD, manufacturing methods, and basic electronics; stimulate interest in engineering; and, illustrate the differences in the three engineering disciplines.

Prior to the 2013-2014 academic year, the three engineering programs shared a common, two-semester introduction to engineering sequence. In the first course, the students developed basic programming and CAD skills and worked on a multidisciplinary design project. The project involved designing and programming a robot that could navigate an obstacle course. In the second course, the students received training on machining operations (use of the lathe, mill, and other basic shop machinery) and basic electronics. The second course also included a design project that was typically an electro-mechanical machine [1].

Assessment of the original two-course sequence revealed that it was meeting most of the goals noted above. However, there were several areas identified for improvement. First, the students were not clearly seeing the distinctions between the various engineering majors. One of the goals of the freshman engineering sequence is to help students determine if they selected the right discipline based on their interests. In the original sequence both of the design projects were electro-mechanical and some students had trouble seeing the distinctions.

A second shortcoming was that having all three engineering majors in both freshman design courses limited the scope and depth of coverage. All three engineering disciplines had basic skill sets they wanted to include as part of the freshman sequence and it became difficult to cover all of the desired topics in sufficient detail.

Third, there were additional skills that were identified for inclusion into the freshman design sequence. All of the engineering programs at York College require the students to complete three semesters of full-time cooperative work

experience. As part of the co-op program, the employers of every co-op student are surveyed to collect feedback on the engineering programs. Through these surveys, each of the engineering disciplines identified several topics that were important to industry but were not being covered. Specific to the mechanical engineering program, industry feedback identified the following needs: additional CAD coverage; additional coverage of CAM and CNC machining; and, new coverage on Geometric Dimensioning and Tolerancing (GD&T). A careful review of the program's curriculum showed that the best place to include these topics was in the freshman design sequence. Similarly, the electrical and computer engineering programs had their own list of topics to add.

Efforts to address these shortcomings led to a complete restructuring of the freshman engineering experience. The new sequence consists of a common first course for all engineering majors in the fall semester followed by a major-specific course in the spring. The common first course is split into two half-semester modules, one focused on mechanical engineering and one on electrical/computer engineering. For the second (major-specific) course the mechanical engineering majors now take a course that integrates advanced CAD, GD&T, CAM, and CNC machining. The following sections describe both of the new freshman engineering courses in detail, focusing on the mechanical engineering majors.

THE FIRST COURSE IN THE FRESHMAN ENGINEERING EXPERIENCE

In the newly developed sequence, all engineering majors at York College take the course Engineering Practice and Design Studio (EPADS) in the fall semester of the freshman year. This course is designed to address most of the goals for the freshman engineering experience noted in the previous section including: a first exposure to the engineering design process; a hands-on design project; multi-disciplinary interactions; initial development of basic engineering skills including CAD, shop practices, electronics, and robotics; and, exposure to the differences in the three engineering disciplines.

The EPADS course is divided into two half-semester modules. For the first part of the semester, half of the students complete an electrical and computer engineering module under the guidance of an ECE faculty member while the other half complete a mechanical engineering module with an ME faculty member. For the second half of the semester, the students switch to the other module.

The electrical and computer engineering module focuses on basic electronics skills and robotics. Students first learn about basic electrical components (resistors, diodes, LEDs, etc). Next, they move on to basic electronics principles including power, voltage, current, switching, and motor control. Students explore these concepts via a mobile, tethered robot project. At the close of this module, the students are exposed to the basics of control including PID control. They cover the basic concepts of control and then explore control applications via a balancing gantry project. In the electrical and computer engineering module the students meet with the instructor for two hours twice a week. There is also a 2 hour project workday that the students can use, as needed, to work on their projects.

The mechanical engineering module within the EPADS class focuses on CAD skills, basic machine shop skills, and the design process. The CAD portion makes use of the commercial program Solidworks. Students learn the basics of creating three-dimensional CAD models, assemblies, and drawings. They also get an initial exposure to determining stresses and deflections using the finite element analysis features of Solidworks. The shop skills focus on shop safety, hand tools, woodworking equipment (table saw, band saw, drill press) and metal working (mill and lathe). As part of the mechanical engineering module, the students are given a design project which they complete over the course of the module. Details on the design projects are given later in this section.

This past fall there were 6 sections of EPADS each with approximately 15 students. In the mechanical engineering module, the students have class two hours per day on Mondays, Wednesdays, and Fridays. On Wednesdays half of each section (6 to 9 students) receives CAD training while the other half receive training on shop skills. On Fridays, the groups switch roles; those who did CAD on Wednesday do shop skills on Friday and vice versa. The two-hour block on Mondays is for the students to work on their design projects.

In the mechanical engineering module, students receive a grade based on three primary components: CAD training, machine shop training, and the project. The grade distribution is 50%, 20%, and 30% correspondingly.

The CAD training part of the class concentrates on introducing students to part/solid model drawings and learning how to use various Solidworks tools. During the CAD classes, a self-guided learning process is implemented. Students follow the tutorials and activities in the class textbook [2] while the instructor monitors their progress, answers questions, and provides tips/advice. Each week the students work to design one or more components of a gear box by following step-by-step instructions in the textbook. To improve students' understanding, additional homework activities are given each week without the detailed step-by-step instructions. At the sixth week of the module, the students assemble the gear box from the individual part models generated in the earlier weeks. The specific skills gained in the first EPADS course are listed in the table below.

TABLE 1
Topics covered in CAD module of the first EPADS course

Week	CAD Skill
1	Introduction to Solidworks Interface
2	Generating a part file
3	Part Modeling
4	Part Modeling
5	Detail Drawings
6	Assembly Drawings Analysis with SimulationXpress

While getting training in CAD, the students also receive a total of four weeks training in the machine shop. At the first shop class, students become familiar with the shop safety and policies. During the following weeks, they learn how to use hand tools and wood and metal working equipment. At the end of the shop training, each student builds a pen and holder that they design. The pens are made using both a manual and CNC lathe while the holders are fabricated using a variety of methods, depending on the design of the holder. Examples of the pen and pen holders built in the fall of 2013 are shown below.

Figure 1
Pen and Pen Holders

For the mechanical engineering modules, two design projects were developed. One project was used for the first half of the semester (i.e. the first module offering) and a different project was used for the second half. Different projects were used to avoid students replicating the successful projects from the first half of the semester. The first project focused on designing, building and testing a device that could propel a tennis ball at a fixed target located 25 feet away. All of the design teams were required to incorporate a prescribed pneumatic cylinder into their design. Also, all of the launchers had to be self-triggering. At the seventh week of the module, the teams presented their design at a design review and demonstrated the functionality of the device during a final competition. Each team was allowed to make up to 5 shots in 5 minutes. The target was a series of concentric rings with decreasing point values moving away from the bullseye. Tennis balls hitting the center ring of the target received 25 points. If the device propelled a tennis ball but did not hit any of the target circles it received 10 points for that throw. The winning design is shown in Figure 3.

Figure 3
Tennis Ball Launcher

The second project was the design of a device which transfers the potential energy of falling water into kinetic energy to propel a model object. This project is a modified form of 2011 ASME National Student Design Project called H_2Go. The teams were allowed to design the transfer device and model object subject to given constraints. In the fall 2013 offering, the model objects used by the teams included toy cars, various balls, and fabricated rollers. Each team was given a $50 budget for purchases but most of the parts needed for fabrication were available in the machine shop. Figure 4 shows one of the student design teams during the water transfer competition.

Figure 4
Water Transfer Project

The grading of both projects takes into account the overall design concept including creativity, craftsmanship, functionality, the design presentation, and a contribution

factor for each team member. The contribution factor is a multiplier that varies between 0 and 1. The value of the multiplier depends on the amount of effort put forth by each team ember. If the student did his/her fair share of work during design, construction, and testing, that student receives a factor of 1. The contribution factor is determined from observations made by the instructors and peer evaluations.

THE SECOND COURSE

For the second course in the sequence, the electrical and computer engineering majors take a course called Introduction to Electrical Engineering whereas the mechanical engineering majors take Introduction to Mechanical Engineering. The Introduction to Electrical Engineering course continues development of basic electrical engineering concepts including circuit components, circuit design and bread boarding, and electronic instrumentation and measurements. The course also includes a combination of laboratory exercises and projects.

The Introduction to Mechanical Engineering course continues development of the CAD and fabrication skills from EPADS. It also includes coverage of Geometric Dimensioning and Tolerancing (GD&T), computer aided manufacturing, Computer-Numerically-Controlled (CNC) machining, and rapid prototyping. The course also includes a hands-on design project. The remainder of this section describes the Introduction to Mechanical Engineering course in more detail [3].

The Introduction to Mechanical Engineering course meets for two hours three times per week and the typical class size is 24 students. For the first half of the semester, half of the students (12) work in the machine shop, constructing projects designed to improve their machining skills. The other half of the students meet in a classroom/computer lab setting and work at developing advanced CAD skills. By splitting the class in this manner the number of students working in the machine shop is kept to a maximum of 12. This number was determined as a good limit based on available CNC machines, shop supervision, and safety. Half way through the semester, the students switch from CAD to shop and vice versa

The group of students assigned to the machine shop work under the supervision of shop technicians. The students are given detailed instructions, complete with toleranced drawings, to create two simple projects. Each project requires the students to perform some manual machining operations as well as some CNC machining operations using software to generate the G-code. Students are allotted three weeks to complete each project.

The first machining project is a milling project consisting of two sliders connected by a rotating arm as shown in Figure 5. The device serves no practical purpose, but it is a good exercise in making sure that the necessary tolerances are held or the device will not move properly. The students first construct the base using a manual mill following a set of step-by-step instructions. Students are then required to apply the same skills to create the sliders with very little instruction. Next, detailed instructions are given on how to use software to generate G-code and use a CNC mill to machine the arm.

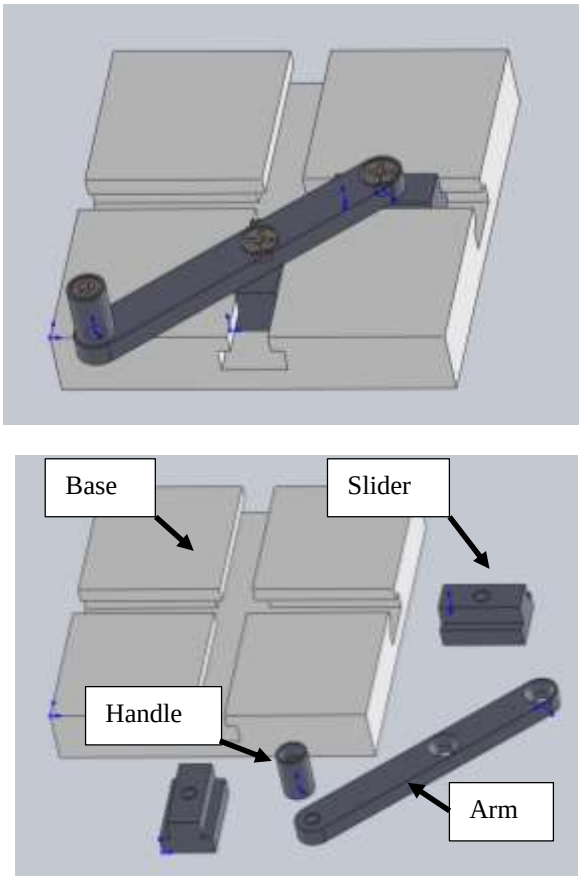

FIGURE 5
Slider Project

The second machining project is a lathe project where the students create their own soft-tipped hammer as shown in Figure 6. Students first create the hammer tips by following detailed instructions using a manual lathe. Next, they follow step-by-step instructions on how to use software to generate the G-code to machine the hammer head using a CNC lathe. Finally, they are allowed to make any design they wish for the handle of the hammer and machine it using either a CNC lathe or a manual lathe.

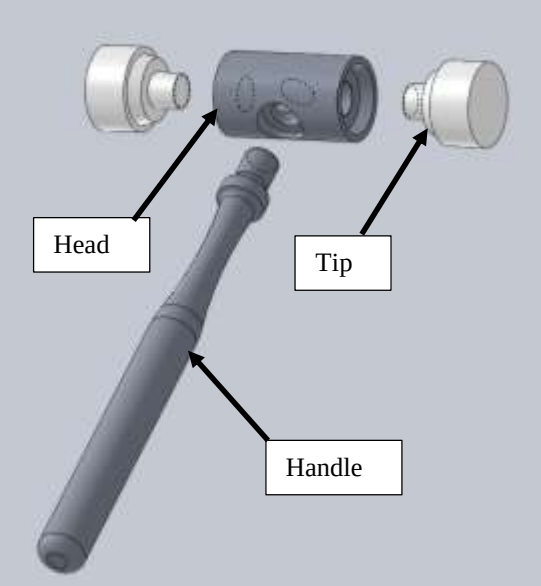

FIGURE 6
Hammer Project

The CAD module of the class concentrates on the creation of proper machine shop drawings using appropriate tolerances. The CAD portion builds upon the basic CAD skills that were developed in the first course in the freshman sequence, EPADS. The specific advanced CAD skills that are coverd are listed in Table 2. After completing the six weeks of advanced CAD activities, the students will then switch with the students who have been working in the shop.

TABLE 2
Topics Covered in CAD Module

Week	CAD Skill
1	Projection and Isometrics
2	Dimensioning and Tolerancing
3	Drawing Views
4	Detail Drawings
5	Assembley Drawings with Bill of Materials
6	Geometric Dimensioning and Tolerancing

OBSERVATIONS AND RESULTS

Assessment of both courses in the new freshman design sequence showed very favorable results. Feedback was collected through observations made by the instructors, course evaluations, and formal assessment efforts. Results show that the overall goals for the freshman year experience are being better met with the new course structure.

A major source of assessment data for the revised course sequence will come from future surveys of the co-op employers. However, the first wave of that data will not be available until August of 2015. The delay is the result of the fact that the students do not perform their first cooperative work assignment until the summer following their sophomore year. The summer 2015 term will be the first time students that have taken the revised sequence will perform a co-op assignment.

As with all course offerings, areas were identified for improvement. In future offerings of the first course in the sequence (EPADS), the project specifications will be modified to better define the project requirements/rules. In the CAD component, proficiency exams will be included to better assess students' Solidworks skills.

In future iterations of the Introduction to Mechanical Engineering course, it is planned to have the students complete a class project. The objective of the project will be to have small groups of students each develop a single part that will be assembled to become part of a larger device. The instructor will provide a basic picture of the device with materials chosen and general sizes of cross sections so that the students will only need to consider fit and tolerance issues. Each group of students will have to develop their individual component taking into consideration how it will fit with other groups' components to complete the device. As this course matures, it may also be adapted to include 3D printing techniques and welding.

ACKNOWLEDGMENT

The authors would like to thank the machine shop supervisors at York College, Barry McFarland and Earl Weaver. Their help in planning, implementing and teaching the new courses was instrumental to their success.

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