2006-1533: INDUSTRY-BASED DESIGN PROJECTS IN THE JUNIOR YEAR: 
MAKING THE TRANSITION TO SENIOR PROJECTS 

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Abstract

The Mechanical Engineering faculty at Western Kentucky University have developed and implemented a Professional Plan to assure that graduates of the program will have experienced key areas of the engineering profession and demonstrated their abilities to perform in a professional manner. This Professional Component has been divided into Engineering Design, Professional Communications, Professional (Computer) Tools, and Ethics, with students receiving instruction and practice in each area at least once per academic year.

The intended transition from students as observers to graduates as competent practitioners is accomplished by project activities demonstrating the practice of engineering over the entire curriculum. Freshmen individually build artifacts, sophomores function in design teams, and juniors extend the design experience to an external audience. Seniors are thus prepared to implement industry-based projects subject to realistic constraints and customer needs. In the junior design course, an industry based design project provides a structured design experience with an external flavor. Student teams must demonstrate problem-solving under time and budget constraints, as well as creativity. Our Professional Plan assessment indicated that immersion of the senior students in an external industrial project was possibly too abrupt an experience without additional opportunities to demonstrate their proficiency as an engineer and to gain confidence in their professional abilities. Through the Junior Design course, students are engaged earlier in their path to becoming practicing engineers through an externally defined design, build and test projects, increasing both their proficiency and confidence.

In the Junior Design course, student teams present their proposed designs to industry engineering and management personnel at a design review and in a professional presentation. In addition, student teams submit a final engineering project report to the client. Over the three offerings of the course, 39 junior mechanical engineering students have engaged in this project based learning experience and have successfully completed the virtual design, build and testing of their systems through their design proposals.

The Junior Design implementation of the external industry design project has evolved over the past three years guided by ongoing assessment of both the course and the Professional Component program outcomes. This is a strength of the Professional Component framework that allows for building upon previous coursework, assessing student progress, and adjusting course coverage based on prior assessments to assure that graduating ME students are capable of practicing as engineers.
Introduction

The engineering programs at Western Kentucky University are relatively new, with the first cohorts completing their degrees in May 2004. The ME faculty at Western Kentucky University have developed and implemented a sequence of professional experiences for students pursuing baccalaureate ME degrees that are consistent with the overall mission of the engineering department (the complete Western Kentucky University Engineering mission statement is found at http://www.wku.edu/engineering/depmiss.php):

...to produce, as its graduates, competent engineering practitioners. An engineering practitioner is one who has a foundation of basic science, mathematics, and engineering knowledge, combined with practical knowledge and experience in applying existing technology to contemporary problems. ... Program curricula will be project-based. Students will have sufficient opportunity to engage in project activities to support development of a clear understanding of engineering practice. ... Projects that provide opportunity to accomplish design, development, and implementation should be available.

With this overall mission, the ME faculty members place considerable emphasis on all graduates possessing professional competence. To achieve this outcome, Western Kentucky University ME students are given a structured Professional Component where they can acquire design tools and skills, as well as competency in mathematical and technical analysis, and communication. The implementation of a Professional Component allows Western Kentucky University to provide consistent and properly assessed instruction, assuring that students will be successful in these experiences [1].

The Western Kentucky University Professional Component coincides with the Criterion 4 requirements EAC of ABET: “Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints” [2].

The ME faculty have defined the following four areas to quantify and assess the Professional Component:

- Engineering Design (teaching and practicing design skills)
- Professional Communications (conveying designs and interacting with peers)
- Professional Skills (teaching and implementing design tools)
- Professional Ethics (evaluating and practicing appropriate professional behavior)

In each of these areas, a formal implementation plan has been developed to coordinate instruction across all four years of the curriculum, assuring student success in developing these skills. It is also necessary to assess the results and progress of students as they move through the curriculum. These outcomes can be difficult to define and therefore assess, so previously agreed-upon descriptions and measurement tools help this process. A final benefit of the plans is the opportunity to make adjustments as the students develop; instead of observing professional shortcomings at the senior level, earlier results can allow for more timely corrections to be made.
The demonstrated result has been that the capstone course is an integrative experience instead of a last minute attempt to introduce the necessary professional skills.

The overall details of the entire Western Kentucky University ME Professional Component Plans have been discussed previously [1]. This paper is intended to focus on a successful portion of the implementation of the Professional Component at an intermediate stage within the Junior Design class. This paper will review the applicable aspects of the Professional Component plan, detail the use of external industry projects as a junior class requirement, and discuss the assessment and evolution of the activity.

**The Professional Component by the Junior Year**

The Professional Component Plan developed by the ME faculty is used to oversee the delivery of professional skills to the ME undergraduates. The four aspects of the plan include: Engineering Design, Professional Communications, Professional Skills, and Professional Ethics. The intent of the plan is to provide students with instruction, reinforcement and finally the opportunity to display competency in each of these areas.

The delivery structure of the Professional Component Plan is shown in Table 1. The freshman class is a fall semester offering, the sophomore and junior classes are taught in the spring, and the senior sequence is a year-long experience with ME412 continuing from ME400.

<table>
<thead>
<tr>
<th>Professional Component Courses</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME175 Freshman Experience</td>
<td>2</td>
</tr>
<tr>
<td>ME200 Sophomore Design</td>
<td>2</td>
</tr>
<tr>
<td>ME300 Junior Design</td>
<td>2</td>
</tr>
<tr>
<td>ME400 Mechanical Engineering Design</td>
<td>2</td>
</tr>
<tr>
<td>ME412 ME Senior Projects</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1: List of Professional Component Courses

By the time students enter Junior Design they have been given instruction in design theory and have completed physical and theoretical design projects requiring a systematic approach, the generation and evaluation of specifications, the creation of designs to achieve defined objectives and satisfy consumer constraints, and the use of iterative decisions to optimize solutions and make compromises between conflicting needs.

Freshmen have built air-powered “steam engines” [3] in a design project that minimizes the engineering science, but develops a sense of the manufacturing skills required for realistic designs. Sophomores have executed two different projects: the design and construction of a device to test the performance of their freshman “steam engines” [4], and a team based synthesis and analysis design problem. Sophomores are expected to demonstrate abilities to apply design skills and technical analysis from previous coursework, and are given additional instruction in design decision-making techniques.
In the junior design course, the primary engineering design goals are to elevate the design experiences technically and to also expand the design problem to include an external audience. Western Kentucky University ME students at the senior level are expected to implement an industry-based project subject to realistic constraints and customer needs.

Students entering Junior Design have also been given instruction in Written, Oral, and Computer/Graphical components of Professional Communications. ME students can most clearly demonstrate their ability to use a variety of communication skills within the execution project activities. As with the Engineering Design component, Professional Communications begins in the freshman class with a focus on professional memos and sketching primarily. Sophomores continue to develop communication through more extensive written documentation (project reports and design review packages), initial efforts with oral presentations (formal and in meeting settings) and computer graphical and technical presentation of information through CAD drawings and calculation software.

The need to clearly identify customer needs as a communication requirement is first given in the sophomore class, but is reinforced in the junior class as the customer becomes more real and distant. Written and graphical documentation expectations are reinforced to the juniors, and continued practice in oral communication is provided.

The Professional Skills component addresses the integration of manufacturing process capabilities, computer skills and technical software usage into the ME curriculum. These tools were selected to support competency in mathematical and technical analysis, communication, and design. Freshmen receive training with a variety of manufacturing tools necessary to fabricate their “steam engines”. They also receive minimal instruction in the MS Office software suite. Sophomores are required to have taken the CAD course as a prerequisite to the sophomore design class, and then are provided with a moderate amount of instruction in the MathCAD calculation software. Both of these skills are required for the design projects.

Juniors are expected to demonstrate use of MathCAD in their design projects, and instruction is provided in MATLAB software to provide an additional tool supporting typical requirements of engineering design. Additionally, the juniors will demonstrate their competencies in graphical presentations using the CAD software (SolidWorks) as well as perform analysis using COSMOSWorks.

The Professional Ethics component is also present in each of the design courses, but is discussed in greater detail elsewhere [5].

**The Junior Year Industry Based Project – Engineering Design**

The Junior Design class, ME300, is taken in the spring semester. The course has prerequisites of the Sophomore Design class, ME200, for the professional components, as well as Mechanical Design, ME344, for the technical components. The two-credit course devotes 70% of the time to two design projects, and the remainder to additional Engineering Ethics and Professional Skills instruction.
All course activities are directed toward one or more of the seven stated course outcomes. By the end of the course students will be able to:

1. Use commercial word processing, calculation, presentation and graphics software to perform and convey engineering design work.
2. Give an effective oral business presentation.
3. Demonstrate effective writing of engineering documentation. Create and use timelines and responsibility charts for project planning.
4. Use creative problem solving techniques for solving business and technical problems.
5. Complete effective performance evaluations of team members and demonstrate that they are effective team members.
6. Describe and implement different design methodologies.
7. Explain the principles and issues of ethical behavior in engineering and professional fields.

One of the two design projects is the ASME Regional Student Design Contest [6]. Using a student contest as a class project provides the opportunity to execute the design process on a well-defined problem, with the final deliverable being a working device. The timing of the competition has also provided a challenging exercise in teamwork necessary to complete a project under a short timeframe. The ASME project supports course outcomes 1 through 5, emphasizing 4 (creative problem solving) and 5 (effective team behavior).

A strength of competition-based projects is delivery of an actual artifact, subject to a challenging schedule. Furthermore, students can compare their final products with other teams, assessing quality through the competition scoring, which provides aspects of design iteration or optimization that are often difficult to achieve otherwise. The weakness of the ASME project is that design competitions have rather artificial final products.

The second junior class project involves an external customer, typically a local industrial partner of the ME Program. Over the past three years the class has designed a cleaning system for a process component of a die cast manufacturer, a pulp roll handling system for a manufacturer of incontinence products, and a robot gripper for a manufacturer of truck brake hubs. As with the ASME project, the external project supports course outcomes 1 through 5, however greater emphasis is on outcomes 1 (use of tools to generate engineering designs), 2 (oral communication) and 3 (written communication) for this project. Each three or four person teams’ final deliverable is a detailed conceptual design report and final presentation, with expectations of appropriate technical analysis and some effort at component selection.

The ME300 industrial based project is delivered to the class as follows:

1. Project Kickoff: Customer Site Visit with Site Evaluation Sheet prepared and submitted prior to the visit
2. Project Concept Statement: Describes project purposes, sponsor, goals, and student team.
3. Project Design Review: Propose final design with drawing package, design calculations (using MathCAD); Demonstrate iterative design process and the optimization of design.
5. Project Presentation: Describes final design to customer.

The schedule of these activities and project point values are shown in Table 2. The 350 points is out of a ME300 class total of 1000 points.

<table>
<thead>
<tr>
<th>Project Milestones</th>
<th>Date Due</th>
<th>Project Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Visit Evaluation Form</td>
<td>Mid March</td>
<td>10</td>
</tr>
<tr>
<td>Project Concept Statement</td>
<td>Late March</td>
<td>10</td>
</tr>
<tr>
<td>Project Design Review</td>
<td>Early April</td>
<td>100</td>
</tr>
<tr>
<td>Project Report Draft</td>
<td>Mid April</td>
<td>20</td>
</tr>
<tr>
<td>Project Final Report</td>
<td>Late April</td>
<td>150</td>
</tr>
<tr>
<td>Project Presentation</td>
<td>Early May</td>
<td>60</td>
</tr>
<tr>
<td><strong>TOTAL PROJECT</strong></td>
<td></td>
<td><strong>350</strong></td>
</tr>
</tbody>
</table>

Table 2: ME300 Junior Design Industry Based Project Grading Component

The industrial based project clearly provides a suitable activity for the students to develop and demonstrate their Engineering Design proficiency, overcoming the weakness of the ASME competition whose explicit rules detract from students defining the problem. An external project has design features that students need to experience: creativity, generating alternative solutions, feasibility, manufacturing considerations, and realism. In contrast to the ASME competition, the emphasis is on a technical evaluation of a customer’s needs, gathering information from an external customer, and formulating a solution to a problem that accommodates the customer’s interests. The teams are expected to generate a variety of potential design solutions, evaluate their solutions in a structured way (typically with some variation of the Pugh Method), and then advance their preferred design to a reasonable initial design stage.

At this stage in the students’ progress, there is little new instruction in the design process, and students are expected to organize and implement the design process on their own. A higher level of scrutiny is provided by the faculty in the design review process and in the evaluation of the final report. This faculty oversight is greater for the external ME300 project than for the ASME project, since the ASME competition provides the students with clear feedback on the quality of their solution.

The final deliverable of a report and presentation, and the required analysis of their solution provide opportunities for the students to practice the Professional Communications and Professional Skills components (described in the next section) that will be required for their senior projects.

The Junior Year Industry Based Project – Professional Communications and Skills

The proper execution of the design process for the external project provides a rich and exciting learning experience for the student, and demands the use of professional communications of
information and professional skills for technical analysis. Therefore, the external project includes Professional Communications in the form of a design review, final written proposal and final formal presentation. Professional Tools such as MS Office for documentation, SolidWorks for CAD and MathCAD for analytical calculations are also required.

The major communication requirements of the external project are the team design review midway through the project, and the final report and presentation at the conclusion. Design reviews are a cornerstone of projects at Western Kentucky University, providing an essential tool for students to demonstrate their grasp of a project as well as to solicit feedback. Faculty members are also in a position to catch faltering teams or non-productive team members early in the project, as well as guide teams away from potential pitfalls. The process of conducting design reviews has evolved and improved over the years. The main purpose of the design review is to improve the quality of the design through feedback from customers and other technical experts. This review process is patterned after the approach used by engineers within industry. At design reviews, the students interact with a customer in a structured semiformal setting. They develop and refine written and oral communication skills related to the technical aspects of their designs. More specifically they learn how to facilitate the design review meeting, handle technical questions, use customer feedback, and make decisions using their engineering skills [7]. By ME300 the students have conducted several design reviews, but this is the first one involving an external customer.

Providing student teams with the opportunity to refine written and oral technical communication skills is also valuable in a project setting [8]. All communication components were introduced in sophomore design, though the level of proficiency expected is greater. The concept of clearly defining the reader and the reader’s needs is a major theme for professional communication with this project, due to the external nature of the customer.

Students use their Professional skills for the external project through the use of a variety of software tools (MS Office, SolidWorks, and MathCAD most commonly). Instruction has been provided in earlier classes for each of these. During ME300, MATLAB instruction is provided, though it is typically not required for the project.

Project milestones and their associated requirements provide students with a definitive set of deliverables throughout the progression of the industry based project experience. Student and student team performance can be monitored and evaluated with timely and appropriate feedback provided. Course outcomes are mapped into these deliverables for course and program level assessment, which is discussed next.

Assessment
The structure for measuring and assessing student performance is provided within the overall ME program assessment. Engineering Design is an aspect of five of the thirteen ME Program Outcomes, which are shown in Table 3 (the complete list of Western Kentucky University ME Program Outcomes is found at http://www.wku.edu/engineering/me/megoals.php).
ME Program Outcomes

Professional Skills

4. ME graduates can use structured problem solving techniques, appraise the needs of clients, produce product/project definition statements, and propose appropriate engineering solutions.

5. ME graduates can execute a design from inception through completion, and convey/document solutions in a wide variety of formats.

Engineering Professionalism

6. ME graduates can successfully manage projects.

7. ME graduates can participate effectively in multi-disciplinary teams.

8. ME graduates can judge appropriate professional and ethical conduct.

Table 3: Partial List of ME Program Outcomes

All ME300 activities are directed toward one or more of the seven course outcomes stated earlier in the paper. Student participation in the two ME300 design projects is expected to provide measurable evidence of students’ abilities to perform the first five course outcomes:

1. Use commercial software to perform and convey engineering design work.
2. Give an effective oral business presentation.
3. Demonstrate effective writing of engineering documentation. Create and use timelines and responsibility charts for project planning.
4. Use creative problem solving techniques.
5. Complete effective performance evaluations of team members and demonstrate that they are effective team members.

The student performance is assessed by the faculty via their grades on various course activities (shown in Table 2 for the external project), which have been linked to course outcomes. At the end of the course students are also surveyed for a self-assessment of their performance. A target score of 8.0 for all outcomes has been selected. Student performance by faculty assessment and student self-assessment in most outcomes was comparable and near the desired targets. 2005 ME300 results are shown in Figure 1 for the five course outcomes related to the external project.
The industry project provides students with most direct experiences related to outcomes 1, 2 and 3, and to a lesser extent supports outcomes 4 and 5. The observation by the two faculty members teaching the course was that the 2005 ME300 class performed at a noticeably higher level than the 2004 class. Their professionalism and the quality of the final design project products—the external project final designs and the ASME robots—were clearly better in 2005. In 2004, students had weak communication skills and their independent implementation of the external project was lacking—this was not the case in 2005.

In all cases, instructor assessment of the outcomes based on student work satisfies the target of 8.0. Outcome 5 was the lone instance where student self-assessment was lower than the faculty assessment. Students were perhaps self-assessing their ability to perform peer evaluations, where only minimal time is spent and peer evaluations are done at the end of the semester. Actual performance by students as team members was stronger. To address student perceptions, this topic will be introduced into Sophomore Design, ME200, with the intention to bring students to a professional competency by their senior year.

Over the three-year history of the course, instructor-based evaluation of the outcomes has risen slightly, with the greatest gains in Outcome 1, reflecting the increased exposure to the Professional Component that is been developed. Student self-assessment has also risen sharply with Outcomes 2, 3 and 4 over this time period, where students are gaining confidence in their abilities to execute projects.

Individual course assessment is integrated for overall Program Outcome assessment at a Peer Review of Course Effectiveness session. A variety of measures are collected: evaluation of selected student work, performance of students in extra-curricular activities, student exit interviews and composite student grades in appropriate courses. The integration of the courses
across the curriculum is then discussed more completely at an annual meeting to discuss the data gathered for each Program Outcome [1].

In particular, the industrial based project provides input to assess Outcome 4: Mechanical Engineering graduates can use structured problem solving techniques, appraise the needs of clients, produce product/project definition statements, and propose appropriate engineering solutions; and Outcome 6: Mechanical Engineering graduates can successfully manage projects.

Rubrics are used to assess student performance for most outcomes (Program Outcome 4 and 6 Rubrics are shown in Tables 4 and 5 below). The same rubrics are used for all levels of student work evaluated, quantifying the growth of professional competence as students progress through the curriculum. The expected total score indicated at the bottom of either rubric table changes, reflecting the increasing expectation for student performance as they move through the elements of the integrated Professional Component.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Absent (0)</th>
<th>Novice (1): some of the elements are present</th>
<th>Intermediate (2): most of the elements are present</th>
<th>Proficient (3): all elements are present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of structured problem solving techniques: created multiple options, implemented and explained evaluation of options, used evaluation for decision making and improvements</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Appraise the needs of clients: identify customer/audience, incorporate needs into design decisions</td>
<td></td>
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<tr>
<td>Produce product/project definition statements: quantitative and qualitative documentation of acceptance criteria</td>
<td></td>
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<tr>
<td>Propose appropriate engineering solutions: justified technical/practical/allowable solution to stated problem at correct level of detail for the stage of the project.</td>
<td></td>
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</tr>
<tr>
<td>Total Score: Expect 6 for Sophomore class, 8 for Junior Class and 10 for Senior Class</td>
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</tbody>
</table>

Table 4: Rubric Applied to Student Work for Outcome 4

The Outcome 4 rubric is applied to a representative sample of student projects in three sophomore, junior and senior design classes. The student work is evaluated by several ME faculty members and then combined. The results of this analysis support both the Engineering Design and Professional Communications components of the Professional Plan. The Outcome 6 rubric is applied to representative student work in three junior and senior design classes.
Table 5: Rubric Applied to Student Work for Outcome 6

For the 2005 students, Outcome 4 work for the sophomore level course (ME200) was assessed at a Total Score of 6 and the junior level course (ME300) at a Total Score of 9. The average Total Score for the senior level course (ME400) was 10. This indicates both an improving level from the students, as well as meeting the target level set by the faculty of 6 for sophomores, 8 for juniors and 10 for seniors.

Again, 2005 student work for Outcome 6 from three courses was gathered and the rubric was applied. The work for the junior level course (ME300) was assessed at a Total Score of 8. The average Total Score for the senior level courses (ME400 and ME412) was 11. This indicates an improving level from the students, and is near the faculty target level.

Rubric-based assessment of representative student work, coupled with assessment of student extra-curricular activities, student exit interviews and composite student grades provides the basis for the ME faculty members to evaluate the overall student progress in the Professional Plan, and adjust the delivery of the components as necessary.

Conclusion

The Western Kentucky University ME faculty’s Professional Plan assures that program graduates have experienced the engineering profession and demonstrated the ability to perform in a professional manner. The Professional Component has been defined to include Engineering Design, Professional Communications, Professional Tools, and Ethics. Students receive instruction and practice in all four areas at least once per academic year.

The industrial based design project in the Junior Design course serves as an effective intermediate component of the Professional Plan. The project provides an excellent activity for the students to develop and demonstrate their Engineering Design proficiency. It is an
appropriate junior-level project because the technical and organizational requirements are sufficient for this stage of the educational process. The introduction of a less completely defined problem and an external customer prepares the teams for expectations in the senior year experience and demonstrated the progress that Western Kentucky University students are making through the Professional Component classes.

The Junior Design implementation of the external project has evolved over the past three years guided by ongoing assessment of both course and program outcomes. In particular, a structure of project milestones and requirements was developed to aid the students in managing the project, while the exposure in earlier courses to design decision-making has resulted in the project being executed in an improving manner. The most recent ME300 class performed at a higher level than the preceding class as measured by overall professionalism and quality of the final design project product. Student communication skills and ability to independently implement the external project has improved. This is a strength of the Professional Component framework that allows for building upon previous coursework, assessing student progress, and adjusting course coverage based on prior assessments to assure that graduating ME students are capable of practicing as engineers.

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References