

# **AC 2007-2810: AN UPDATE ON THE IMPLEMENTATION OF A NEW MULTIDISCIPLINARY ENGINEERING PROGRAM**

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# **An Update on the Implementation of a New Multidisciplinary Engineering Program**

## **Introduction**

In 2003, a founding team of seven faculty members was given the unprecedented freedom and flexibility of designing an engineering program from a blank slate. After a two-year planning process including a review of the current literature and site visits to many engineering programs, the new multidisciplinary engineering program was implemented. Currently, the new engineering program is in its second year of implementation offering freshman and sophomore level courses. The program design is grounded in pedagogies of engagement, curricular flexibility, and a focus on the individual. Student outcomes are based on a developmental model patterned somewhat after Alverno College. Outcomes assessment includes oral examinations and the use of ePortfolios. This paper presents an update on the evolving program design and implementation, its challenges and our solutions to those challenges..

## **Identity – Mission and Vision**

An important step in the program design process was the development of brand identity. Brand identity is a reflection of a program's mission, vision, values and competitive position. It is a mixture of attributes, tangible and intangible, which, if executed properly creates value and influence. It also can align internal decision-making and behavior in ways that are consistent with the brand and, therefore, with the department's mission, vision, values and competitive position. The development of brand identity was a valuable mechanism for refining and clarifying the engineering team's collective vision for the program. A structured process<sup>1</sup> resulted in the following values: Engaged Learning, Agility, and a Focus on the individual.

These values are related to the program mission as the program is built around the concept of engaged learning: discovery-based education and learning by doing. Classrooms are defined not as lecture halls but as engineering studios. Courses are delivered not as lengthy exercises in theory but as integrated opportunities to apply knowledge in real-world projects. The expected outcome of the program is an agile engineer, a lifelong learner with a comprehensive set of skills appropriate to the needs of today and tomorrow. Agility also characterizes the program itself: streamlined, purposeful and flexible in adapting to changes in pedagogy, knowledge or the needs of its stakeholders. We also express the brand value of agility through its unique ability to cross or eradicate traditional boundaries between engineering disciplines, enhancing innovation through the synergistic combination of previously bounded boxes of knowledge. Lastly, the engineering program is focused on the individual student. Each person is valued for his or her unique skills. We measure our success by the quality of each individual's education and our effectiveness and responsiveness in meeting their individual learning needs.

## **Student Outcomes**

Development of program student outcomes was a significant part of the program design process. A structured design process<sup>1</sup> was used to create the student outcomes with input from students, faculty, and industry. Important influences on the outcomes structure are attributed to Perry's<sup>2</sup> model of intellectual development that spans nine stages of student progression and to the assessment approach at Alverno College<sup>3,4</sup>. Table 1 shows the program student outcomes and four developmental levels associated with each outcome.

The outcomes reflect the developmental nature of student growth as they progress through the curriculum. Instead of viewing outcomes as subjects covered in one or two courses, we view outcomes as incrementally developed over the entire engineering learning experience. Each outcome has four associated developmental levels describing student progress in achieving the outcome. The developmental levels are similar to the model developed by Alverno College<sup>3,4</sup>. It is expected that students will typically progress from lower to higher levels, but that this progression will not always be linear or proceed at a constant rate. The primary approach to assess student progress within these outcomes is the requirement that students demonstrate achievement of one or more specific outcomes and levels in each course. Generally, we triangulate, or require that students demonstrate achievement of a given outcome level in multiple contexts or settings (e.g. courses), increasing the likelihood that their learning will be generalizable and transferable to new contexts. Each outcome (and level) is further defined by one or more "rubrics" that embody detailed criteria by which achievement of some component of the outcome can be evaluated. These rubrics are structured to evaluate developmental progress. Our initial assessment of the rubric structure's effectiveness, detailed in both student and faculty assessments, indicates that the rubrics were too complex and included too many criteria to be used effectively. Thus, we have begun simplification of the rubrics.

The developmental levels associated with each outcome describe a possible path for a student to achieve mastery of that outcome. A critical part of the assessment process for each student is to track their development through the levels as they progress through the program. As alluded to above, student development is tracked by mapping outcome levels to one or more courses in the curriculum. Then, student achievement of these levels is assessed in these courses. A student can pass a given course (and proceed forward in the curriculum) only after demonstrating mastery of outcome levels associated with the course. Each course's content is designed to support student mastery of the levels associated with that course. Student outcomes are also mapped to the ABET a-k criteria<sup>5</sup>.

## **Curricular Structure**

The curricular structure includes a multidisciplinary "engineering foundation" in the first two years and "primary and secondary areas of concentration" in the third and four years. A project-based course is offered in each of the eight semesters, composing the program of study. The engineering foundation is illustrated in Figure 1.

## ENGINEERING OUTCOMES AND DEVELOPMENTAL LEVELS

<p><b>Design</b>—An ability to design a system, component, or process to meet desired needs within realistic constraints.</p> <p><i>Level 1</i> Recites the steps and information flow in the engineering design process and uses at least one organizational or technical tool in each step.</p> <p><i>Level 2</i> Given a problem definition, uses a design process and design tools to produce a documented design solution including a prototype and explains how the design meets the constraints and criteria.</p> <p><i>Level 3</i> Evaluates design process and resulting design quality and suggests improvements.</p> <p><i>Level 4</i> Customizes design process and communication for varying design situations.</p> <p><b>Engineering Practice</b>—An ability to use the knowledge, techniques, skills, and modern tools necessary for engineering practice.</p> <p><i>Level 1</i> Describes the essential elements of good engineering practice.</p> <p><i>Level 2</i> Given a problem statement, characterizes a plan and identifies the necessary engineering tools that will produce a technical solution.</p> <p><i>Level 3</i> With direction, identifies and applies an appropriate set of engineering tools in a “real world” professional context to develop a valid solution to a problem.</p> <p><i>Level 4</i> Independently identifies the appropriate set of engineering tools and applies them in the context of sound professional practice to obtain optimal (defensible) solutions to problems.</p> <p><b>Critical Thinking and Decision Making</b>—An ability to think critically, clearly identifying and using evidence, criteria, and values in the decision making process.</p> <p><i>Level 1</i> Articulates the critical thinking process.</p> <p><i>Level 2</i> Identifies assumptions, criteria, and evidence to make informed decisions.</p> <p><i>Level 3</i> Evaluates alternative perspectives, contexts, and the quality of evidence in making informed judgments.</p> <p><i>Level 4</i> Examines and cultivates own value system to make informed decisions.</p> <p><b>Professionalism</b>—An understanding of professional and ethical responsibility, a commitment to on-going professional competence and possession of basic professional and organizational success skills.</p> <p><i>Level 1</i> Exhibits professionally appropriate behavior patterns, appreciates engineering as a learned profession and possesses daily success skills.</p> <p><i>Level 2</i> Accepts responsibility for their education, understands the major professional and ethical responsibilities of engineers, the major specialties of engineering and basic corporate structures and purposes.</p> <p><i>Level 3</i> Uses common moral theories and concepts to guide their ethical decision making and has formulated a probable career path that accounts for current trends in technology and society.</p> <p><i>Level 4</i> Effectively guides their own efforts to gain and maintain their professional competence and reputation.</p>	<p><b>Perspective</b>—An understanding of the role and impact of engineering in contemporary business, global, economic, environmental, and societal contexts.</p> <p><i>Level 1</i> Understands that technological change and development have both positive and negative effects.</p> <p><i>Level 2</i> Identifies and evaluates the assumptions made by others in their description of the role and impact of engineering on the world.</p> <p><i>Level 3</i> Selects from different scenarios for the future and appropriately adapts them to match current technical, social, economic and political concerns.</p> <p><i>Level 4</i> Has formed their own model for the probable future of our society and makes life and career decisions informed by this model.</p> <p><b>Problem Solving</b>—An ability to identify, formulate, and solve engineering problems.</p> <p><i>Level 1</i> Articulates the problem solving process by making explicit the generic steps taken to approach a problem.</p> <p><i>Level 2</i> Performs all steps of the problem solving process including evaluation and implementation in both closed and open-ended design and analysis problems.</p> <p><i>Level 3</i> Independently analyzes, selects, uses, and evaluates various methods and frameworks to develop solutions to multi-faceted engineering problems.</p> <p><i>Level 4</i> Adapts methods and frameworks of problem solving to a wide variety complex engineering problems requiring a collaborative teamwork approach.</p> <p><b>Communication</b>—An ability to communicate effectively.</p> <p><i>Level 1</i> Recognizes, describes, and assesses own processes used in various modes of communication.</p> <p><i>Level 2</i> Uses a process to develop appropriately structured communications.</p> <p><i>Level 3</i> Purposefully applies communication strategies to interact meaningfully with their audience.</p> <p><i>Level 4</i> Selects and adapts communication strategies to fully engage their audience.</p> <p><b>Technical Competence</b>—An ability to apply knowledge of mathematics, science, and engineering as well as collect, analyze, and interpret data.</p> <p><i>Level 1</i> Verbally and mathematically communicates the conceptual engineering and science principles underlying engineering problems and recognizes own strengths and weakness in their conceptual knowledge.</p> <p><i>Level 2</i> Applies provided math and science principles to engineering problems using mathematical modeling, engineering analysis, and the scientific method.</p> <p><i>Level 3</i> Selects and applies appropriate math and science principles to domain specific engineering problems using mathematical modeling, engineering analysis, and the scientific method.</p> <p><i>Level 4</i> Selects and applies appropriate math and science principles to complex or multidisciplinary engineering problems using mathematical modeling, engineering analysis, and the scientific method.</p>
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## The Engineering Foundation

The bulk of content common to all students' programs of study is in the first two years, which forms the foundation (depicted in Figure 1). The curriculum in this foundation lays the groundwork for student achievement of the eight program outcomes. The foundation includes eleven one-hour engineering modules (red); four project courses (blue); math and science courses (green) that include a calculus sequence, physics, chemistry, and biology; and some general studies courses.

Freshman Year

Engineering Design I 3 hours	Calculus I 3 hours	Chemistry 4 hours	English I 3 hours	
Engineering Design II 4 hours 1-hour embedded module	Calculus II 3 hours	Physics I 3 hours	English II 3 Hours	General Studies 3 Hours

Sophomore Year

Engineering Project I 3 hours	Engineering Modules 5 hours	Engineering Statistics	General Studies 3 hours	Unrestricted Elective 3 hours
Engineering Project II 3 Hours	Engineering Modules 5 hours	Differential Equations	Biology for Engineers 4 Hours	General Studies 3 Hours

Figure 1. The Multidisciplinary Engineering Foundation

In the freshman year, students are introduced to engineering content and practice through two project-based courses: Introduction to Engineering Design I and II. In the sophomore year, students participate in two project courses (Engineering Studio I and II), each coupled with companion content courses as described in below. The project courses use projects as vehicles to integrate student learning and provide program outcome development opportunities. The Aalborg curriculum model<sup>6</sup>, with its projects in every semester and significant problem-based learning, heavily influenced our curricular design. In our project courses, students work in teams on engineering projects. For example, a second semester freshman project was to design and fabricate a rescue device that would safely transport a child or small animal from a three-story building. Major projects are not used in other courses. The National Academy of Engineering<sup>7</sup> recommends that "... students should be introduced to the essence of engineering early in their undergraduate careers" and that "... engineering educators should introduce interdisciplinary learning in the undergraduate curriculum ...". The project courses are designed to be consistent with these recommendations.

We have attempted to have the project topics drive the content and selection of companion modules, rather than content driving the projects. The project then provides an engineering context for these companion modules. The flexibility that allows project topics to drive course content is obtained by using small one-hour engineering content modules as companion courses

to the project. The content of a module often will be drawn from the standard formal engineering science content. Our intent is to place many of the one-hour modules online. We believe that by contextualizing the engineering content in the modules through a project that the students will acquire deeper learning. This approach shifts the curriculum design activity to that of designing good projects, representing breadth in engineering for these foundation years. While the faculty determine what projects are implemented in the foundation, students have input in project selection. Projects progressively become more open-ended throughout the curriculum.

As an example, the first semester sophomore project was to build an aquatic robot for a swimming pool that met customer needs and to produce a manufacturing plan that explicitly projected the cost of delivering the robot demand to the market. We selected five companion one-hour modules for the project. They were: Materials Selection, Manufacturing Processes I, Strength of Materials, Dynamic Mechanics, and Instrumentation. During the semester we offered a sixth non-required module: Manufacturing Processes II.

Four of the six modules were directly relevant to the project. The Materials Selection module focused on material properties and the selection of materials based on usage criteria. The Manufacturing Process I module focused on manufacturing process characteristics including economics and typical uses. The Manufacturing Process II module was a traditional process course that included the fabrication of a small product using a variety of traditional processes. The Strength of Materials, Static Mechanics, and Dynamic Mechanics were traditional. An example of a problem-based activity integrating many of the modules was the design of a plastic fork. The students first tested a variety of plastic forks purchased locally in the strength of materials module course. They then designed a fork, including the selection of materials and the process. The cost to manufacture the forks was then modeled and compared with costs for plastic forks in the market.

In our first implementation of modules, we carefully integrated the modules to enhance the relationship between the different subjects (e.g., the fork problem-based learning assignment) and to integrate the content with the project activities. However, each module had a separate instructor with its own grading criteria and assignments. In an assessment of the integrated approach, we determined that while there is merit to this approach, the complexity of the implementation makes it difficult to sustain. We are now teaching modules as linear self-contained modules.

### **The Concentration Years**

In the second two years of the program, students choose a primary and secondary concentration. A primary concentration consists of 20 credit hours of focused engineering content, including two three-hour project courses. We currently have three primary concentration options: Electrical Systems Engineering, Mechanical Systems Engineering, and a Civil Engineering with a focus in land development. The secondary concentration consists of 16 credit hours of content. The curriculum also has nine-credit hours of unrestricted electives.

The concentration structure provides considerable flexibility to the student. One feature of this approach is that students may choose the secondary concentration from inside or outside of

engineering and still obtain an ABET-accredited engineering degree. For example, by combining the secondary concentration with the unrestricted elective hours and the humanities/social science hours, a student could take 30 hours of economics, 27 hours of literature, or 21 hours of Chinese as part of a program of study that culminates in a Bachelor's degree in engineering. Of course, the secondary and electives could also be engineering content, a choice that many students have indicated they will make. In theory, a student could use all primary, secondary, and elective hours in a specific engineering area and end up with a similar background to many traditional disciplinary engineering programs. This curriculum satisfies the "general" ABET criteria (but not program specific criteria such as electrical or mechanical). Design of the particular content within these concentrations is ongoing. Industry has had a significant role in helping define the concentration's critical outcomes. The initial phase of the concentration curriculum structure will be implemented in the fall of 2007.

### **The Assessment Process**

Assessment has become institutionalized within the department. The department faculty developed and implemented a formal assessment process as a part of its initial course offerings, using many of the typical assessment instruments found in other programs. One of the less typical instruments used is an individual student oral examination every semester in the project courses, currently with two faculty in each oral (discussed in the next section).

The department assessment process has two primary goals. The first is to foster the development of each individual student towards meeting the student program outcomes. The second is to periodically evaluate the program curriculum and its implementation to improve the student educational experience and to respond to changing constituent needs and expectations. The department assessment process is shown in Figure 2.

The process has four feedback loops in which assessment information is used. The top loop in the flow chart represents individual assessment of student performance as they progress developmentally towards meeting the program outcomes. These activities are expected to occupy the largest portion of our assessment time and effort. The next loop represents assessment of the content and structure of each course in the curriculum. The third loop represents evaluation of overall student achievement of the program objectives and outcomes and the effectiveness of program practices in helping students achieve the objectives and outcomes. The bottom loop represents the process by which objectives and outcomes are updated in response to assessment data and constituent input. The information collected in assessing individual students in the top loop can be aggregated to drive the other three loops in the process.

A primary source of data for assessment of individual student progress is the student work collected and assessed by course instructors and project mentors. This is done using relevant components of the student outcome component rubrics. We also use oral examinations and, during the spring 2007 semester, initial use of ePortfolios.

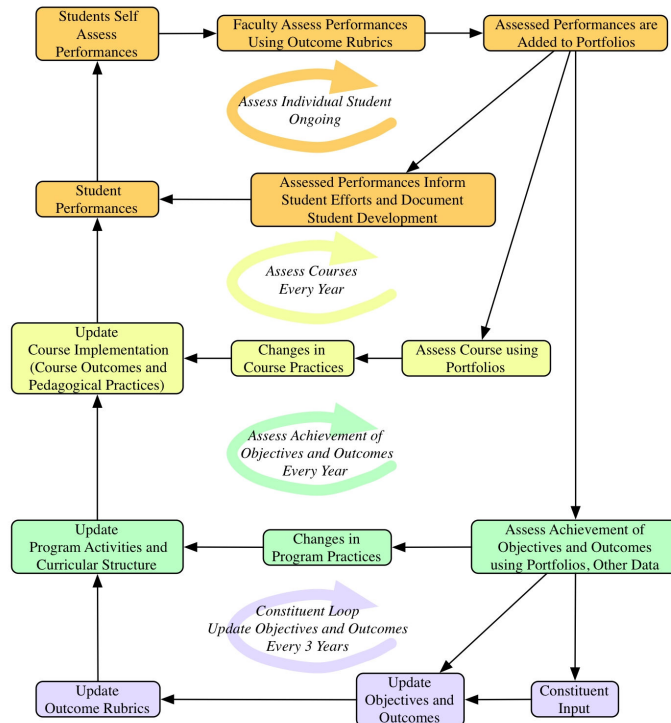


Figure 2. A Graphical Depiction of the Assessment Process

## Oral Examinations and ePortfolios

A part of the final examination for each project course is an oral examination, a technique consistent with our value of a focus on the individual as well as a highly valuable assessment tool. Oral examinations are scheduled for 30 minutes with a minimum of two faculty members. Each oral examination is video taped. The first step in the oral examination process is the development of an oral examination rubric, derived from the outcomes and levels associated with the specific project course. Next, to aid student self-assessment, a set of guiding questions is developed from the relevant outcome rubrics. In the week prior to the assessment, students are required to write a self-assessment addressing their perception of their personal attainment of the learning outcomes and levels for the course. We found that it necessary to provide the students with the written questions to guide their self-assessment. The faculty individually evaluate the self-assessment document and formulate clarification questions for the oral examination. After the oral examination, the faculty evaluators meet to review their individual assessments and develop formative feedback as well as assign a grade for the examination.

We have found the process of self-assessments and oral examinations to be very time intensive and produces lots of data. By the end of the degree, most of our students will have accumulated four hours of recorded oral examinations. Thus far we have only reviewed the tapes when we differ in opinion or when a particular faculty mentor desires to see the student's progress. Our plan is to archive these tapes so that each student will have access to their own oral examination as another source of self-assessment. Despite the significant investment of time and the large accumulation of data, the entire faculty unanimously wants to continue the practice. We feel we



have a much better understanding of each of the individual student's strengths and weakness, which provides us with the opportunity to be much better mentors.

This semester we are beta testing a newly developed ePortfolio system expected to aid the assessment process. The system is a configurable repository permitting students to store and present their work in an electronic format. Student can store work products in a variety of data formats. We hope to use this system for storing and coding oral examinations. One use of the portfolio is the development of an electronic resume. For assessment purposes, we have developed an assessment process and forms within the system allowing students to submit self-assessments with links to work products stored in the ePortfolio system. Faculty use an electronic form to record their evaluation and to capture formative feedback. There is a hierarchy of evaluation forms, with top-level forms corresponding to each of the eight student outcomes. The top-level form has links to individual faculty evaluation forms, which in turn link to student self-assessments and to student work products. This hierarchy allows users to view any specific student's current level of outcome attainment for any outcomes with all corresponding faculty evaluation and feedback. The ePortfolio system provides a potential mechanism for automating and organizing parts of our assessment process.

### **Reflections and Observations**

Developing a new multidisciplinary engineering department from a clean slate is an extraordinarily rewarding, but difficult task. The development was undertaken by a core group of faculty that was given the time and resources needed to refine a shared vision and to incrementally develop the program and department. Now, in our second year of implementation, much has been learned and many challenges remain to be resolved.

The value of pedagogies of engagement, the one-hour modular structure, and the pervasive contextualization of engineering content within a project structure has required a complete redevelopment of curricular materials. Curricular materials already prepared for this unique structure are not readily available. To better understand the challenge, suppose that you wanted to teach a one-hour module (15 contact hours in a semester) on an engineering topic (e.g. static mechanics) that supported a semester long project in another course where the material could likely be applied. Also, you want to use a problem-based learning approach in much of the course. Further suppose that depending on the concentration a student selected, this might be the only exposure to the subject. While there are some potential guides to material selection such as the fundamental concepts made explicit in concept inventories and the engineering fundamentals exam, the choice of materials is not obvious. Also, what reading materials should be required for the students?

A departure from a curriculum dominated by traditional lecture-based instruction has been difficult for some faculty members. In a traditional lecture-based approach, much more material can be presented than in a problem-based learning approach. While there is good evidence to support pedagogies of engagement<sup>8</sup>, the program faculty continuously deliberate about the appropriate balance. We plan on using a preparatory engineering fundamental examination service to assess technical competency and student learning. While this will provide us with one measure of student technical competency, the exam questions are multiple-choice questions and typically represent textbook type problems. What is the trade-off, if any, with the ability to

apply engineering knowledge to realistic open-ended problems, and the ability to solve typical textbook problems?

We are challenged with sustaining our assessment process while making use of all of our assessment instruments in a period of growth. Scheduling and video taping every student, every semester, takes a significant investment of time. We hope that the ePortfolio system will help with some of the organization issues. However, we will continue to archive large volumes of data and attempt to efficiently use this data to both enhance student learning and improve the program. But, where is the published tome that elucidates good practice and provides some measure of resource modeling in this situation?

Via our focus on the individual, we have come to know our students much better than we have ever done before. While this provides us with the knowledge to be better mentors, it also requires that we learn to be good mentors. It also amplifies each student's setbacks and successes.

We continue to look forward to these challenges.

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