Competency-based Outcomes Assessment for Agricultural Engineering Programs*

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The ABET 2000 criteria have provided the impetus for the Agricultural and Biosystems Engineering Department at Iowa State University to re-structure the assessment of its undergraduate agricultural engineering program. We linked ABET student outcomes to validated work-place competencies with key actions that are measurable in academic and experiential education environments. Two tools are being used to assess competencies: an on-line assessment system and electronic portfolios developed by each student as a requirement for graduation. This paper discusses the overall philosophy of our assessment program, how the assessment tools are being implemented, and the implications for change in the curriculum.

Keywords: Outcomes, assessment, competencies, electronic portfolios, on-line assessment, experiential education, internships, ABET.

BACKGROUND

ABET Outcomes and Competencies

ENGINEERING EDUCATION programs in the United States are moving from an 'input' to an 'outcomes' paradigm. Success is now focused on how well students achieve desired learning outcomes, not simply whether they've completed required coursework. The ABET 2000 Engineering Criteria 3 Program Outcomes and Assessment [1] have provided engineering programs with the impetus and opportunity to re-craft how they educate students.

Although institutions may use different terminology, for purposes of Criterion 3, program outcomes are intended to be statements that describe what students are expected to know or be able to do by the time of graduation from the program.

Engineering programs, based on ABET Engineering Criteria 3 Program Outcomes and Assessment for 2003–2004 [1], must demonstrate that their graduates have:

a. an ability to apply knowledge of mathematics, science, and engineering
b. an ability to design and conduct experiments, as well as to analyze and interpret data
c. an ability to design a system, component, or process to meet desired needs
d. an ability to function on multi-disciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility

g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Each program must have an assessment process with documented results. Evidence must be given that the results are applied to the further development and improvement of the program. The assessment process must demonstrate that the outcomes of the program, including those listed above, are being measured.

There are a variety of ways in which engineering departments can respond to the new ABET Criteria. Felder and Brent [2] give an excellent overview of ways to redesign courses and curricula for meeting ABET engineering criteria.

ISU approach to meeting ABET Outcomes

The College of Engineering (COE) at Iowa State University (ISU) has taken the unique approach of addressing the ABET Outcomes criteria as workplace competencies [3, 4]. In the technologically and structurally expanding workplace, employers need different measures to use when recruiting and retraining employees [5]. Competencies fulfill this need by focusing on what people can do with what they learn, not solely on the acquisition of skill or knowledge [6]. Employers of the graduates of our agricultural engineering (AE) program are increasingly focusing on workplace competencies in their

hiring practices (e.g., USDA National Resource and Conservation Service, John Deere, ConAgra Foods, Caterpillar), and student development of competencies are, therefore, critical to career success after graduation.

Competencies are the application of behavior and motivation to knowledge, understanding, and skill. They are 'the result of integrative learning experiences in which skills, abilities and knowledge interact' to impact the task at hand [7]. As such, competencies are directly measurable through key actions or through demonstrations of the existence of those competencies in the individual.

In the Fall of 1999, a constituency of over 200 ISU faculty, partnering international faculty, co-op and intern students, employers, and alumni were asked to assist the ISU College of Engineering Cooperative Education and Internship Program in developing a next generation of performance assessment tools, ones that would be aligned with the new ABET Engineering Criteria 2000. Specifically, we set out to create a set of assessment metrics for the co-op and intern workplace that would be sufficient to document our students' development and demonstration of the ABET (a-k) Outcomes. Our hypotheses were that each the Outcomes are too complex to measure directly and that each Outcome represented some collection of workplace competencies necessary for the practice of engineering at the professional level. To support our efforts, the College collaborated with Development Dimensions International, Inc. (DDI), a global provider of competency-based performance management tools and services [8].

Constituents participated in DDI-facilitated focus sessions, using a 'Critical Incident' data gathering technique, following a DACUM strategy [9]. In these sessions, they provided hundreds of examples of successful and unsuccessful demonstrations of the eleven ABET (a–k) Outcomes by engineering students and graduates. DDI professionals analyzed these 'Critical Incident' stories and extracted fourteen dimensions or ISU Competencies:

- engineering knowledge
- continuous learning
- initiative
- cultural adaptability
- planning
- teamwork
- professional impact
- general knowledge
- quality orientation
- innovation
- analysis and judgment
- communication
- integrity
- customer focus.

The definition of each ISU competency was written clearly, concisely, and independently. Specific to each definition is a set of observable and measurable key actions. For example, the definition of Com-

munication competency is: involves clearly conveying information and ideas through a variety of media to individuals or groups in a manner that engages the audience and helps them understand and retain the message.

Key actions involve:

- Organizes the communication—Clarifies purpose and importance; stresses major points; follows a logical sequence.
- Maintains audience attention—Keeps the audience engaged through use of techniques such as analogies, illustrations, body language, and voice inflection.
- Adjusts to the audience—Frames message in line with audience experience, background, and expectations; uses terms, examples, and analogies that are meaningful to the audience.
- Ensures understanding—Seeks input from audience; checks understanding; presents message in different ways to enhance understanding.
- Adheres to accepted conventions—Uses syntax, pace, volume, diction, and mechanics appropriate to the media being used.
- Comprehends communication from others—Attends to messages from others; correctly interprets messages and responds appropriately.

A complete set of competency definitions and key actions can be found at: http://learn.ae.iastate.edu/assessment/CompetencyDefinitions.pdf.

COE faculty involved in the constituency dialogue then mapped the competencies to the ABET (a–k) Outcomes. Further constituent dialogue using a survey tool validated these competencies as necessary and sufficient to demonstrate the Outcomes. Figure 1 shows this mapping in the form of a matrix.

COMPETENCY-BASED LEARNING

A conceptual model of learning based on competencies does not work solely at the level of skill, abilities, and knowledge (the conventional approach to engineering education), but seeks to formulate curriculum and assessment at the competency level which embodies integration of skills, abilities, and knowledge needed to become part of the disciplinary community of practice [10]. Such a model is illustrated in Fig. 2.

Competency-based learning (CBL) involves redefining program, classroom, and experiential education objectives as competencies or skills, and focusing coursework on competency development. The advantage to CBL is that competencies are transparent; that is, all participants in the learning process understand the learning goals and outcomes. Competencies provide students with a clear map and the navigational tools needed to move expeditiously toward their goals [7]. Competencies have a stronger impact on student learning when they are linked to and embedded within specific courses and across the

Engineering 2003-2004 Criterion 3 Program Outcomes and Assessment	Engineering Knowledge	General Knowledge	Continuous Learning	Quality Orientation	Initiative	Innovation	Cultural Adaptability	Analysis and Judgment	Planning	Communication	Teamwork	Integrity	Professional Impact	Customer Focus
(a) an ability to apply knowledge of mathematics, science and engineering	X		X		X			X						
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	X		X	X	X	X		X	X		X			X
(c) an ability to design a system, component, or process to meet desired needs	X		X	X	X	X	X	X	X	X	X			X
(d) an ability to function on interdisciplinary teams					X		X	X	X	X	X	X	X	X
(e) an ability to identify, formulate and solve engineering problems	X		X	X	X	X		X		X	X			X
(f) an understanding of professional and ethical responsibility		X	X	X			X	X				X		
(g) an ability to communicate effectively		X			X					X			X	X
(h) the broad education necessary to understand the impact of engineering solutions is a global and societal context	X	X	X				X	X						
(i) a recognition of the need for, and the ability to engage in, life-long learning			X			X								
(j) a knowledge of contemporary issues		X	X				X	X						
(k) an ability to use the techniques, skills and modern engineering tools necessary for engineering practice	X		X	X	X		X	X						

Fig. 1. ABET Outcomes—ISU competencies matrix.

curriculum [9]. CBL models rely on both the judgment of those external to the learning process and on measurable assessment [7].

Other institutions have linked competencies to the learning process with some success [9]. King's College in London, UK, Alverno College, Wisconsin, USA, and Northwest Missouri State University, USA, have all used competency-based learning as an integral part of student development and learning assessment. However, few engineering programs have embraced CBL across the entire curriculum.

ePortfolios

Portfolios provide a broad assessment tool for student intellectual development and for technical expertise. They are powerful vehicles for both pedagogy and assessment, demonstrating a student's learning as an organic process involving three key factors: collection, reflection, and selection [11].

Portfolios can be a powerful learning experience. Using portfolios allows students to revisit their accomplishments over a given period of time, select various artifacts for the collection, and reflect on their growth and development through the creation of those artifacts: 'Revisiting past work, students often improve the earlier work but also comment in a way that demonstrates their thinking around that work. In such a reflective text, students make their thinking visible' [12]. Through students' reflections and choice of artifacts, assessors and instructors have the opportunity to see explicitly how instruction is being interpreted and evaluated long after the class has ended [11].

Although there are many types of portfolios (e.g. professional, classroom, and learning portfolios), generally they can be broken down into two categories: summative and formative [13]. Summative portfolios center themselves on learning outcomes and seek to demonstrate the student's knowledge through the presentation of artifacts. In contrast, formative portfolios emphasize the process of learning and seek to show how students arrive at various artifacts. Moreover, formative portfolios provide feedback to students throughout the learning process.

In the last five years, portfolios have been moving increasingly online. Online electronic portfolios (ePortfolios) are useful pedagogical tools for providing both efficiency and effectiveness for assessment [13]. Because ePortfolios are online, the portfolio process can be streamlined through intelligent database control, electronic guides, and web design templates. All of these procedures can increase the effectiveness of the assessment process for students, faculty, and programs. ePortfolio
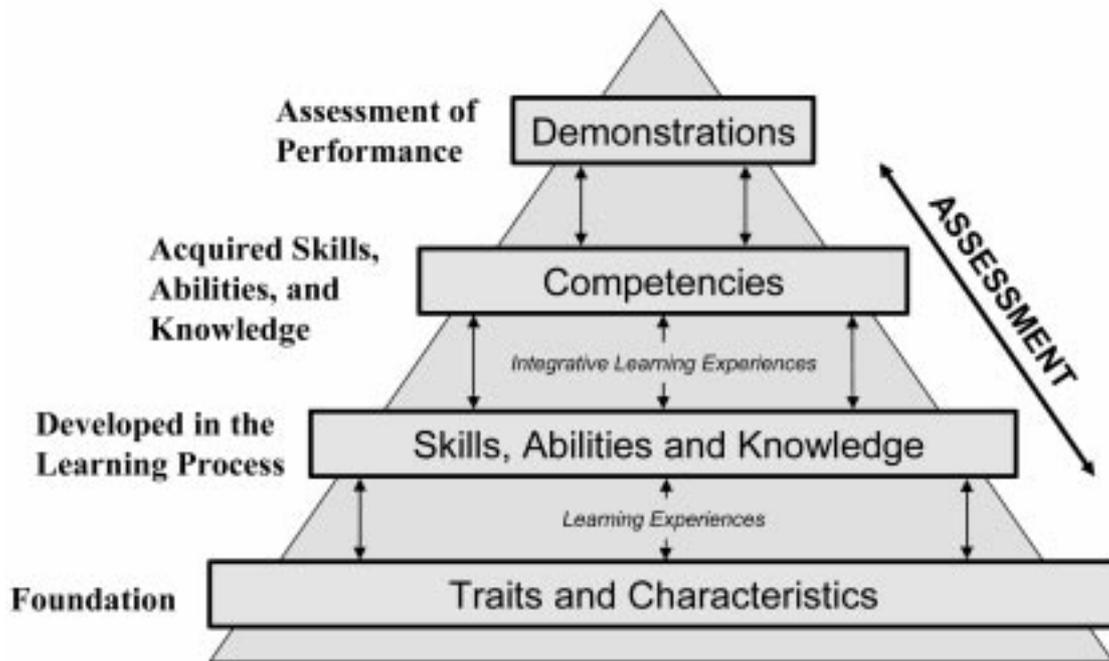
Fig. 2. A conceptual learning model based on competencies [10].

systems range from the generic tool/template approach (GT) to the customized systems/free design approach (CS) of development [14]. GT systems rely on databases and templates, which give students little individual expression in their portfolio while CS systems rely on free design which gives students flexibility and personal creativity. CS systems, however, do not lend themselves to competency-based portfolios.

Competency driven portfolios hosted within writing programs have been successfully used at a variety of institutions [15, 16]. For example, Rose-Hulman Institute of Technology, Indiana USA, has developed an ePortfolio system that allows students to archive multimedia artifacts. Their faculty can rate the artifacts based on learning outcome goals and performance criteria [17]. A slightly different model is the Learning Record Online at the University of Texas at Austin, USA, which includes both formative and summative assessment in its reading and writing portfolio system [18]. Similarly, the University of Wisconsin-Superior, U.S., piloted a portfolio system for assessment in their general education program [19]. More recently, Alverno College, Wisconsin, U.S., has developed the Diagnostic Digital Portfolio system where students display key performances in a GT environment, linked to abilities and educational standards across the entire college [20].

OUR ASSESSMENT PLAN

Through the integration of ABET Outcomes and ISU Competencies, the Agricultural and Biosystems Engineering (ABE) department devel-

oped the outcomes assessment plan for the Agricultural Engineering (AE) undergraduate degree program, as illustrated in Fig. 3.

The mission, goals, and objectives of the program are reviewed (and changed as necessary) every three years in consultation with stakeholders and our industrial advisory board, concurrent with the ABET accreditation cycle. From this process, the desired student learning outcomes are developed, taking into account ABET accreditation and American Society of Agricultural and Biological Engineers (ASABE) recognition criteria.

Each class in the curriculum is examined to determine which of the outcomes it addresses. Then curriculum as a whole is examined to ensure adequate coverage of the outcomes. Should there be gaps in coverage, the curriculum is re-examined to determine if different classes are needed, or if courses within the department need to be changed or added to ensure all the outcomes are adequately addressed.

Once the outcomes are mapped to the individual classes, we determine from the outcomes-competency matrix which competencies are addressed in each of the classes taught in our department. We thus know which competencies should be focused on in each class. Finally, the faculty designate key assignments in each class that students can use to demonstrate these competencies.

The primary evidence of students achieving the outcomes (or in our case, achieving the fourteen ISU competencies) is direct evidence of performance: student portfolios, workplace evaluations of students on internships and alumni five years post-graduation, and the results of the Fundamentals of Engineering (FE) exam. Indirect measures

(e.g., senior exit surveys, student evaluation of instruction, post graduate surveys, program reviews, advisor evaluations and placement statistics) are reviewed as background information but are not the basis of judgment for the attainment of outcomes.

The direct and indirect measures are reviewed annually by the AE Curriculum Committee to identify strengths and weaknesses of the program, and in consultation with the ABE External Advisory Committee, makes recommendations for change. The faculty as a whole (e.g., curriculum changes) or individual faculty (specific classes) implement the recommendations.

This outcomes assessment plan is identical for our other undergraduate degrees offered by our department, agricultural systems technology and industrial technology. The outcomes for this program were modeled after the ABET technology criteria [21], with a similar set of competencies mapped to the outcomes, although the program is not accredited by ABET. Thus all undergraduate students in our department, both engineers and technologists, will be creating electronic portfolios, and will be evaluated in internship experiences and in the workplace post-graduation.

Direct and indirect measures

Before implementing this new assessment plan, we relied on 'indirect' measures of student performance, i.e., student exit surveys, placement rates, and alumni surveys. While these instruments, especially surveys, can provide some useful infor-mation, they are ultimately just opinions and not direct evidence of student performance. With the new ABET accreditation guidelines, credence is given to direct measures, i.e., evaluations of student work and performance [22].

Our assessment plan uses these direct measures to evaluate student performance: electronic port-folios created and owned by students, online competency assessments (evaluations by supervi-sors of students on internships and alumni practi-cing in the field of engineering), and the results of the Fundamentals of Engineering examination, the first step towards professional licensure.

CONNECTING COMPETENCIES TO OUTCOMES

The direct measures result in numerical evalua-tions of student performances. Workplace and ePortfolios competency assessments are charted on a Likert Scale, allowing us to rank the weakest and strongest competencies. The aggregate results of the FE exam provide evidence for the attain-ment of the 'engineering knowledge' competency by our students.

We apply a numerical rating to each of the outcomes, given that all the competencies are mapped to outcomes, and we can then rank how well each outcome is achieved. A system which weighs each competency within an outcome could also be developed to determine how each outcome is being met. However, since we are only now
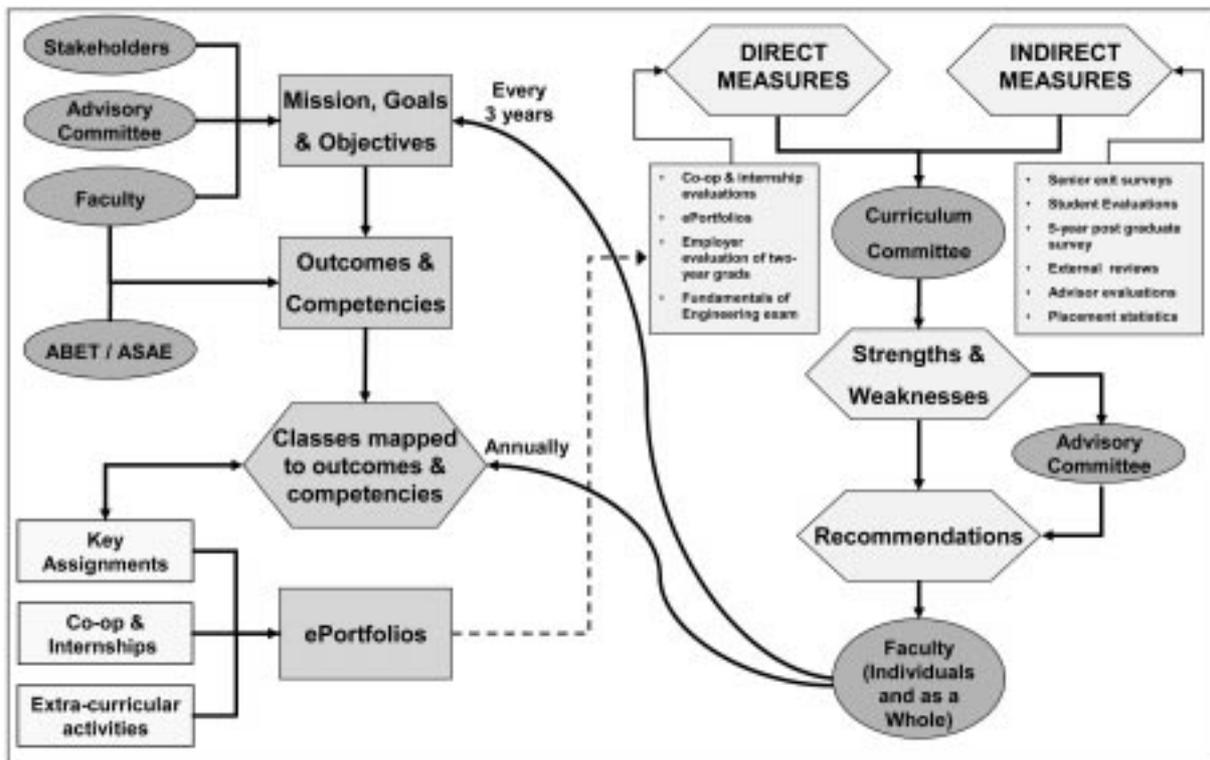

Fig. 3. The ABE outcomes assessment plan.

working to complete our first cycle of assessment, we don't have the experience with our plan to implement such a system.

ePortfolios

Incorporating a portfolio program into our curriculum allows us to continually renegotiate what our program is teaching and what our students are learning, and also provides us with a strong qualitative methodology for continual program assessment.

Our electronic portfolio system is a compromise between the generic template and the customized system approaches. The foundation of the system is a proprietary database system that we developed to hold the artifacts. This system is based on Macromedia's Rich Internet Application (RIA) model using Dreamweaver, Flash, and Cold Fusion [23]. The system (Fig. 4) can be accessed at *http://learn.ae.iastate.edu/portfolio/* (username = guest, password = guest). Built into the database system is an assessment component.

Students upload artifacts that demonstrate achievement of one or more competencies. These artifacts can be papers they have written, examinations, laboratory reports, videos of presentations, design projects, or any form of evidence the student chooses that can be stored electronically. Artifacts, however, are not restricted to formal class settings. They can include internship experiences, student club activities, service learning projects, volunteer work, or any extra-curricular experiences that help demonstrate the competencies. Students must attach a reflection to the artifact by explaining its significance and impact. They must also self-assess the artifact, rating it on a Likert Scale for each of the key actions associated with the competency.

Fig. 4. The ABE ePortfolio System introduction screen.

Using Dreamweaver and Flash, students then develop an interface which accesses the database to display the artifacts in whatever fashion they deem appropriate. For assessment purposes, artifacts are presented around a competency theme. They can also develop electronic resumes and portfolios for prospective employers in the same interface.

Students own the artifacts they place in the database. They decide to make the artifacts public (available for viewing by faculty and assessors) or private. They also control, outside of the classroom and assessment settings, who has access to their portfolios.

Faculty and assessors, in the context of class assignments and assessment, can access the 'public' student artifacts and their ePortfolios. Just as the students self-assess the artifacts based on competencies, faculty and assessors assess the artifacts, resulting in a numerical evaluation of the students' achievement of the competencies.

On-line competency assessment

OPAL® is DDI's online competency development and performance management software that provides assessment, development, coaching, and learning tools [24]. Following customization of OPAL® to present the ISU Competencies, key actions, and assessment surveys, the system is now used by all Iowa State engineering cooperative education and internship (semester long only) students and their supervisors. To receive academic credit for the work term, each student is required to complete the standard self-assessment and to ensure that the supervisor completes the same assessment of the student.

The standard assessment survey consists of sixty-one key actions associated with the fourteen ISU Competencies. Using a Likert Scale, each student and each supervisor provides an assessment of the student's demonstration of each key action. The average value of each key action is computed from the student's self assessment and from the supervisor's assessment. A value for student development and demonstration of each ISU Competency is computed as the average of the averages of the associated Key Actions (Fig. 2). These assessments are anonymous to the ABE faculty, in that we can see aggregate results, but cannot identify individual evaluations. Mickelson *et al.* [25] summarize the results of such assessments for students in the AE program.

The same standard assessment survey is given to alumni (two years post-graduation) and their supervisors. While their participation is voluntary, we are finding that we have approximately the same response rate as the alumni surveys we previously administered.

While not part of our assessment plan, we are using OPAL® in the classroom and having students evaluate themselves and others in team projects and capstone design experiences. The

evaluations of an individual competency within the OPAL® assessment surveys are identical to the assessments they make on artifacts within the ABE portfolio system.

IMPLEMENTING THE PLAN IN OUR CURRICULUM

Changes in the curriculum

Upon entering the program, agricultural engineering (AE) students are exposed to workplace competencies. All freshmen are placed in a learning community for the first two semesters of their academic program [26]. In these learning communities, the students take three linked courses each semester as a cohort group. The first semester link includes Engineering Orientation (Engr 101, R credit), First-Year Composition I (English 104, 3 credits), and Engineering Graphics and Design (Engr 170, 3 credits). The second semester includes a link between Engineering Problem Solving (AE 160, 3 credits), First-Year Composition II (Engl 105, 3 credits), and a hands-on laboratory course, Experiencing Agricultural and Biosystems Engineering (AE 110, 1 credit).

AE students are introduced to the 14 ISU competencies in these course linkages through several assignments. For example, in Engr 101 and AE 110, students prepare behavior-based answers to workplace related questions for each of the 14 competencies. Upper-class mentors conduct behavior-based interviews in our college interview rooms to help prepare the students for coop/internship interviews. Assignments in the First-Year Composition courses tie in with the competency theme, where the students write papers related to competencies in engineering, technology, agriculture, and biological systems. From these classes, and the freshman engineering courses, students also start collecting artifacts that demonstrate their proficiency for each ISU competency. An example that demonstrates the teamwork competency would be an open-ended team design report in Engr 170 describing the design of a robot to collect contaminated materials. Another example would be documenting the solution to an engineering economics problem in AE 160, thus demonstrating 'engineering knowledge.' OPAL® is used in each of these courses. Education materials that correlate with each competency are available within OPAL®. Faculty and students can access these materials for course or personal development.

Two required one-credit seminar classes for the sophomore and junior years have been created. These seminars focus on entrepreneurships, internships, ethics and leadership. Within these seminars, students also work on competency development and ePortfolio creation, ensuring a continuous process rather that something that students can delay until the semester in which the portfolio is required.

Portfolios are summatively evaluated as part of the senior seminar. While there is some discussion of competencies and ePortfolios in the class, much of the student work will already have been completed. If the student doesn't submit a satisfactory ePortfolio, she/he will not pass the seminar class, which is required for graduation. Using the assessment tools imbedded in the database system, a team of three engineering professionals, two faculty members and one external reviewer, evaluate portfolios and their artifacts. External reviewers come from our External Advisory Committee and members of the Iowa Section of ASABE. The local section of our professional society has over 400 members and has been actively involved in student professional development in our department for many years. We anticipate evaluating 35 to 40 portfolios each year. With approximately 17 teaching faculty, each faculty will review four portfolios, which is a reasonable workload.

Changes for faculty

Implementing an assessment plan based on competencies requires faculty to engage in competency-based learning. Faculty must think, teach and assess in terms of competencies. In short, we must formulate our learning objectives in terms of competencies. This requires us to change how we approach the educational process in our department.

We are at the beginning stages of this process. Faculty know which outcomes their classes address, and the Outcomes-Competency matrix (Fig. 2) lets them know the competencies they need to address in their classes. We are providing faculty with workshops and graduate student assistance to help them to include competencies as part of course foundations. Our faculty, through the unanimous adoption of the assessment plan, are committed to the process of implementing competency based learning in our curriculum.

As a first step, faculty designate key assignments for inclusion into student ePortfolios. These designations spring from a recognition of the competencies that the assignment addresses. Sharing these designations with students provides opportunities outside the seminars to discuss competencies.

We recognize that faculty time is always at a premium. As such, we worked hard to create a system that does not place undue burdens on the faculty. The only additional workload involved for individual faculty is evaluating four ePortfolios each year. Incorporating competencies into classes, with guidance and access to resources, can be part of the normal class development and evolution process.

CURRENT STATUS

To date, we have accomplished these aspects of our outcomes assessment plan:

- The ABE portfolio system has been constructed and tested. Students are uploading artifacts. Students have created ePortfolios which will been assessed, beginning in the fall of 2004.
- Competency-based learning has been incorporated into the ABE Learning Communities (coursework) at the freshman and sophomore level.
- The curriculum has been revised to include sophomore and junior seminars.
- Outcomes have been mapped to individual classes.
- Faculty have identified competencies addressed in individual classes and key assignments to be included in student portfolios.
- We are just completing an entire assessment cycle. The data is being analyzed and recommendations for change are being developed and implemented.

There are some important things we have yet to accomplish:

- The whole ABE undergraduate student body needs to be fully engaged in ePortfolio system. While we have tested the ABE portfolio system with a small cohort, we are must now gaining experience managing the system with approximately 550 students from the three undergraduate degree programs in the department.
- We need to train the faculty and external evaluators on assessing ePortfolios.
- Faculty need to fully integrate competency-based learning into their courses.

The first complete assessment cycle is scheduled for the 2005–2006 academic year, in preparation for the ABET accreditation visit in the fall of 2006. We will learn a great deal in the process—we understand that we cannot fully anticipate all the ramifications of our plan. However, we are willing to adjust and modify are plan as needed to obtain a thorough and on-going outcomes assessment of the students in our degree program.

SUMMARY AND CONCLUSIONS

The Agricultural and Biosystems Engineering Department at Iowa State University has embarked on a process of outcomes assessment that requires us to radically change how we think about the education process. By interpreting the ABET (a–k) Criterion 3 Program Outcomes in terms of competencies, we are committing ourselves to transforming our curriculum into one built on competency-based learning.

While change is often difficult, the ABE faculty view this change as an opportunity to re-craft our curriculum to more effectively prepare students for the professional practice of engineering. Students will benefit by developing competencies that are necessary for success in the engineering workplace. Competencies and ePortfolios will allow them to

make connections across the entire curriculum and see their academic experience as an integrated whole rather than just a series of classroom requirements. Faculty will design their classes in ways that address competencies and long-term student success.

Admittedly, we are in the early stages of this process. Even so, we have constructed the pieces of an assessment system radically different from anything we've done before. As we gain experience, we will make the necessary adjustments, refinements, and changes to the process. We believe, however, that our assessment plan is based on sound learning and assessment theory, resulting in a stronger and more successful academic program.

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