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Definition of Student Competencies and Development of an Educational Plan to Assess Student Mastery Level*

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Our experience with the development of an outcomes-based educational plan to satisfy ABET EC 2000 is documented. Critical aspects of our plan include: the method used to define student outcomes; definition of mastery levels that reflect the relative importance of individual outcomes; definition of a core set of outcomes targeted for mastery by all of our students; feedback from our constituencies; a variety of assessment tools including course-level assessment and a core competency exam; and a method for continuous improvement of our curriculum, teaching pedagogy, and the plan itself. Assessment is performed at the competency level in order to provide the feedback necessary to facilitate evaluation and improvement of student learning.

INTRODUCTION

IMPLEMENTATION of ABET's (Accreditation Board for Engineering and Technology, Inc.) EC 2000 represents a considerable dedication of time and effort. In spite of this, EC 2000 provides an excellent opportunity to improve engineering education by providing flexibility and encouraging creativity in the development of a process to achieve desired educational outcomes. How can we take advantage of this opportunity to improve the education of our students? This paper describes the efforts of the faculty of the Chemical Engineering Department at Brigham Young University to provide meaningful answers to this question. In this document we share our approach and discuss some of the results and benefits that have been observed.

DEFINITION OF STUDENT OUTCOMES

Figure 1 is a schematic diagram of the overall educational plan that has been developed. The plan includes a systematic process, shown on the left side of the diagram, with feedback at multiple levels. The process is used to define desired outcomes and to develop methods for helping students to achieve those outcomes. The methods are implemented on the product side of the diagram and the effectiveness of the plan is judged by evaluating student performance against the desired outcomes. The initial pass through the process required some additional steps that are not reflected in the figure. These included prioritization and preliminary evaluation of the specified outcomes, and development of an assessment plan. As shown in the diagram, feedback and change are most active at the classroom level (instructional activities), with less frequent adjustments in the curriculum, and infrequent modifications to target outcomes.

Terminology

EC 2000, Criterion 2 specifies that accredited institutions will have detailed program objectives that incorporate constituency needs, and will have processes in place that ensure that these objectives are achieved [1]. In addition, Criterion 3 lists eleven program outcomes which engineering programs must demonstrate that their graduates possess.

These two criteria suggest at least two levels of program goals—objectives and outcomes. We have used the term 'attributes' rather than 'outcomes', and have defined a list of specific competencies that correspond to each attribute. Hence, our educational plan uses the terms objectives, attributes, and competencies, where the competencies represent a third level of detail to our program goals.

Definition of attributes and competencies

Prior to formally defining our outcomes or attributes, we solicited information from several of our constituencies including alumni, students, faculty, and recruiters in two separate instruments [2]. This feedback served to highlight areas of both strength and weakness in our program, and provided information on the relative importance of the different learning outcomes defined in EC 2000's Criterion 3.

With this feedback from our constituency

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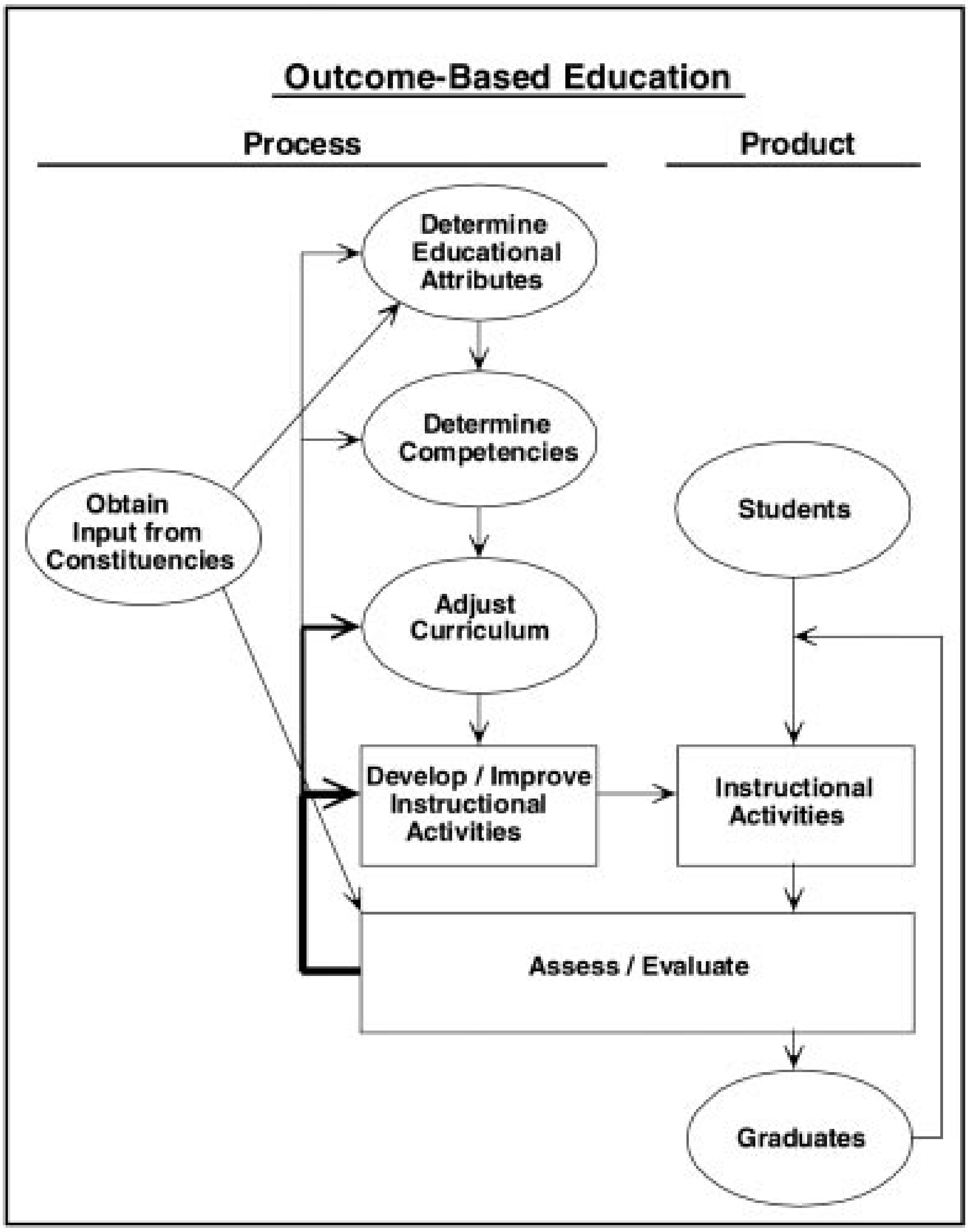

Fig. 1. Outcome-based education plan.

groups, we moved to the task of defining our own targeted attributes. At first we simply used the eleven items given in EC 2000 Criterion 3 along with the Program Criteria under EC 2000 Criterion 8, as our attributes. We divided our entire faculty (13) into groups of two or three with the assignment of identifying specific competencies for each of the attributes. We felt the additional level of detail was going to be necessary to develop an effective assessment plan.

Several problems quickly became evident:

- The attitude of the faculty was that we were doing 'extra' work simply to satisfy ABET.
- There was no feeling of ownership for the process and no sense of forthcoming benefit from the exercise.
- There were some serious reservations about the relative importance of the different criteria and a definite feeling that they should not be weighted equally.
- There was no clear connection between our current curriculum and the EC 2000 process.
- It was evident that interest in the process varied significantly from faculty member to faculty member, with attitudes ranging from enthusiastically positive to antagonistic.

At this point we recognized that broad ownership of the process and a commitment to the learning outcomes would be essential to our success. We also recognized the need to involve all of the faculty, but at different levels. Our undergraduate committee, consisting of five faculty members (including the four authors) with a relatively high level of interest in the process, was given the assignment to do the initial work and prepare items for discussion by the full faculty. This two-tier structure (committee and faculty) has worked very well in balancing faculty interests with the need to involve the entire department faculty.

Our experience has shown that the discussion and synergism derived from the committee has been extremely beneficial and is strongly preferred over use of a single individual. The workload has also been more evenly distributed.

Finally, we decided to develop our own attributes, instead of using those defined by ABET, in order to better meet the goals of our program, maintain ownership of the process, and connect it to our current curricular activities. Of course, we were careful to verify that our list of attributes encompassed those in EC 2000.

The detailed steps we used to define attributes and competencies have been documented elsewhere [3] and are summarized here for completeness. The skills and experiences expected of each student for each semester and course were first listed for our entire program. These skills and experiences were labeled 'competencies' and represented the specific characteristics that we desired for our students. Similar competencies were grouped together and used to define an attribute that characterized that group of competencies. The net result was the twelve attributes listed in Table 1. Table 2 shows an example of the competencies that correspond to a particular attribute.

Table 1. Desired attributes for chemical engineering students at BYU

1	An understanding of the chemical engineering major and profession
2	An understanding of fundamental principles of mathematics and science
3	An understanding of chemical engineering fundamentals
4	Practical experience with chemical process equipment, chemical handling, chemical analysis, and process instrumentation
5	An ability to use modern engineering tools necessary for engineering practice
6	An ability to define and solve engineering problems
7	An awareness and a sensitivity to safety and environmental issues
8	An ability to communicate ideas effectively in both oral and written form
9	An ability to work effectively with others to accomplish common goals
10	An ability to apply chemical engineering fundamentals to solve open-ended problems and to design process units and systems of process units including multiple operations
11	An appreciation for and a commitment to ethical and professional responsibilities
12	An appreciation for and a commitment to the continuing pursuit of excellence and the full realization of human potential

Comparison of our attributes to the eleven outcomes specified by EC 2000 showed that, although there was not a one-to-one correspondence, our attributes encompassed EC 2000 Criteria 3, 4, and 8 (Program Outcomes and Assessment, Professional Component, and Program Criteria, respectively) and thus satisfied ABET requirements. Perhaps more importantly, the process of developing our own attributes resulted in some critical additional benefits, including:

- inclusion of goals specific to our institution;
- insight into the proper weighting of attributes;
- faculty ownership (buy-in);
- a clear connection to our current curriculum.

We believe that these benefits were the direct result of going through the process of defining our own attributes, and that they would not have resulted from the simple adoption of an external set of attributes (e.g. ABET's a–k in Criterion 3).

Definition of mastery levels

As we examined our competencies, it became clear that the level of mastery expected from students varied from competency to competency. Exposure to the material was all that was required for some competencies. For others, it was our

Table 2. Attribute summary sheet for Attribute 8

Attribute 8: An ability to communicate ideas effectively in both oral and written form.

Description: Students should be able to express ideas clearly and concisely in an organized manner both orally and in writing. They should be familiar with the current elements of written and oral presentations such as effective visual aids. Students should be effective readers and listeners and be able to develop and interpret graphical descriptions of objects.

Competencies:
Graduates must be able to:

Level 3: (none)

Level 2:
8.1. Give effective, well-organized oral presentations of technical material including the handling of questions and the use of appropriate visual aids (ChEn 475 *x*, ChEn 477 *x*, ChEn 451 *x*, ChEn 491 *x*)
8.2. Write effective, well-organized technical reports, including formal engineering reports, short letter reports, and a personal resume (Eng 316 *x*, ChEn 475 *x*, ChEn 477 *x*, ChEn 451 *x*)

Level 1:
8.3. Demonstrate effective reading of technical material (ChEn 170 *I*, ChEn 273 *R*, ChEn 374 *R*, ChEn 378 *R*, ChEn 373 *R*, ChEn 376 *R*, ChEn 478 *R*, ChEn 436 *R*, ChEn 476 *R*, ChEn 475 *R*, ChEn 477 *R*, ChEn 451 *R*, ChEn 491 *x*)
8.4. Demonstrate effective interpretation of graphical data (ChEn 273 *x*, ChEn 374 *R*, ChEn 378 *R*, ChEn 373 *R*, ChEn 376 *R*, ChEn 478 *R*, ChEn 436 *R*, ChEn 476 *R*, ChEn 475 *R*, ChEn 477 *R*, ChEn 451 *x*)
8.5. Demonstrate experience and ability in interviewing skills (ChEn 491 *x*)

Level 0: (none)

Table 3. Mastery levels for competencies

Mastery Level	Description
0	Optional
1	Evidence of Exposure
2	Competency With Course Grade Standard and Systematic Feedback
3	Competency With Multipoint Assessment, Systematic Feedback and Student Recycle (minimum competency for graduation)

expectation that students should not graduate without demonstrating a specified level of mastery. The expected level of mastery is intimately connected to the types of practices, assessment, and feedback associated with a given competency. Consequently, four different mastery levels (see Table 3) were defined and used to classify the competencies.

Level 0, which is described as optional, includes competencies that are desirable, but not required, such as having an industrial internship. Level 1 indicates some familiarity and experience, but defines no minimum level of performance. Level 2 includes chemical engineering skills such as determination of pressure drop in a pipe, the number of trays in a distillation column, or the volume of a reactor. Students must be proficient at these competencies in order to be qualified chemical engineering graduates, and our curriculum has always aimed at developing these competencies. The intent of the Level 3 competencies is to focus on fundamental concepts and principles upon which the skills/applications are based. We refer to these Level 3 competencies as 'core competencies' because they emphasize the core concepts that provide the foundation for problem solving, as discussed in the next section. Emphasis is given in our curriculum to practices and assessment methods that are focused on these core competencies.

Once the mastery levels had been defined, each competency was evaluated and assigned an appropriate mastery level. This task was much more difficult than development of the mastery levels definitions (Table 3). Initial assignments were made by the undergraduate committee and then brought before the full faculty for discussion and refinement. The whole exercise of trying to define and achieve consensus on the core elements of our curriculum was very enlightening and beneficial. It was also our observation that this procedure permitted faculty members to provide significant input into the process and have ownership for the product without requiring a significant investment in time from each member of the faculty.

After the assignment of a mastery level to each competency, the competencies were grouped according to course in order to facilitate implementation. As mentioned previously, Table 2 contains one of our attributes with its description and competencies. The competencies are categorized by mastery level. The courses in which a given competency is addressed are also listed after the competency statement. Following the course number, a letter, *I*, *x*, or *R* is listed. These letters correspond to whether the competency is simply introduced (*I*), covered significantly (*x*), or reviewed (*R*), in the given course.

Core competencies

When a student successfully solves an engineering problem, it is commonly assumed that the underlying fundamental concepts have been mastered. Our experience indicates that students can become adept at applying correlations or procedures to obtain a correct or partially correct solution by simply mimicking a process demonstrated by an instructor or in a textbook, and that they frequently do this without a firm grasp of the underlying physics or in other words the 'core' concepts. This acquired problem-solving ability is short lived and limited because it is not founded upon a mastery of the underlying core concepts. When these students are required to apply the concepts to the solution of a somewhat different problem, or to apply these concepts after some time has passed, they are frequently at a loss as to how to proceed. They try to remember an equation or correlation and write whatever they are able to retrieve from their memory without thinking through the problem in a manner consistent with a well-founded conceptual understanding.

As an example, consider the results of a simple problem that has been given to senior students in the chemical engineering capstone design course. They have been asked to solve the following problem.

In your reactor design course, you derived and used the CSTR (Constant Stirred Tank Reactor) design equation in terms of the following variables:

V: reactor volume;
F_{A0}: input feed rate (moles A/time);
F_A: output of A (moles A/time);
X_A: conversion;
$-r_A$: rate of disappearance of A (moles/volume/time);
F_{A0} F_A.

(a) Use the words 'accumulation', 'disappearance' (or 'generation'), 'in', and 'out', to write an expression representing the material balance for the reactor.
(b) Derive the steady-state CSTR design equation in terms of V, F_{A0}, X_A, and $-r_A$.

Students are introduced to the CSTR design equation in their reaction engineering course, which they take in the second semester of their junior year. In addition, they also see and use the material balance aspect of this problem, part (a) in both freshman and sophomore courses.

Consider part (a) of the problem, which probes students' understanding of the factors that go into a material balance. This understanding is arguably the most fundamental aspect of chemical engineering problem solving. The first time this problem was given to our seniors, four years ago, only 21% successfully completed part (a). Contrast this result with the fact that at least 75% of these same students were able to calculate the *correct* numerical answer when given a problem that required them simply to apply the CSTR design equation as part of the same capstone design course. In other words, students with a poor grasp of the fundamental concepts were successfully able to complete application problems.

This is consistent with 'surface' learning, and may be influenced by a number of factors that include the type of assessment methods used [4, 5]. Note that such application problems are similar to the type of problems found on the FE exam or comparable competency exam.

We feel that if students master the core concepts and if these concepts are grounded in students' grasp of physical reality, they should pass part (a) at a 100% level. This mastery would improve their ability to complete the derivation required in part (b) as well as their ability to approach application problems. Furthermore, this ability will persist because they are able to address problems using a thought process based on conceptual understanding rather than on imperfect recall of a memorized equation. Note that the poor performance on part (a) noted above has led to increased emphasis on the fundamental concepts in our reaction engineering course.

A partial list of core competencies defined for our students is provided in Table 4. We have identified a total of 23 core competencies that involve concepts and skills that provide the foundation for problem solving in chemical engineering. Emphasis is given in the department curriculum to practices and assessment methods that are focused on these core competencies.

Table 4. Partial list of core competencies

Be able to use basic engineering units in both SI and AES systems in solving problems, and be able to interconvert between unit systems
Understand the phase behavior of pure substances in relationship to the variables T, P and ?
Understand qualitatively conduction, forced and free convection, and radiation
Be able to analyze systems containing multiple resistances to heat transfer
Understand the fundamentals of kinetics including the definitions of rate and forms of rate expressions
Understand and be able to use Raoult's Law to describe the phase equilibrium behavior of ideal mixtures

Acquisition and use of feedback from constituencies

A key component of EC 2000 is the use of constituency groups to help academic departments develop educational plans. We have defined our constituency to be students, alumni, our own faculty, faculty of other graduate programs, and the employers of companies that hire our students. Surveys were used to gather initial information from these constituencies [2]. In addition, we have formed two advisory boards, an external advisory board and a student advisory board.

The external board consists of four industrial representatives and one academic representative. The industrial representatives are all alumni and/or employers of our students. This advisory board has provided invaluable input to our plan as shown below. The second advisory board has recently been formed and consists of 10 undergraduate students with 2–3 representatives from each class in the chemical engineering program. These students have been asked to provide feedback on class instruction and advising issues, as well as on any other issues that they feel are important. The student advisory group met regularly during our last semester (Winter 2001), and has compiled recommendations that the faculty will review in upcoming meetings.

The initial charge given to our external advisory board was to review the competencies and mastery level designations. A description of our attributes and competencies was sent to each member of the board for review, after which the board met on campus to conduct a joint review and offer recommendations. The campus meeting was conducted without the faculty present, after which a joint session of the advisory board and faculty was held. A follow-up meeting of the faculty was held later to discuss the recommendations of the board.

Our experience with the advisory board was very positive and several important recommendations and suggestions were offered. For example, the board recognized that our students were not skilled in giving a business type of presentation where they needed to sell the merit of an idea or project to management. Although we have offered instruction and practice with technical presentations for many years, we have not provided any instruction on business presentations. Our advisory board not only recommended that such instruction be provided, they also offered resources to help us complete this objective. As a result, Competency 8.1 under Attribute 8 (see Table 2) has been modified to include business presentations and appropriate adjustments have been made to the curriculum. Competency 8.1 now reads:

> Give effective, well-organized oral presentations of technical material in both business and engineering formats including the handling of questions and the use of appropriate visual aids.

Safety is another area where our advisory board provided important feedback. The need to help students develop an 'attitude of safety' was emphasized, and several implementation suggestions were provided. For example, they suggested that we may want to add something like 'safety bucks' to our Unit Operations Lab where students who practice safe engineering would be given safety bucks which could be accumulated and redeemed for some sort of 'valuable' prize at a future date.

The emphasis on safety by the advisory board was instrumental in our decision to assign HAZCOM training a mastery level of 3; our students are now required to pass the HAZCOM test as a condition for graduation. In a follow-up discussion on chemical safety, the faculty also realized that the layout of our Unit Operations Laboratory could be improved to emphasize safe chemical handling practices. Plans to do this are being developed.

Another valuable suggestion offered by our advisory board was related to lifelong learning. The board pointed out that while most students were well focused on the goal to graduate, few had a plan for continuing their learning after graduation. It was suggested that the development of a life plan be included as part of the curriculum. This is an excellent suggestion that is likely to have a positive effect on the lives and lifelong learning of many of our students.

Several other recommendations and suggestions were provided by the board, although space does not permit a complete documentation here. In many cases they expressed support for the direction that we were headed and offered resources to help us achieve the desired outcomes. For example, board members have sent us information on how safety is practiced in industry, the use of statistics in industry, tailoring presentations to a management audience, and sustainable development. In summary, our advisory board has been an extremely valuable resource in helping us to define student outcomes and implement methods to help students achieve those outcomes.

Self-assessment and initial program changes

With the competencies and attributes in place, and initial feedback from our external advisory board, we then conducted a preliminary self-assessment of our curriculum. The objective of this self-assessment was to identify and address any obvious deficiencies. For example, changes would clearly be required for any competency that was not addressed in our current curriculum. Other changes were made in response to advisory board feedback. The following is a list of our initial changes:

- A statistics course covering the design of experiments is now required.
- A new chemical engineering course, Chemical Engineering in Society, which includes topics in ethics, safety, and environmental responsibility is now required of first-semester juniors.
- The material in the new course (Chemical Engineering in Society) will be further developed throughout the curriculum by incorporating problems that address elements of safety, environment and/or ethics in our upper division courses.
- Our senior seminar was moved to the junior year and will include instruction on résumé writing, lifelong learning, business presentations, and other career issues.
- Our freshman seminar was modified to include discussions of the need for lifelong learning, taking responsibility for one's own learning, and appreciating the value and contribution of other disciplines.

DEVELOPMENT OF AN ASSESSMENT PLAN TO ACHIEVE THE DESIRED ATTRIBUTES AND COMPETENCIES

Once we had defined attributes, competencies, and mastery levels, received input from our constituencies, and made initial changes to address obvious deficiencies, our attention turned to development of an assessment process that would provide for continuous feedback and improvement. As documented in the literature, it is important that such a process incorporate a variety of different assessment tools [6].

Our assessment plan involves use of the following tools:

- one-on-one faculty interviews/advisement;
- qualification for the professional program (upper division courses);
- instructor assessment at the course level (including exams, quizzes, and homework that address specific competencies, student self-assessment, etc.);
- standard university course evaluations;
- a core competency exam;
- student portfolios;
- exit interviews between department chair and graduating seniors;
- alumni surveys;
- placement data;
- informal interviews with recruiters;
- interviews with the graduate advisors of former students.

Many of these tools are commonly used and will not be discussed in this manuscript. Instead, we will discuss the tools that we have developed to assist in the assessment of student competencies.

Before doing this, however, we will discuss a critical element of our assessment plan—competency-level rather than attribute-level assessment.

In order to have an effective assessment plan which measures how well our students are developing the desired abilities, we felt that it was necessary to assess the students at the competency level. Assessing at the attribute level would not yield the specific information that we needed to evaluate and improve the effectiveness of student learning. Attribute-level assessment is like making an overall assessment as to whether or not an athlete is a good basketball player. In contrast, competency-level assessment of a basketball player requires that an individual evaluation of the skills of dribbling, passing, shooting, playing defense, etc. be made before making an overall assessment of the player's abilities. An overall assessment is made in both cases. However, the competency-level assessment provides detailed information as to where the weaknesses exist (e.g. the player can't dribble). This type of detailed information from our students can greatly facilitate the improvement of student learning. Hence, our assessment plan focuses on assessing competencies.

Course-level assessment

An important aspect of course-level assessment is the evaluation of student performance in the core competencies. The goal is that all of our graduating students (about 60 per year) will be proficient in these core competencies. This goal can only be met if the core competencies are explicitly defined, addressed through learning activities, and assessed in each of the courses to which they pertain. Assessment of these core competencies throughout the curriculum also makes it possible to provide remedial action, individual or global, in a timely fashion as needed to help students achieve the desired objectives.

Assessment of technical competencies is frequently in the form of exam, quiz, and/or homework problems. These assessment tools should include at least two classes of problems:

- Problems that test competency in core areas.
- More challenging problems for which a range of performance is expected.

All students are expected to complete successfully the problems designed to assess mastery of core competencies. The failure of students to do this indicates the need for remedial action by the instructor and/or student(s). We believe that focusing on the core competencies will result in a significant improvement of student learning.

To help with the individual course assessment, we have implemented the two-part Summary Course Assessment Form shown in Tables 5 and 6.

The first part is a summary that is compiled from student self-assessment and instructor assessment of each of the competencies for a given course. A blank copy of this part of the form for Ch En 170, Introduction to Chemical Engineering, is shown in Table 5. The second part of the form (Table 6) contains a few simple questions for an instructor to consider as he/she assesses how well the competencies were addressed. This two-part form for all of the department courses will be an important part of the documentation that will be provided to an ABET evaluator during an accreditation visit.

Throughout the semester it is the responsibility of each faculty member to assess student performance for each of the competencies associated with the course or courses that he/she is teaching. The faculty member is at liberty to choose the particular method(s) of assessment, which may include exam problems, design problems logged into a portfolio, etc.

Each of our faculty has extensive experience in assessing student performance in competencies. We have encouraged our faculty to use assessment tools with which they are familiar. Also, instruction on and discussion of the use of particular assessment methods is a regular faculty meeting topic. At the end of the course, the instructor is asked to use this assessment to evaluate student mastery of the competencies and to summarize the

Table 5. Course Summary Evaluation Form—Part 1 (For Ch En 170)

		EVALUATION 0—none 3—good 1—poor 4—very good 2—fair 5—excellent	
COMPETENCY/ LEVEL/EMPHASIS	DESCRIPTION	Student's evaluation of proficiency in the skill or competency	Instructor's evaluation of proficiency in the skill or competency
1.1/3/X	Knowledge of the chemical engineering major, the required curriculum, and the option		
1.3/1/X	Familiarity with the chemical engineering field, career options, and potential job functions		
1.4/1/X	Appreciation and respect for other disciplines and a knowledge of how chemical engineering relates to other disciplines		
3.1.1/3/X	Be able to use basic engineering units in both SI and AES systems in solving problems, and be able to interconvert between unit systems		
9.1/2/X	Understand teamwork principles including: recognize team members' strengths and weaknesses; use effective communication skills as evidenced by mutual respect and brainstorming skills; share responsibility; demonstrate reliability in individual responsibilities; support/facilitate other team members' development; understand the importance of being a team player.		

Table 6. Course Summary Evaluation Form—Part 2

Chemical Engineering

Course ________________ Instructor ________________

1. Were student competencies included in the course syllabus? Yes/No
2. Were learning activities directed at each of the specified competencies? Yes/No
3. If answer to Q 2 is no, which competencies were omitted? Why?
4. Did you include material that you considered valuable that is not covered in the specified competencies?Yes No
5. If answer to Q4 is yes, what material was included?
6. Are there competencies with which students were particularly weak? Which?
7. What plans are there for modifying the course to better address student competencies?

evaluations and methods on Parts 1 and 2 of the Summary Course Assessment Form. In addition, the students are asked to perform a self-assessment of their mastery of each of the course competencies by rating their understanding on a five-point scale. The rating form also asks the students to rate how well that particular course has helped develop their competencies.

The department undergraduate committee reviews all the summary forms annually (as well as data from the other assessment tools that are currently in use). Concerns, deficiencies and/or recommendations for curriculum modifications are brought to the full department faculty for discussion and action.

Core Competency Exam

To assist in our assessment of the core competencies, we have implemented a Core Competency Exam to be administered during the senior year. This exam is to ensure that the fundamental concepts of chemical engineering are mastered by each of our students prior to graduation. The curriculum has been structured to focus and build upon these concepts so that by the senior year it is hoped that mastery of these concepts already will have been achieved to a large degree. The application of engineering principles will always rely on a firm grasp of these key concepts.

Hochstein and Perry have described the use of a pedagogical tool, Direct Competency Testing (DCT), to measure the ability of engineering students to correctly solve simple problems that relate to a particular skill or competency [7]. Others have advocated the use of the Fundamentals of Engineering (FE) Exam to assess student competency [e.g. 8, 9]. On such exams, students are typically given a set of short problems that require them to demonstrate an ability to perform a specific task or skill. For example, a student may be required to calculate the heat flux through a flat plate given the required data. As illustrated previously, it is possible for students to successfully complete this type of application question without an adequate understanding of the fundamental concepts behind the application.

We have struggled to try to write questions that do a better job of probing the conceptual understanding of students. The following is an example of a question on the same subject (heat transfer) that we feel does a better job of probing conceptual understanding.

In a flat-plate heat exchanger operating at steady state, a hot liquid flows along one side of a copper plate, while a cool liquid flows along the other side. Conditions are such that the temperatures of the two surfaces of the plate are fixed. If the thickness of the plate is doubled but the temperatures remain the same, the rate of heat transfer through the plate will:

(a) double
(b) remain the same
(c) be cut in half
(d) be reduced by the ratio $\ln(t_{\text{initial}}/t_{\text{final}})$ where $t =$ thickness

Note that we have constrained ourselves to multiple-choice questions in order to facilitate the evaluation and assembly of the data. Student responses to the above question were quite interesting as discussed later in the paper.

Our Core Competency Exam consists of 25 multiple-choice problems that the students are expected to be able to solve in about 2 hours. Completed exams are machine scored, thus eliminating the need for a faculty member to spend time grading the exams. Several questions for each competency are being written to permit computer generation of individual exams in future years. If the faculty has done a credible job through the curriculum in helping students to master the core competencies, and if questions are generated such that they probe understanding at the appropriate level, then we anticipate that the successful completion of the exam will be routine.

The objectives of the Core Competency Exam present interesting challenges in exam administration. Because the exam assesses minimum proficiency in core competencies and there are only one or two questions per competency, the desired level of performance on the exam is 100%. Recognizing that it is unlikely that all of our students will pass at this level in a single attempt, students will be allowed to take the exam multiple times throughout their senior year. All competencies will be tested the first time the students take the exam, but only those competencies not yet passed will be tested on subsequent tries (with a larger number of questions per competency). The exams will be self-scheduled during permitted windows of time throughout the year.

We have designed a web-based, ‘smart-exam’ system that:

- puts together the appropriate exam from a pool of questions for each competency;
- allows students to complete the exam on-line;
- grades the exam;
- records the completed competencies;
- provides statistics on all students and exam

questions for continual evaluation and assessment of the exam questions and procedures.

When a student logs into the welcome page of the exam, information about the student's previous exam results will be retrieved and a new exam will be constructed. Questions will be randomly pulled from a database of questions available for each competency. The student selects answers to the multiple-choice questions by clicking on the appropriate radio button. Upon completion of the exam, the student submits the exam and is able to receive immediate feedback, including a list of competencies that have not yet been mastered in order to facilitate preparation for the subsequent exam attempt. Correct/incorrect answers are logged both by student name and by question. The latter is done so that statistics about student responses to questions can be maintained in order to evaluate and improve upon the exam.

EXPERIENCE WITH IMPLEMENTATION OF THE ASSESSMENT PLAN

Experience with course-level assessment

A listing of all of the competencies corresponding to a given course was available prior to the 1999–2000 academic year. All faculty members assigned to teach required undergraduate courses were provided with the list for their course(s) and encouraged to begin assessment activities. Progress was made as exam problems to test core competencies were written and utilized in some classes. Quizzes were used by several instructors to evaluate student mastery and retention of a few core concepts. The idea of using student self-assessment to complement other assessment techniques was first conceived and implemented during this trial period. In particular, we found that a significant difference between the student and faculty assessment of a particular competency tends to indicate an area of concern. Based on our experience, we decided to include the student self-assessment as part of our formal plan.

Our assessment plan was formally implemented during the 2000–2001 academic year. Use of the procedure explained in the previous section is now required of all faculty members assigned to teach required undergraduate courses. Our undergraduate committee has nearly completed a course-by-course evaluation of the data from the Fall 2000 and Winter 2001 semesters. The data indicate that adjustments to the initial assignment of competencies to courses for significant treatment (x's) are needed. In some cases, students rated themselves as competent in an area but stated that the course contributed little to that competency. In other cases, the course instructor did not feel that the competency was appropriate or did not see how to incorporate it into the course.

Recommendations for these adjustments have been developed and will be brought before the faculty for a final decision. A new competency has also been recommended for consideration by the faculty. Weaknesses in student performance on individual competencies were noted and efforts are underway to make sure that these weaknesses are addressed in the next offering of the course. Several weaknesses were recognized as spanning across multiple courses. A coordinated strategy to address these weaknesses is under development.

All of the data evaluation has been documented in order to facilitate feedback and follow up. In addition, numerical scores from evaluations are being entered into an ACCESS database for future reference, cross-coordination, and report generation. For example, the database will allow us to easily view the data by competency rather than by class. The course assessment data will be compared to data from other sources as part of the evaluation process.

Experience with the Core Competency Exam

Our first attempt at having seniors take the Core Competency Exam was conducted in the Winter Semester 2001. Since we are in the pilot stage, the exam was given to the seniors with no minimum passing standard and with no consequence of 'recycle'. We felt this was a fair way to implement the exam for the following two reasons:

1. There was much for the faculty to learn about writing the kinds of problems that are necessary to appropriately assess the competencies.
2. The course assessment and emphasis of the Level 3 competencies had not been put in place throughout the curriculum.

The average score on this exam was 64%, and the high score was 84%. The scores were disappointing but not surprising since these students had not had the benefit of a curriculum focused on the core concepts, and took the exam without preparation in order to establish a first-pass benchmark. Students also provided detailed feedback on the exam in order to help improve its effectiveness.

The strengths and weaknesses of the initial exam became readily apparent from a review of student performance, student feedback, and the exam questions themselves. This led to a healthy discussion amongst the faculty as to what we were really trying to accomplish and the type of questions that would best satisfy that objective. A consensus was reached and assignments were made for the development of the next round of exam questions. It is interesting to note that, as a result of our experience with the Core Competency Exam, many of our faculty used similar types of questions on course exams to assess student performance in the core competencies.

Although the initial exam was less than perfect, we were able to gain insight into the extent to which students had mastered core competencies. For example, responses to the heat transfer question presented earlier were enlightening. The breakdown of responses was as follows (total of 61 students):

(a) 4 students
(b) 14 students
(c) 37 students (correct answer)
(d) 6 students.

A substantial fraction of the students (23%) selected 'b' and concluded that the rate of heat transfer would remain the same if the temperatures were the same, in spite of the fact that the thickness of the plate was doubled. This clearly illustrates a flaw in their conceptual understanding of conduction. The number of students who selected 'd' is also interesting since it appears that these students remembered something about a logarithmic ratio related to conduction, but really didn't understand the concept behind what they were using.

SUMMARY AND CONCLUSIONS

This paper documents our experience with the development of an outcomes-based educational plan to satisfy EC 2000. We began by defining the overall structure of the educational plan, which includes both a process loop and a product loop. The process loop has feedback at multiple levels, and is used to define learning outcomes and to develop methods for helping students to achieve those outcomes. We refer to our student outcomes as 'attributes' and have added another level of detail called 'competencies'. Methods are implemented in the product loop and the effectiveness of the plan is judged by evaluating student performance against the desired competencies.

An important aspect of the development of our plan was the method used to define attributes and competencies. The development of our own set of attributes, rather than the simple adoption of an attribute list such as the eleven outcomes in EC 2000 Criterion 3, was critical to our ownership of the process. Other benefits included effective incorporation of goals specific to our institution, insight into relative importance of competencies, and a clear connection to our current curriculum.

Another critical aspect of our plan was the definition of mastery levels that reflect the relative importance of individual competencies. Based on these levels, a core set of competencies, targeted for mastery by all of our students, was identified. Definition and agreement on these core competencies has had a significant impact on the structure of our educational plan, and will influence instruction and evaluation throughout the curriculum.

Feedback from our constituencies is another essential element of our plan. In fact, feedback from our external advisory board coupled with our own self-assessment has already resulted in changes to our curriculum that will be of significant benefit to our students.

An assessment plan that includes a variety of different assessment methods has been developed. An important element of this plan is course-level assessment. A Summary Course Assessment Form is used to guide course-level assessment and provide a vehicle for documentation. Instructors are responsible for assessment of competencies relevant to their course(s), but have the flexibility to choose appropriate assessment tools. Another important element of the assessment plan is the Core Competency Exam. The purpose of this exam is to ensure that graduating students have mastered the core competencies identified for our program.

Although assessment is an ongoing process, we have already benefited considerably from implementing our EC 2000 education plan. We are optimistic and confident that our continued efforts will produce many additional benefits that will lead directly to improved student learning and preparation.

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