A COURSE-LEVEL STRATEGY FOR CONTINUOUS IMPROVEMENT

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The ABET Engineering Criteria (EC)[1] is generating an unprecedented sensitivity to assessment and tracking of student performance in engineering learning.[2,3] This flurry of activity has many faculty and departments searching for and inventing various models for assessing student performance as well as for establishing a record of those assessments and ultimately applying them within a process for continuous improvement.[4,5] In this context, continuous improvement means making changes to the course/curriculum to quantitatively improve student performance against outcomes. As such, many of the recently introduced continuous-improvement activities can be broadly categorized as outcomes-based assessment[6,7] and are being driven by the ABET defined Criteria 3.[1] And, while ABET did not invent outcomes-based assessment, the accreditation organization has clearly defined the outcomes-based movement in U.S. four-year engineering programs.

One key aspect within this trend is to find the most effective assessment tools as well as the ones with economical bookkeeping strategies. While the literature offers far too many strategies to be cited here, among them are the following notable examples that illustrate the range of approaches. These include a skills assessment worksheet,[8] application of quality-control theory,[9,10] the use of questionnaires,[11,12] and a grading matrix.[13]

Shor and Robson's *Student Centered Control Model* requires course-level ABET-based accounting and suggests a "scoring guides" practice that tracks ABET skills performance.[9] McCreanor demonstrated a college-level approach to tracking a specific outcome—ABET Criterion 3b, the ability to design and conduct experiments.[8] McCreanor's approach relies on a "standardized" skill assessment worksheet distributed to select courses across all departments and centrally assessed. Mandayam, *et al.*, has implemented a curriculum-wide assessment tool called *X-files*, which captures student assessments across the curriculum.[14] On a course-level, Terenzini, *et al.*, demonstrated a student-based questionnaire used to gather course-level student responses and feedback.[11]

Shor and Robson's[9] work suggests that objective (outcomes-based) scores be given at the course level rather than an overall score, but focuses mainly on using the outcome results in the context of a control loop. Winter[13] provides details regarding his course-level accounting practice that tracks student achievement against "tasks" on exams. Winter links tasks to objectives such as ". . . obtaining the velocity field," or ". . . conservation of linear momentum," but does not map objectives to skill-based proficiencies, *e.g.,* ABET outcomes. His accounting practice scores exams according to task, thereby enabling him to identify strengths and weaknesses against specific, topical (task) areas of the course. Terenzini, *et al.*, use student self-assessment rather than objective measures of proficiency such as test or project scores. All report their results in a descriptive and qualitative manner.

The present study uses some of these concepts[9,13] yet illustrates direct connectivity to skills-based (ABET) outcomes. It also details the course-level practices and presents quantitative results from a case study.

Prior to ABET Engineering Criteria, most faculty in engineering colleges designed their courses in what will be re-

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ferred to here as the *requirements domain*. This form of course design specifies requirements (such as homework, exams, attendance, projects, etc.) and places a value on each, thereby establishing what we generally refer to as the *course breakdown* or requirement breakdown (r_i). For example, a lecture-based course in stage-wise separation might be broken down such that homework is 15%, projects are 20%, attendance and participation are 5%, a portfolio is 5%, and exams are 55%, of the grade. In this way, the traditional requirements domain scorecard is produced by summing individual assignment scores for each requirement, and computing the overall score by summing the weighted average of the scores for each requirement.* This form of breakdown is both simple for the instructor and tangible to the students. The requirements may be further categorized or mapped to a pedagogical device such as a classroom activity, team assignment, in-class assessment, etc. (see insert in Figure 1).

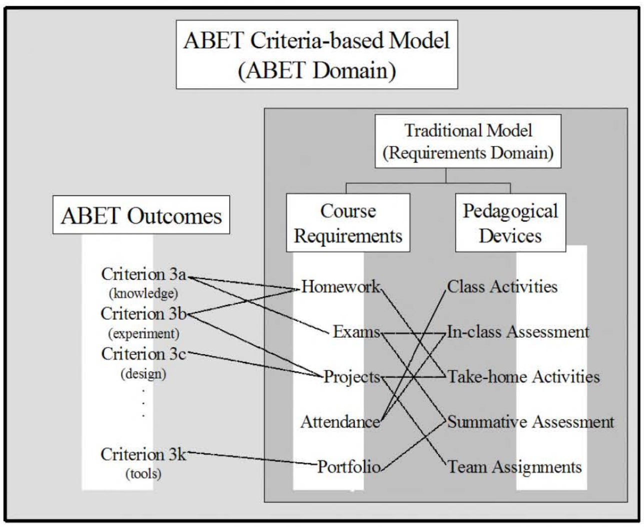

Figure 1. *Framework for the ABET criteria-based model.*

To satisfy ABET, however, it is not enough to provide this form of breakdown alone. In the ABET environment the following questions must be answered: *How did students perform against Criterion 3x? What changes were made to improve student outcomes as measured against criteria . . . ? What strategy is being used to ensure continuous improvement?*

These questions cannot easily or convincingly be answered in the traditional domain. The traditional requirements must somehow be further subdivided to reflect the ABET Criterion 3 categories[1] and then mapped to the desired outcome (Figure 1). In this way, the traditional approach is not simply encompassed within the ABET model, but must be extended to adapt to the outcomes-based assessment protocol. This new way of distributing course requirements is the topic of the present experiment, which offers one faculty's experience in tracking outcomes-based, course-level assessment information. The experiment also demonstrates how such can be used to objectively alter course content, track and hopefully influence student performance, and at the same time, maintain a quantitative record for ABET reviews. The goal in the end is course-level continuous improvement that enhances student learning and the overall quality of the educational experience.

OUTCOMES-BASED METHODOLOGY

The following outcomes-based strategy, which connects course requirements (such as exams and homework) to outcomes (such as ability to apply mathematics and science), was applied to various learning environments, including: two required lecture-based unit-operations courses, a required senior-level chemical engineering laboratory, a required senior-level departmental technical seminar, and a nontraditional interdisciplinary technical elective (see Table 1). First, the catalog description of the course from which content-based learning objectives were developed was consulted. The appropriate ABET EC Criterion 3 were selected and a set of outcomes were written that map the content-based objectives to the ABET criteria. The course requirements were then established and mapped to the outcomes so that each requirement would have assessment standards linked to one or more of the selected ABET Criterion 3 outcomes. This establishes what will be referred to here as the *assessment map*. An example assessment map for Transfer

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* $\hat{S}^i = \sum_j^{n_a^i} s_j^i \Big/ \sum_j^{n_a^i} p_j^i, \quad \hat{S} = \sum_i^{n_r} r_i \hat{S}^i$

where $\hat{S}^i$ *is the total normalized score for the* i^{th} *requirement,* s_j^i *are the scores for the* j^{th} *assignment within the* i^{th} *requirement,* p_j^i *are the possible scores for the* j^{th} *assignment within the* i^{th} *requirements, and* n_a^i *is the number of assignments for the* i^{th} *requirement,* $\hat{S}$ *is the normalized score,* r_i *is the weighting factor, and* n_r *is the number of requirements for the course.*

TABLE 1
Test-Beds for Course-Level ABET Strategy

Course	*Title*	*Pedagogy*	*Subject*	*Level*	*Credit Hrs*
CHE 3110	Transfer Science I	Lecture	Momentum and heat transfer	Junior	4
CHE 3120	Transfer Science II	Lecture	Stage-wise separations	Junior	3
CHE 4240	Chemical Engineering Laboratory	Lab	Unit operations	Senior	2
CHE 4810	Developing Areas in Chemical Engineering	Seminar	Miscellaneous	Senior	1
CHE 4470	Ceramic Materials Engineering	Lecture/Lab	Materials engineering	Junior/Senior	3

Science II, a junior-level required stage-wise separations course, is given in Table 2.

With each requirement mapped to one or more of the select ABET Criterion 3 it is possible to explicitly track performance, assuming that the requirements are adequately designed to demonstrate the desired outcomes. In this new *outcomes domain*, the requirements must contain elements of assessment that map to the criteria. For example, since exams are mapped to communication (ABET Criterion 3g), student exams must include elements of communication and likewise be appropriately assessed and be assigned a communication score. A simple approach is to include a free-writing problem and score it both for technical content and written articulation. Similarly, since homework is mapped to use of engineering tools (ABET Criterion 3k), at least a portion of homework must involve the use of tools such as programming software, spreadsheets, process simulators, the Internet, etc., and be appropriately assessed for mastery of this element.

It is important to note that assessment is a distributed process in which all components of the grade are related to outcomes and are assessed individually. Exam performance on its own does not demonstrate that a given criterion is met. Rather, a combination of requirements and assessment approaches must be used to provide a valid assessment. Furthermore, for the present accounting strategy to be broadly applicable to program-level quality improvement beyond the classroom, persons other than the instructor must be involved in the process, *i.e.,* an external reviewer for a final project or a colleague who assesses or writes an exam problem, etc.

Finally, skills assessment against a learning model, *i.e.*, *Bloom's Taxonomy*,[15] can also be addressed in this context, although this experiment did not include this higher level of assessment. Table 3 illustrates the bookkeeping required to track performance by both requirement and criterion.

IMPLEMENTATION

The methodology described here was implemented in five chemical engineering courses over a three-year period to test general suitability for application across the curriculum (see Table 1). A single junior-level required course in stage-wise separations was used as a case study to illustrate the process of implementation and feedback at the course level. The results are later discussed in the broader context of laboratory and elective courses and, finally, curriculum-level feedback.

Course description

CHE 3120, Transfer Science II, is a junior-level required course in stage-wise separation processes. When broken down in the traditional requirements domain, 55% of the grade will come from exams, 20% from projects, 15% from homework, and 5% each for attendance and a portfolio. Five midterm exams and a final are given. The project varies from year to year but typically involves using or developing a process simulation.

Breaking the course requirements into ABET criteria

Traditionally an instructor will assign a problem and grade it according to a rubric that establishes the correctness of the solution and will then assign credit for the problem—a score. This score becomes one of many that will be accumulated to make up the elements of the grade. In the outcomes domain the same problem must be analyzed so as to assess for select ABET Criterion 3. For example, consider a typical homework problem in stage-wise separations:

> *Specify the number of ideal equilibrium stages required to separate a 40 mole % methanol in water stream at its bubble point into a distillate containing not more than 5 mole % water and a waste stream not containing more than 2 mole % methanol.*

The question itself need not be altered in the new outcomes environment, but how we view assessment must be changed. This problem clearly contains a variety of ABET Criterion 3 elements that can be individually assessed. First, it contains elements of design (ABET criterion 3c), regardless of the fact that the word *design* does not appear in it. In addition, it requires that the student apply knowledge of science (Criterion 3a), *i.e.,* students will have to select appropriate models for the phase equilibrium. Students must select a methodology to solve the problem (Criterion 3e) and to formulate and solve engineering problems. Is a material balance required? Is a heat balance required? What are the governing equations relating the material, heat, and equilibrium relationships? The problem must be solved, requiring application of mathematics (again, Criterion 3a). The instructor may also specify that the problem be solved using a process simulator or that a mathematical model be developed, including elements of Criterion 3k—use of modern engineering tools. Finally, students must assemble their results into a format that can be understood (Criterion 3g, communications). So, a *simple* problem that chemical engineering faculty have been assigning for decades is rich with outcomes-based information—only, however, if it is subdivided and scored according to the outcomes criteria. A similar approach was used for exams, the project, and other assigned coursework.

TABLE 2
Assessment Map for a Junior-Level Stage-Wise Separations Course

Requirement	*Criterion 3a Knowledge*	*Criterion 3c Design*	*Criterion 3e Formulation*	*Criterion 3g Communication*	*Criterion 3k Tools*
Attendance				X	
Project		X	X	X	X
Exams	X	X	X	X	X
Homework	X	X	X	X	X
Portfolio				X	

TABLE 3
Outcomes-Domain Bookkeeping Approach

for Requirement i						
Assignment No.	ABET Criteria					Overall Assignment Score
	C_1	C_2	C_3	…	C_k	
a_1	S^i_{11}	S^i_{12}	S^i_{13}	…	S^i_{1k}	S^i_1
a_2	S^i_{21}	S^i_{22}	S^i_{23}	…	S^i_{2k}	S^i_1
a_3	S^i_{31}	S^i_{32}	S^i_{33}	…	S^i_{3k}	S^i_1
a_j	S^i_{j1}	S^i_{j2}	S^i_{j3}	…	S^i_{jk}	S^i_j
Overall Criterion Score	s^i_1	s^i_2	s^i_3	…	s^i_k	

$$s^i_k = \sum_j^{n^i_{ak}} S^i_{jk}$$

$$S^i_j = \sum_k^{n^i_{cj}} S^i_{jk}$$

Where the S^i_{jk} are the scores for the k^{th} outcome criteria of the j^{th} assignment of the i^{th} requirement; the s^i_k are the criteria score sums for the k^{th} criteria of the i^{th} requirement; and the S^i_j are the assignment sums for the j^{th} assignment of the i^{th} requirement.

TABLE 4
ABET Scorecard

Student	ABET Criteria					Overall Score
	3a	3c	3e	3g	3k	
#1	72.3	65.5	72.6	88.5	94.5	76.3
#2	90.0	89.5	90.2	95.9	89.9	91.1
#3	74.0	67.9	74.4	93.2	90.4	78.3
#N	62.4	53.6	62.9	90.0	86.6	68.7

$$\hat{s}_k = \frac{\sum_i^{n_r}\sum_j^{n^i_{ak}} S^i_{jk}}{\sum_i^{n_r}\sum_j^{n^i_{ak}} p^i_{jk}}$$

$$\hat{S} = \sum_k^{n_c} a_k \hat{s}_k$$

Where $\hat{s}_k$ is the overall normalized score for the individual ABET criterion 3 (one of the a-k), p^i_{jk} are the possible points for requirement i, assignment j and criterion k and n^i_{ak} and n^i_c are the number of assignments for requirement i with criterion k and the number of criteria for requirement i respectively.

TABLE 5
Comparison of
Requirements Breakdown and Outcomes-Based Breakdown
for a Junior-Level Stage-Wise Separations Course

Requirement	Requirement Breakdown	3a knowledge	3c design	3e formulation	3g comm.	3k tools
Exams	55%	43.9%	15.1%	35.2%	4.7%	1%
Projects	20%	28.9%		20.5%	18.9%	31.6%
Homework	15%	37.7%	6.8%	36.5%	19.1%	
Participation	5%				100.0%	
Portfolio	5%				100.0%	
ABET Breakdown	100%	35.6%	9.4%	29%	19.2%	6.9%

a_k $\quad a^i_k$

Where a^i_k are the breakdown for the i^{th} requirement associated with the k^{th} criterion and a_k is the ABET breakdown for the k^{th} ABET criterion.

Another noteworthy point is that the assessment of an assignment is only as good as the assessment protocol used. Within the context of the proposed course-level strategy for use of assessment information for continuous improvement, the faculty are responsible for ensuring meaningful assessment of student proficiencies. This might include projects, oral presentations, observation, peer input, and, yes, even exam scores. Further discussion on this subject can be found in the literature and is outside the scope of this paper.

Doing the bookkeeping

The accounting practice is simple: With each requirement (i) broken into assignments (j) and each assignment broken into elements of the criteria (k), a score for each assignment element (S^i_{jk}) within a requirement is given, rather than just an overall assignment score (see Table 3). These outcomes-based (criteria-based) requirement subscores can then be summed by assignment (across rows) to give overall assignment scores S^i_j or by criteria (down columns) to give overall outcomes-based scores s^i_k for that requirement. Summing the requirement subscores by assignment is equivalent to a traditional approach in which a single score is given for a single assignment without attaching performance to a particular outcome. Summing the assignment subscores by outcome (criteria), however, provides the outcomes-based distributed information that we are seeking in this approach. In this way, an *outcomes-based scorecard* is generated, thus creating an explicit record of student performance against stated ABET outcomes (Table 4).

A strategy for computing and tracking the outcomes-based breakdown on an ongoing basis was also devised for formative assessment purposes. At any point in the semester the outcomes breakdowns by requirement (a^i_k) or overall (a_k) can be computed. By summing the possible points by criterion within a requirement and normalizing by the total possible points, the normalized-outcomes criteria breakdown (a_k) within a requirement is determined. By further forming the sum of the requirement-weighted normalized criteria breakdown, the overall outcomes-based criteria breakdowns can be computed. This produces the outcomes-based breakdowns (Table 5), which can be computed at any time, including term-end.

Establishing proficiency levels

How should proficiency levels be established? As with any grading system, scores (Table 4) represent a proficiency level measured against some standard, *i.e.*, a known correct problem solution, an accepted format for a report, the expected outcome of an experiment, or an anticipated level of team participation. At this time, assessments (*i.e.*, exams, projects, homework, etc.) are deliberately designed to evaluate student learning at various levels, but are not tied to a learning framework such as *Bloom's Taxonomy*. Traditional guidelines were used in accordance with the instructor's judgment concerning the level of difficulty and content of each assignment, *i.e.*, average passing scores for each outcome (criteria) were taken to be 60%, with each grade level generally at 10% increments. Admittedly, one of the next challenges will be to tie assignments to "domains of learning," for example, as defined by Bloom.[15] This would provide a more defendable basis upon which to make competency decisions.

Finally, the distributed outcomes-based information for each students' performance (Table 4) provides a unique dataset that forms the basis for a new way of grading. Since outcomes are based on ABET criteria that state that "students will demonstrate" proficiency in a specific topic, a passing grade (for example) should no longer be tied to an overall score alone. Proficiency levels in each outcome area should be defined and a grading protocol established that incorporates an outcomes-based strategy. This, however, was beyond the scope of the present study.

Planning so the process is manageable . . . tips for implementing at the course level

Preplanning a course in this way can be extremely difficult, time consuming, and some might even say "impossible." The following guidelines, however, were used to make it more achievable as the result of lessons learned in this pilot study.

As usual, the requirements domain was fixed prior to teaching the course, while only a rough idea of the outcomes breakdown was established *a priori* as a target. Analyzing every assignment, in the detail described above, is a daunting task, however. When implementing such a strategy, a week-by-week approach works well: Identify the homework to be assigned for a given week; review the problems one-by-one; break them into outcomes criteria and grade them accordingly once students have completed them. If a teaching assistant is going to do the grading, some *calibration* may be required. Examples may be necessary to train the grader to recognize the outcomes elements of an assignment and to grade in the outcomes domain.

DISCUSSION

Results of implementation

The results of three semesters (three years) of data from CHE 3120 are discussed. The course was successively taught in 2001, 2002, and 2003 by the same instructor (the author) and the methodology described herein applied. Three performance metrics were used to study student and course outcomes:

- *Outcomes breakdown (Figure 2)*
- *Class-average performance against Criteria 3a, 3c, 3e, 3g, and 3k and class-average term-end performance against requirements as a function of time (Figures 3a and 3b, respectively)*
- *Class-average term-end performance against the ABET criteria (the outcomes), (Figure 4)*

The net outcomes breakdown at the end of each term is illustrated in Figure 2. This figure represents the portion of the overall coursework that could be attributed to each of the five ABET criteria emphasized in the course. During the first two semesters (2001 and 2002), no conscious effort was made to alter the course content to adjust the outcomes breakdown. Since the new methodology was being developed, these first two semesters were used as a baseline to establish nominal course performance without significant intervention to alter the outcomes breakdown. During these two semesters the knowledge content was about 37%, the formulation content 32%, the design content 6%, the communications content 18%, and the tools content 7%. During the third semester (2003), however, an effort was made so that roughly 15% of the course content was design related, 10% tools (3k), and 10% communication, with the remainder split between knowledge (3a) 35%, and formulation (3e) 30%. This was not done to *balance* the emphasis, but rather to reflect this instructor's opinion that the particular course content should have a more significant design aspect and a more appropriate weight given for communications. Figure 2 illustrates that, without appropriate assessment tracking, an instructor may inadvertently over- or under-assess specific criteria.

Using this outcomes-based methodology can yield valuable formative feedback provided that the data are reviewed throughout the semester. Figure 3a illustrates the time-sequenced class-average performance against the five ABET criteria for CHE 3120. An assessment of all course requirements was made following each exam. This includes exam scores, homework, projects, etc.—all-inclusive. Exam peri-

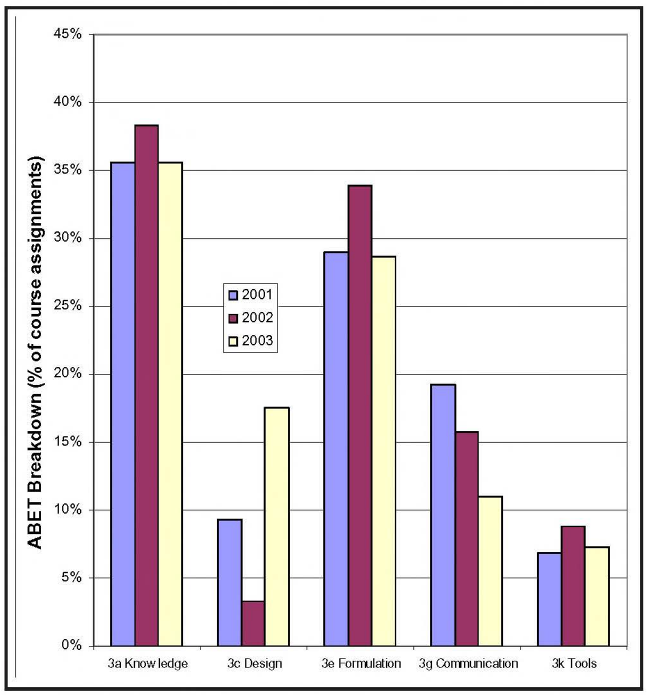

Figure 2. *Term-end ABET breakdown for three consecutive years (2001-2003).*

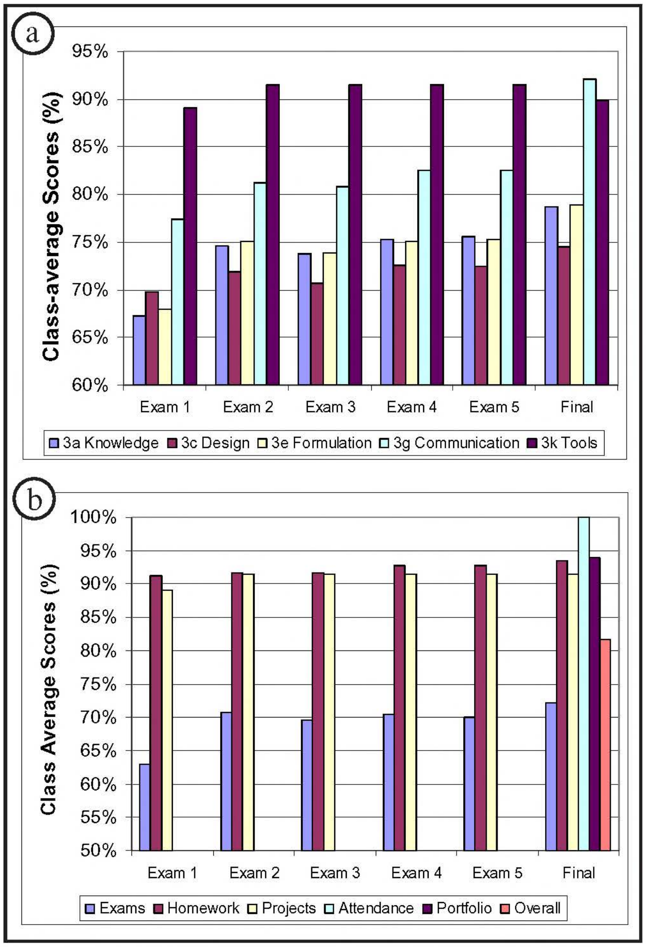

Figure 3. (a) *Time sequence, class-average scores against ABET criteria for 2001.* ***(b)*** *Time sequence, class-average scores against requirements, attendance, and portfolios were assessed at term end as well as the overall score.*

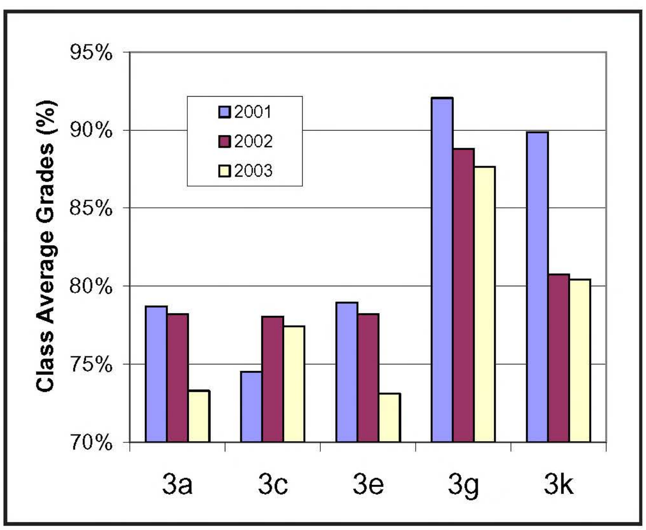

Figure 4. *Class-average term-end performance against ABET Criterion 3a (knowledge), 3c (design), 3e (formulation), 3g (communication), and 3k (tools).*

ods were used rather than uniform chronological periods since coursework can sometimes be somewhat nonuniformly distributed in time. This data can be compared to Figure 3b, time-sequenced performance on a requirements basis.

The requirements-based analysis can tell an instructor how students perform on various forms of assessment, *i.e.,* exams, projects, homework. As expected, students clearly perform better on homework (>90%) and projects (>90%)—forms of assessment that offer students more time to find solutions, work in teams, and *practice engineering* in a more *open* environment (see Figure 3b). At the same time, exam scores, which were typically but not exclusively in-class activities, hardly exceeded 70%. It should also be noted that the attendance and portfolio components of the grade were assessed at term end, although an ongoing approach would likely offer better feedback to both instructor and student. And, while the portfolio has typically been treated as a term-end project containing student-selected course products (*i.e.*, exams, reports, homework, etc.), a model for reviewing at one or more midterm points has also been used. A communication-based rubric was applied to assess the portfolio quality.

While providing feedback on a requirements-basis offers a lumped view of how students are performing, it does not offer outcomes-based insight into *what they are doing well* or more importantly, *what they may not be doing well*. Figure 4, on the other hand, offers a view of student performance against the instructor's goals (outcomes). In this case it was clear that during the first two semesters, 2001 and 2002, students had excellent mastery of engineering tools (Criterion 3k) and a good command of communication skills, with scores upwards of 80%. Knowledge (Criterion 3a) and formulation (Criterion 3e) lagged behind, with design (Criterion 3c) scores being even lower. While none of these scores suggested a problem with this student population, they clearly identified which areas might be focal points for instructional emphasis.

Since design was identified as the most challenging area for students, during the third year of this experiment a conscious effort was made to not only increase design content, but also to emphasize design concepts through lecture, homework, and projects. Figure 2 illustrates the outcomes-based course breakdown for the three-year period of 2000 through 2003, and Figure 4 illustrates term-end class-average performance for the same period. While emphasizing design concepts did not produce an obviously better outcome (*i.e.*, improved scores on the design-related course elements), student scores as compared to the cumulative average of the prior two years were marginally higher but still well within the year-to-year variability. Surely, one would hope that emphasizing a concept would lead to improved student performance, and while the proposed method of formative and summative course-level assessment of outcomes criteria makes it possible to make such course-level changes, a more detailed long-term study is required to validate cause and effect of using this strategy. Such a study should include a control group that does not use the new accounting strategy. At least three years of data in several course formats, *i.e.,* lab, lecture, etc., should be included. Input from an external assessor, such as an ABET reviewer, would also be extremely valuable.

Experience in other learning environments

The outcomes-base strategy was also tested in other learning environments, including a self-learning environment (required seminar), a discovery-based environment (nontraditional technical elective), and a hands-on environment (laboratory). These courses also used a broad range of assessment protocols (tools), including term projects, oral presentations, assessments of team interaction, and similar, more authentic forms of assessment.[16,17] Thereby, the proposed outcomes-based scorecard was tested in an environment of broadly differing outcomes as well as with tools that are widely considered to provide a "richer" form of assessment than exams and homework alone. While the accounting and mapping strategy was the same in each case, the outcomes selected were considerably different and in some cases represent the more difficult to quantify of the ABET criteria—thus providing a test bed for evaluating the practicality and functionality of the methodology for the entire range of ABET outcomes.

The chemical engineering department at TTU offers a seminar course titled "Developing Areas in Chemical Engineering." It was broken into three requirements: attendance, homework (weekly assignments), and a term project. Students were required to submit weekly assignments that were designed to facilitate their ability to engage in the process of self-education (a lifelong learning skill). The first assignment was to define lifelong learning. Other assignments included writing a column about microelectromechanical systems (MEMS) for a popular science magazine, researching a micromachining technology, reviewing a technical publication, and inventing a micromachine concept. The course culminated in short presentations and a brief written paper describing the micromachine each student invented.

The outcomes selected for the course included ABET criterion 3e (formulation), 3g (communications), and 3i (lifelong learning). The lifelong-learning goal was typically addressed in terms of how well the student was able to find the resources needed to answer a question, and the form of articulation used apart from simply the ability to communicate well.

"Interdisciplinary Studies in Ceramic Materials Engineering," a course co-offered, developed, and taught by Mechanical and Chemical Engineering,[18] was also part of the study. In this case, ABET Criterion 3d (ability to function on multidisciplinary teams) was included; again, a rather difficult criterion to assess. The interdisciplinary and teaming aspects are addressed in this course by offering students rather open-ended research problems that require a multidisciplinary approach. Teams and individuals conduct self-assessment and peer assessment, and the scores are kept in the manner defined by the ABET course-level accounting strategy defined above. Finally, a hands-on laboratory course was also included in this experiment. ABET Criterion 3b, as well as team aspects of 3d (not necessary multidisciplinary), were the focal outcomes. While authentic assessment activities, rubrics, and metrics for lifelong learning and team interaction will be debated at length for some time, the course-level strategy presented here was found to provide a basis for quantifying obvious elements of these processes.

After three years of pilot testing this methodology in a broad range of courses that included a traditional lecture-based course, a discovery-based research-oriented environment,[18] and a self-directed seminar, several course-level improvements have been made as the result of the outcomes-based assessment data. These can be generalized into two categories: (1) altering course content to change the outcomes-based breakdown, and (2) modification of course content to emphasize outcomes with low performance scores. In the lecture-based stage-wise separations course, the course breakdown was altered to increase design content and decrease communications content. Content emphasizing design—including in-class workshops, more use of computer simulations, and lectures on design methodology—was included. In the more open-ended courses, "Interdisciplinary Materials Engineering," "Chemical Engineering Lab II," and "Developing Areas in Chemical Engineering," systemic problems were identified in the area of written communications and research methodology. Performance scores on communication (Criteria 3g) and experimentation (Criteria 3b) were low. Surprisingly, some students could not organize their thoughts to produce a good research report, conduct literature review, or design an experiment (thinking through the steps associated with identification and specification of an experiment). Similarly, their information-interpretation skills were weak, which translated into low-quality research reports. Outcomes-based scorekeeping helps to identify and quantify such deficiencies and to track the response to changes in the classroom. Course content was altered in each case to include in-class workshops and mini lectures on skills-based topics that would otherwise not be included in such classes, *i.e.,* research-report writing, the scientific method, and discovery-based learning.

Suggestions for using the course-level strategy in the overall context of program-level continuous improvement

The course-level outcomes-based assessment strategy presented here has a number of advantages, including real-time loop closure at the instructional level. It also has a number of disadvantages, including a significant one-time start-up effort and some additional effort to prepare and grade assignments in a nonconventional way. Once implemented, however, this strategy could provide a new way of optimizing instructional efficiency. Furthermore, while this experiment focused on applying the outcomes assessment to the course-level, the approach may have significant utility if applied, even on a limited basis, throughout the curriculum, to quantitatively address issues of feedback both at the curriculum level and the course level. For example, if students are found to be particularly weak in ABET Criterion 3a (ability to apply knowledge of . . . mathematics . . .), the source of the deficiency may be in the prerequisite course sequence. If applied to a significant number of courses within the department, trends that suggest such deficiencies would be quantitatively identifiable. This form of quantitative information would then become one of a number of indicators that could be used to improve student performance through curriculum-level continuous improvement.

Ultimately, the objective should be to integrate course-level information into an integrative process that is summative and probes *deep* retained learning rather than superfluous short-term learning. If strategically implemented throughout the curriculum to include early, mid-curriculum, and capstone courses, this methodology may have value as one part of a comprehensive evaluation system.

Yet another benefit of using an outcomes-based performance accounting strategy is possibly one of administrative record keeping. Course-end reports including Tables 4 and 5 can be kept. When combined with student portfolios or select student papers, they provide the basis for an ABET exhibit that quantitatively illustrates student performance against ABET criteria as well as a methodology for continuous course and curriculum feedback and improvement.

IMPRESSIONS AND RECOMMENDATIONS

Since the ABET criteria address a broad range of skills, an ABET-based course-level approach for using assessment outcomes was implemented and assessed in laboratory-, lecture-, and seminar-based settings. The use of a systematic mapping between the requirements domain and ABET domain provides a detailed record of student performance against ABET Criterion 3 Outcomes (Tables 3, 4, and Figure 4). The strategy described here is time consuming at first, but once established, it is no more labor intensive than other methods and yields far more insights into the teaching and learning processes. While the traditional approach neatly itemizes the overall performance on individual course requirements (something that every instructor and student wants to know), it gives no insight as to what are the strengths or weaknesses based on any performance criterion (Figure 3b). The ABET scorecard, however, itemizes the overall performance by the specific performance criteria and offers the instructor a window into student skill-based abilities (Table 4). Both are important and both should be considered when assessing student performance and when addressing course improvement.

Streamlining the process on the front end and providing faculty training and retraining in this new ABET-based course-level strategy should make it a more attractive alternative for faculty to implement. A more extensive experiment is needed to validate and extend the results presented in this case study. Additional test beds wherein other departmental and extra-departmental faculty adopt the strategy must be included in the next level of the experiment. Direct feedback from an ABET review team should be sought during the next review cycle in 2009. Furthermore, elements of skill level should be included in the assessment matrix using, for example, *Bloom's Taxonomy*, or a similar model.

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