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Preparing for ABET EC 2000: Research-Based Assessment Methods and Processes*

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On-going research on outcome-based assessment processes conducted by a multidisciplinary team from five major universities is described. The research has been guided, in large part, by ABET's innovative criteria—EC 2000. The paper provides examples of several by-products of this research that have been applied in the engineering education environment. The reader is exposed to strategies for objective setting, an attribute database for use in defining student learning outcomes, and examples of technology-enabled systems that provide constituents with timely results. Specific assessment methodologies currently embedded in triangulation and validation experiments are described.

INTRODUCTION

THIS PAPER describes one approach to addressing the outcome assessment requirements of ABET's (Accreditation Board of Engineering and Technology) innovative criteria—EC 2000 [1], whose outcome-based criteria are now required for all 1600 plus US engineering programs. (ABET accredits individual programs rather than the entire college; hence, each program in the engineering college must seek separate accreditation and institute its own outcome oriented process.) As evidenced by this special issue of the *International Journal of Engineering Education*, assessment and EC 2000 have also attracted considerable international interest. As a result, US engineering educators have become especially interested in assessment issues in general and successful applications in particular.

Hence, in addition to presenting a way to prepare for EC 2000, we discuss several methodologies that we either have applied or are in the process of applying in the engineering education environment. We also describe our efforts in expanding the 'assessment toolkit' as part of a five-university collaborative research project:

- Colorado School of Mines (CSM)
- Columbia University (CU)
- University of Pittsburgh (UP)
- Rose-Hulman Institute of Technology (RHIT)
- University of Washington (UW).

EC 2000 is more than outcome assessment. It requires the implementation of a closed-loop system. To do this, engineering educators must first establish program and learning objectives, specify measurable outcomes, typically in terms of desired outcome attributes, and use the resultant information to make real improvements.

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A SYSTEMS-BASED ASSESSMENT PROCESS

To provide a comprehensive approach for EC 2000, we propose an underlying model that views outcome assessment as a systems-based process [2]. This process begins by defining program and course objectives in terms of student learning outcomes. It is only after these have been clearly defined that appropriate assessment methodologies can be selected. These methods then are implemented and data collection commences. The final phase of this systems process is the reduction of collected data into information that clearly informs academic decisions and programmatic improvements. This process is continuous in nature with feedback from each phase influencing future actions.

To implement such a system, we further propose that engineering educators complete a series of five tasks that might entail:

1. Creating a structured process to facilitate objective setting and outcome definition at the program and course level.
2. Defining a comprehensive listing of measurable attributes for each of the desired outcomes. (Criteria 3 of EC 2000 prescribes a minimum set of eleven learning outcomes, often referred to as 3a–k.)

3. Delivering educational sessions/workshops to both develop faculty assessment knowledge and skills and achieve the necessary 'buy-in'. (While 100% support may be difficult to obtain, certainly 'buy-in' from 75 to 80% of program faculty is achievable.)
4. Identifying the most effective assessment methods for measuring student learning outcomes.
5. Using information technologies to support the presentation of information in a systematic way so that it can be acted upon by administrators and faculty.

Each of these tasks is discussed below along with the procedures we have developed or are in the process of developing for implementing them.

Task 1. Defining program objectives via a structured process

This first task involves implementing a structured, facilitated process to help department chairs and faculty develop program objectives and learning outcomes. It encompasses some of the most important and challenging activities in the overall process; experience has shown that often an outside facilitator can more effectively move the process along than an internal colleague. An effective way to define the program objectives, strategies, and measurable outcomes is to establish both a college-wide committee and separate committees for each program. In this manner, the college will achieve consistency among its programs, each of which will be separately evaluated, and facilitate the implementation of college-wide information systems. This college-wide committee should include appropriate representation from each program—either the department chair or a senior faculty member. At the program level, small workgroups comprised of the department chair and two or three key faculty members should be formed. These groups will work with administrators, faculty, and external constituents to define programmatic and course-level objectives, strategies and measurable outcomes for approval by the full faculty. The college-wide committee also should perform a coordination role among programs, establishing common processes, especially for collecting data and sharing information. Due to the large cost and effort required, the more uniform the process is across the college's programs, the better will be the overall result.

At the program level, the focus should be on establishing learning objectives, strategies, and outcomes. Input should be obtained from administrators, faculty, students and external constituents including industry leaders, alumni, and, in some cases, even parents. Programmatic objectives then can be used to review the curriculum and establish course-level objectives for its key academic components. In addition to course learning objectives, strategies for achieving these objective and anticipated outcomes should be formulated.

We have developed workbooks for departmental and course-level planning in order to support these formal-planning efforts [3]. Our approach has been for the program's workgroup to identify no more than five major educational objectives. For each objective, associated curriculum strategies, student learning outcomes and assessment methods are then generated. These initial program plans are referred to as 'version zero' and can be completed within a three-month period. All program plans can then be reviewed in the cross-departmental environment where each workgroup presents their program plans to be critiqued by the other groups. Plans are reviewed to assure that the objectives are clear, the curriculum strategies realistic, and the learning outcomes measurable. These sessions provide a vehicle for faculty to identify ways in which they could better collaborate across disciplines, for example, to create exciting new course offerings. These meetings also provide an additional opportunity to achieve uniformity among the program processes.

Task 2. Defining student learning outcomes

In addressing this second task, faculty may want to utilize our detailed specification of each EC 2000 outcome in terms of its possible attributes [4]. These specifications provide engineering educators with a framework for outcome definition. For each outcome, there is a menu of attributes arranged by increasing student learning level; faculty can then 'pick and choose' learning objectives at both the program level and course level. The complete Outcomes and Attributes set can be download from our website: www.engrng.pitt.edu/~ec2000.

Our framework is based upon Bloom's Taxonomy of Cognitive Domain [5], Krathwohl's Taxonomy of Affective Domain [6] and McBeath's Translation to Learning Outcomes [7]. We piloted these outcome attributes sets at the *1999 ASEE National Meeting* [8], refined them based upon feedback from faculty and subject experts, and then presented the current version at the *Best Assessment Practices III Workshop* (Rose-Hulman Institute of Technology) in April, 2000 [9]. An example of how the attributes can be used for assessment, in this case design, is given by Atman, Adams and Turns [10].

Task 3: Getting faculty involved: an assessment workshop

As noted, achieving faculty buy-in can be a major obstacle. One effective mechanism that we have used is an interactive workshop—'*A Baker's Dozen: Assessment Methods and Their Strengths and Weaknesses*'—that we developed. This workshop introduces administrators and faculty to various assessment methodologies within the educational context. The workshop, which has been presented in a variety of settings and to a variety of audiences, has four main goals:

- to familiarize attendees with various assessment methods that can be used to measure achievement of educational goals;
- to create a forum for discussing the pros and cons of each assessment method;
- to provide participants with assessment materials that they can use in their own educational environment;
- to initiate a discussion about assessment among peers.

The assessment techniques introduced in the workshop are adapted from Prus and Johnson's work [11] that catalogues a variety of assessment methods, provides brief definitions and includes a list of the advantages and disadvantages along with 'ways to reduce disadvantages.' A 'bottom line' on each assessment method is given. We have modified their list, added a section on each method's 'target' audience, provided examples of engineering applications for each method, given examples of instruments that can be used, and developed bibliographic references.

The list of assessment methods includes:

- norm-referenced, standardized examinations
- locally developed written examinations
- oral examinations
- performance appraisals
- simulations
- written surveys and questionnaires
- exit or other interviews
- focus groups
- external examiners
- behavioral observations
- archival records
- portfolios.

Our typical workshop is organized around a series of mini-lectures and structured group exercises. A short overview of the principles of assessment, emphasizing the importance of assessment as a complete process, is first provided. Participants are then divided into teams for a jigsaw exercise where each person is a member of both a 'specialist' team and a 'generalist' team. (A jigsaw is a teamwork exercise in which each team member becomes an expert for one part of the material, and then teaches each of the other team members that material.)

Each specialist team is given a handout on one or two of the assessment methods and spends approximately 30 minutes discussing the method with other 'specialists', learning as much as he/she can from the information provided and the peer discussion. The 'generalist' teams then convene. Since one person from each team has been assigned to a 'specialist' team for each method, each generalist team has members who are now 'expert' in each one of the methods examined. For the next 40 minutes, each specialist has a few minutes to educate his/her generalist team about the method(s). He or she then serves as the resource person on that method as the team works on a case study.

A second mini-lecture on setting measurable objectives may be included. After this, the 'generalist' teams are given a brief assessment case study. The content varies depending on the interests of the audience (e.g. ABET accreditation, project evaluation), but the idea is to give participants an opportunity to immediately apply the knowledge they have just gained.

The workshop concludes with a 'lessons learned' mini-lecture. For an audience interested in ABET, the concluding piece may focus on the assessment process from the eyes of an ABET evaluator. For a project assessment audience, the focus might be on examples of effective project evaluation. This format is relatively straightforward to use and works well with a knowledgeable facilitator and well-prepared summary sheets. We have used it for 15 to 125 participants.

Task 4. Identification of assessment methods—selected examples

As we point out through our workshop, there are many assessment methods, a number of which have been successfully used in other areas, available to engineering faculty. As a research team, we have been investigating several of these more promising methodologies. Below is a brief overview, including issues still to be resolved:

- *Multi-source feedback* using the *Team Developer*. This is a competency-based, computerized survey that can be used to assess both basic team skills and behaviors. We are currently using it to assess several EC 2000 learning outcomes. It does this by combining self/peer ratings to provide individual, team, and/or class feedback [12–14]. From our preliminary research, the *Team Developer* has proven to be both a reliable and valid instrument for measuring certain EC 2000 learning outcomes. It also serves as an intervention tool by providing students with feedback on areas that their team mates perceive are weak. This intervention function works best if the Team Developer is used two or three times over the semester. For example, one sophomore engineering student commented: 'The *Team Developer* was helpful because it identified areas where I needed to improve my teamwork skills. I addressed areas where I rated myself higher than my team rated me. I also learned to give myself a little more credit in areas where I rated myself lower than my team rated me.'
- *Reflective portfolios* hold the promise of providing a thorough outcome measurement. However, they are both costly to collect and then to accurately assess. They can be used to measure various EC 2000 outcomes including: 3b (design), 3d (teams), 3f (ethics), 3g (communications), 3h (societal), 3i (life-long learning),

and 3j (contemporary issues). An outstanding issue has been how to develop rubrics and other assessment measures that will allow cross-institutional evaluation of reflective portfolios. In addition, we need to determine the extent that portfolio collection and evaluation can be made both efficient and effective [15–20].

- *Intellectual development measurement* is based on William Perry's nine stages or positions from 'dualism' to 'commitment' [21]. This has been refined and validated by King and Kitchener's seven-stage Reflective Judgment model that focuses on 'relationship between epistemology and judgment at each point in the developmental sequence' [22]. *Cogito*, computer software to measure intellectual development, is being tested and refined. *Cogito* presents the student with a series of scenarios with response choices at various RJ levels. A neural network is used to score the responses. Currently in 'alpha stage', computer responses and in-depth interviews have been collected from over 100 subjects. *Cogito* holds the promise of being a valuable assessment tool if it can be demonstrated that its neural net and computer software, when fully developed, will closely approximate the results of a formal interview. Also to be determined is if curricula can be developed to foster intellectual development in students and enable them to reach the level of intellectual development at which professional engineers should/do function [23, 24].
- *Concept maps/concept learning.* Concepts are defined/understood in terms of their relationships to other concepts. These tools can provide a mechanism to assess students' ability to recognize and then make connections among important concepts. In this way we could track the growth of an individual as he/she progresses through the educational program and assess the achievement of targeted outcomes. The outstanding issue is how to score concept maps. The 'state-of-the-art' remains simplistic, that is, counting links. We are currently investigating several approaches to better 'score' maps and hence improve our understanding of how they can be used for outcome assessment [25–28].
- *Verbal protocol analysis (VPA)* is a behavioral observation method in which subjects solve problems while thinking aloud [29]. The resultant protocol is transcribed; the transcript is segmented into codable 'chunks' of subject statements; coded; and, after reliability checks, analyzed to answer specific research questions. VPA has been used to study engineering student design processes [30–35]. The methodology provides a very accurate, in-depth understanding of the process used by the student, and hence, is an important assessment tool. However, it is extremely costly and time consuming to administer. If it is to be widely used, more efficient ways of conducting VPAs will have to be determined.
- *Closed form questionnaires* are a practical method for evaluating student or alumni attitudes about engineering, aspects of their education, and their self-assessed abilities and competencies. They are less costly to develop, administer and analyze than other types of assessment methodologies, particularly if a large data set is being collected and if statistically reliable conclusions are desired. By limiting the response choices, data collection can be repeated over time. Thus, we can examine how attitudes are affected by particular interventions, change over time, or vary among groups of individuals. Like any valid method, a good closed-form questionnaire design requires considerable knowledge and skill if results are to be valid. We have developed closed-form questionnaires at both the student and post-graduation level. These questionnaires are designed to measure: engineering related attitudes; preparedness in knowledge and communication skills; attitudes about studying, working in groups and personal abilities; confidence in engineering outcomes (freshman, sophomore and junior); and pre-professional experiences (junior and senior), in addition to obtaining graduate education and employment information (senior). In addition, an alumni survey measures: overall ratings about the program and school; competence in engineering outcomes; and alumni's critique on curriculum, culture, in-class instruction, learning through experience, university support, and self as student. Our Pittsburgh Freshman Engineering Attitudes Survey (PFEAS) has been used by over 25 engineering colleges and the sophomore and junior instruments are now being exported, using a web-based system as described below. We are using questionnaires to track changes in students' self-assessed confidence and capabilities as they matriculate through the curriculum. In addition we are investigating how to better deal with missing data (individual and cohort); estimate underlying distributions; and predict certain outcomes, for example, attrition, probation, and math placement. We are also examining the issue of the accuracy of inferences made from ordinal data and investigating the use of Bonferroni adjustment for Type I errors. Finally we are examining the efficacy of web-based questionnaires [36–41].

The assessment of student learning must be tailored to match the information needs of the educators who are designing and delivering the learning experience. Here we describe examples of situations where we have chosen or developed assessment tools to meet specific needs. Two examples are at the course level, and the other two are at the program level.

The **first example** is described in detail in another paper in this issue [42]. Here we assessed a unique international learning experience at the

University of Washington (UW) where student teams from both the UW and Tohoku University in Japan worked with faculty members on an engineering research project that was offered in the fall of 1999. The course was developed to introduce college freshmen to international collaboration in engineering design. The goal of the assessment in this study was to understand ways in which freshmen engineering students learn in both a group and international cooperative setting. There was little in the literature for course developers to draw upon in designing this novel learning experience. Hence, part of the assessment work needed to include a descriptive understanding of what students would learn from the course.

By necessity, the assessment included a large amount of descriptive information about what the students experienced so that the faculty developing the course could understand how to interpret student feedback. A detailed description of the assessment methods used is provided elsewhere [43]. We decided to invest a large amount of time by conducting both an observational study of two class project teams and in-depth interviews with all eight project teams, faculty and graduate students involved in the course. This extensive descriptive data was augmented with information obtained with the PFEAS© attitude survey (described above) and closed-ended questions. The information obtained through this in-depth assessment was provided as feedback to the instructors for use in the design and delivery of instruction in the subsequent offering of the course (Fall 2000). The assessment of that offering was scaled back from the previous level of effort. We designed a new version of the questionnaire to obtain information that was previously learned from the observational study. We also conducted interviews with a subset of the students and faculty to obtain more insight into the questionnaire results. It is likely that future offerings of the course can be assessed using the questionnaire alone.

The **second example** is for a more traditional freshman level engineering design course (described in more detail in [44]). Here students at the UW engaged in four hands-on engineering design projects in the fall of 1999. The faculty who taught the course and a team of evaluators applied the design attribute framework (discussed earlier in this paper) to describe the learning objectives for each of the four projects. The assessment goal for this work was much more specific than in the previous example. In this instance, the course instructors wanted to know if student confidence in design learning outcomes matched the instructor's assessment of student learning. Utilizing the design attribute framework, a questionnaire was developed and administered to both students and faculty. The results showed that there was substantial agreement between the two groups for 10 of the 13 outcomes. The differences in the three remaining outcomes were addressed in the design of the next offering of the class.

In the **third example** we discuss assessment at the program level in which we have been following three cohorts of students. The first two cohorts consist of University of Pittsburgh industrial engineering students who we are tracking over three semesters (first semester sophomore through first semester junior year). We are specifically targeting three EC 2000 outcomes:

- 'e', an ability to identify, formulate and solve engineering problems;
- 'd', an ability to function on multi-disciplinary teams;
- 'g', an ability to communicate effectively [45].

To do this we are using:

- The Pittsburgh Engineering Attitudes Surveys (freshman, sophomore, junior and senior) to measure the effect of self-reflection and metacognitive skills development on student attitudes about their education and chosen profession [46].
- CSM's *Cogito* software and Reflective Judgment interviews to measure the effect of self-reflection on intellectual development [47, 48] of undergraduate engineering students [49, 50].
- Concept maps to measure how students' views of their profession incorporate the outcomes listed above [51].
- Multi-source feedback instruments, particularly the *Team Developer* to also examine gender and learning style issues that may effect team performance. This part of the methodological development also involves Columbia University [52–54].

Part of the study is being replicated at the Colorado School of Mines (CSM) with a third cohort of students from the McBride Honors Program, a seven-semester minor in public affairs for CSM engineering students. Here, portfolios are being used in place of multi-source feedback. By using portfolios, we will be able to obtain 'anchor' outcome measures that can then be used to assess the efficacy of our other measures. McBride students prepare reflective portfolios during each of their seven semesters in the program. Student entries are assessed for evidence of development in each of the outcomes of interest. Rubrics to complete these assessments are being developed and validated as part of this 'triangulation experiment'. (In 'triangulation' we use multiple assessment methodologies to measure specific undergraduate outcomes on defined student cohorts. Because we currently lack a true measure or *anchor metric* for EC 2000 outcomes, triangulation is a necessary assessment step. Consequently, almost all measures will serve as surrogates for the 'true' measure. By triangulating, our aim is to build upon the strength of each method while minimizing the weaknesses of a single method.) As part of this study, we want to assess the relative efficacy of intellectual development measures using computer software, attitudinal surveys, and concept map techniques and to determine how best to gather quantitative and qualitative assessment data on engineering students.

Our **fourth example** involves a second triangulation study that investigates the use of reflective portfolios at two institutions—Colorado School of Mines and the Rose-Hulman Institute of Technology (RHIT). In this experiment we are developing assessment methods and tools to focus on five important but difficult to measure 'professional' outcomes of undergraduate engineering education:

- life-long learning
- communication
- global and societal issues
- contemporary issues
- professional ethics.

Here, we are addressing the following issues:

- Relative efficacy of different modes of reflective portfolios (paper and electronic).
- Efficacy of rubrics to score portfolios and assess the five outcomes listed above.

Additional assessment measures will be used to collect triangulation data that will be correlated with results from rubric assessment of the portfolios. The reflective portfolio assessment system for the CSM McBride honors students was described above. At Rose-Hulman, first-year students have been introduced to the RosE-Portfolio since 1998. RHIT students are asked to make portfolio submissions of their choice that they believe best demonstrate their progress toward specific learning outcomes. For each submission, they must write a 'reflective statement' that tells the reader why they believe it meets the specific learning outcome.

Faculty rate the reflective statements in two ways:

1. Does the reflective statement indicate that the student understands the criterion?
2. Does the student make a convincing argument that the submission is relevant to the criterion?

Because students' performance in writing reflective statements has been disappointing, the 2000 first-year class is given a one-hour training session on the value and importance of reflection and guided experience writing reflective statements [55].

Task 5: Using information technologies for data capture and presentation

A final task would involve encompassing the entire process in an on-line system to first collect, analyze, and then disseminate the resultant information so it can be readily applied for program and course improvement. While such a system has yet to appear, we have begun the process. Here are two examples.

- Columbia University's Fu Foundation School of Engineering and Applied Science (SEAS) team members have developed the Web Course Evaluation System (WCES), a web-enabled application that allows faculty to customize surveys to the objectives of a specific course. Students complete these surveys at their convenience. Data are easily coordinated with the institution's existing information and administrative system via a file transfer with the registrar's office. Reports are produced for students, faculty, and administration in a timely manner for curricula improvement. The current WCES has several important features: providing a measurement of core questions on course and faculty quality; allowing faculty to add course-specific questions either created by them or selected from a library of EC 2000-specific items; and generating timely feedback reports to all constituents. First, the current web-enhanced course evaluation system (WCES) is designed to measure a core set of questions for all SEAS courses. These are questions that SEAS faculty and administration have agreed upon so the results can be reviewed each year and on a longitudinal basis. Second, SEAS faculty can add their own scaled questions and open-ended questions based on specific course learning objectives and intended outcomes. We also have provided a library of EC 2000 items from which they can select as applicable for the course in question. Students then can go to the WCES website and complete evaluations for each of their registered courses. Third, once the evaluation period is over, survey results are immediately e-mailed to each faculty member, with summary information sent to department chairs and dean's office. The faculty report includes the student response rate, quantitative ratings of core and custom questions, and qualitative comments. The system also provides faculty with a systematic mechanism to document what improvement actions they plan to take based on the results of the course evaluations. These improvement plans become part of an on-going process to monitor actions taken and their subsequent impact as measured via future course evaluations. The summary reports provide department chairs and deans with aggregate survey data by department and faculty member. In addition, the students' website provides all students with final ratings for the course (but not the comments). WCES is designed to provide all relevant constituents with feedback regarding the course in a very timely manner—a major benefit of the system.
- The University of Pittsburgh's *On-line Student Survey System* (OS^3) is another example of an assessment tool that we have recently developed and that is currently being used by seven universities. By utilizing the Java programming language, an Oracle database management system and e-mail, we have developed an infrastructure for assessment that incorporates the series of integrated, student attitude surveys

described above (e.g., freshman pre- and post-sophomore, junior, senior exit and alumni) for outcome measurement. These surveys can be made available via the web to students anywhere with Internet access under the guidance of a local administrator who can then download the data for benchmarking and research purposes. Hence, student outcome data can be shared with faculty during key points throughout the student's academic experience, thus allowing more effective curriculum planning decisions [56, 57]. We are adding a reporting mechanism to the OS^3 that performs a 'strength and weakness' analysis for visualizing the results as well as being an input source to our data warehouse. Our methodology, the *Pitt-SW Analysis* [58], is an adaptation of the competitive strategy principle of SWOT (strength, weakness, opportunities and threats) [59, 60]. It can be used to efficiently reduce survey data to a format that facilitates quick and accurate faculty feedback as part of an EC 2000 continuous improvement process. The methodology consists of four steps—data collection, data summarization, display of proportions, and construction of a strengths and weakness (SW) table by the application of rules that reflect the desired sensitivity of the methodology. The results of the SW table can be displayed graphically using basic symbols to highlight and track changes in students' perceptions. In this way, student progress towards meeting the program's EC 2000 objectives can be monitored and fed back to faculty. We have tested the method using 1999 and 2000 academic year data to track four student cohorts. The results have been highly consistent and indicate the usefulness of this methodology to efficiently measure student performance. Utilizing a 'strengths and weaknesses' analysis approach, a series of reports provides faculty with critical information and feedback in order to determine areas for improvement.

As part of the design of any assessment process, how the results will be used should be well specified. The formal design process must include:

- who will receive final reports,
- what types of decisions can be handled based on the results provided,
- plans for follow-up actions,
- timelines for these future actions.

CONCLUSIONS

This paper provides the reader with a structured framework for approaching EC 2000 accreditation including objective-setting, an extensive attribute database for use in defining student learning outcomes, selected methodologies, and examples of technology-enabled systems that provide timely information to all constituents.

Clearly, EC 2000 has created a need for valid assessment methodologies that can be applied to engineering education programs across a broad spectrum of settings. Further, as discussed above, there is a relatively diverse array of assessment methodologies that should be applicable to engineering, many of which have been developed and successfully applied in other settings. However, before applying one or more of these assessment methodologies to the eleven EC 2000 outcomes ('3a–k'), several major challenges must be addressed.

First, each program must achieve faculty consensus on the meaning and translation of the outcomes. This is not an easy task. A structured process must be applied in order to ensure that all faculty have the opportunity to provide input, and generally, participate in relevant decisions. Second, the desired outcomes must be converted into useful metrics for assessment. The ABET outcomes are vague by intent in order to encourage individual programs to distinguish themselves by the education they provided. Although this has given engineering faculty the flexibility and opportunity to satisfy 'customer needs', the task of outcome definition has proven to be both substantive and often overwhelming. Further, the context in which each outcome is used impacts its definition. Our outcome attribute framework with its high level of specificity should serve as a valuable resource for tailoring EC 2000 to meet individual programmatic needs. Each outcome has been thoroughly researched and divided into a comprehensive, ordered set of attributes using a consistent framework. In this manner we have presented engineering educators with a 'buffet of attributes' from which they can select and use in the measurement of either courses or programs.

Having defined the outcomes and selected attributes, a third challenge is assessing the validity of the various methods. To do this in an effective manner, we are using a triangulation process. The purpose of triangulation in assessment is to provide multiple measures for a particular outcome. In this way, we learn the extent to which the various methods corroborate each other, and how effective each is. We also see where they give conflicting results, a situation that would clearly call for further analysis. For example, the 'ability to work on multi-disciplinary teams' may be assessed in the following ways: student's own self assessment of their enjoyment for working on teams via closed-form questionnaires; ratings of a student's peers on a team; or direct observation of a team by a trained evaluator. Using triangulation, all three methods would be applied. Ideally, this would be across two or more institutions, resulting in a more thorough validation. Because many of the methods and instruments currently being used in engineering education have not been fully validated in terms of content or construct, triangulation provides one means for increasing the validity of measuring the outcomes. In addition, a metric/method that adequately measures a particular outcome in question may not currently exist. By triangulating the methods and metrics, one obtains multiple surrogates for the real measure of the outcome, thus providing a much needed anchor measure where none exists.

Once triangulation results have been obtained, the various metrics can be correlated and statistically compared. If sufficient correlation exists among the metrics, then certain ones may be eliminated. Consequently, those metrics/measures that are efficient and cost effective would be used to routinely assess students' progress on an outcome(s) basis. The more in-depth, and often more costly metrics would be used only periodically or with a sample of the students. This approach helps to minimize costs, and also provides a streamlined approach towards program evaluation.

Finally, there is a need to expand exploration on how information technologies can support the validity and effectiveness of comprehensive assessment programs in the university environment. From our early experience, we believe that technology is a key enabler aiding institutions to effectively collect, analyze, report, and apply results to the benefit of all constituents.

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REFERENCES

1. ABET, *Engineering Criteria 2000 Third Edition: Criteria for Accrediting Programs in Engineering in the United States*, The Accreditation Board for Engineering and Technology Baltimore, Maryland (1997). http://www.abet.org/EAC/eac2000.html
2. J. McGourty, Four integrated strategies to embed assessment into the engineering educational environment, *J. Eng. Ed.*, **88**, pp. 391–296, (1999).
3. J. McGourty, *Departmental and Course Workbooks: Defining Program and Course Objectives*, Gateway Coalition. http://www.gatewaycoalition.org.
4. M. E. Besterfield-Sacre, L. J. Shuman, H. Wolfe, C. J. Atman, J. McGourty, R. L. Miller, B. M. Olds and G. Rogers, 'Defining the outcomes: a framework for EC 2000, *IEEE. Eng. Ed.*, **43**(2), pp. 100–110 (2000).
5. B. S. Bloom, M. D. Englehart, E. J. Furst, W. H. Hill and D. R. Krathwohl, *Taxonomy of Educational Objectives: Handbook 1: Cognitive Domain*, New York: Longman, (1956).
6. D. R. Krathwohl, B. S. Bloom and B. B. Masia, *Taxonomy of Educational Objectives: The Classification of Educational Goals Handbook II: Affective Domain*, New York: McKay Company, Inc. (1956).
7. R. McBeath, Ed., *Instructing and Evaluation in Higher Education: A Guidebook for Planning Learning Outcomes*, Education Technology Publications, Inc., (1992).
8. M. E. Besterfield-Sacre, chair, Try this! Ideas for assessment, *1999 ASEE Annual Conference*, Special Session 2330, Charlotte, NC, (1999).
9. M. E. Besterfield-Sacre, L. J. Shuman, H. Wolfe, C. J. Atman, J. McGourty, R. L. Miller and B. Olds, *EC 2000 Outcome Attributes: Definition and Use; Best Assessment Processes III*, Rose-Hulman Institute of Technology, (2000).
10. C. J. Atman, R. S. Adams and J. Turns, Using multiple methods to evaluate a freshmen design course, *Proc. Frontiers in Education Conference 2000*, Kansas City, MO (2000).
11. J. Prus and R. Johnson, Assessment & testing myths and realities, *New Directions for Community Colleges*, 88 (Winter), (1994).
12. J. McGourty and K. De Meuse, *The Team Developer: An Assessment and Skill Building Program*, Wiley, New York, (2000).
13. J. McGourty, C. Sebastian and W. Swart, Development of a comprehensive assessment program in engineering education, *J. Eng. Ed.*, **87**, pp. 355–361 (1998).
14. J. McGourty, Using multisource feedback in the classroom: a computer-based approach, *IEEE T. Eng. Ed.*, **43**(2), pp. 120–124, (2000).
15. B. M. Olds, *Using Portfolios to Assess Student Writing. Proceedings of the 1997 ASEE National Conference*, Milwaukee, Wisconsin, (1997).
16. P. Belanoff and M. Dickson, eds., *Portfolios: Process and Product*, Boynton/Cook, Portsmouth, NH (1991).
17. K. Yancy, ed., *Portfolios in the Writing Classroom*, NCTE, Champaign-Urbana, Illinois, (1992).
18. B. S. Sunstein and J. B. Cheville, eds., Assessing portfolios: a portfolio, *Iowa English Bulletin*, Iowa Council of Teachers of English and Language Arts, (1995).
19. K. B. Yancy and I. Weiser, eds., *Situating Portfolios: Four Perspectives*, Utah State U Press, Salt Lake City (1997).
20. G. Rogers and T. Chow, Electronic portfolios and the assessment of student learning, *Assessment Update*, **12**(1), pp. 4–6, 11, Jossey-Bass, San Francisco (2000).
21. W. G. Perry, Jr., *Forms of Intellectual and Ethical Development in the College Years*, Holt, New York (1970).
22. P. M. King and K. S. Kitchener, *Developing Reflective Judgment*, Jossey-Bass, San Francisco (1994).
23. M. J. Pavelich and W. S. Moore, Measuring the effect of experiential education using the Perry Model, *J. Eng. Ed.*, **85**, p. 287 (1996).
24. B. M. Olds, R. L. Miller and M. J. Pavelich, Measuring the intellectual development of engineering students using intelligent assessment software, *Proc. ICEE 2000*, Taipei, Taiwan (2000).
25. T. A. Angelo and K. P. Cross, *Classroom Assessment Techniques: A Handbook for College Teachers*, 2nd ed. Jossey-Bass, San Francisco (1993).

26. J. Novak, Concept Mapping: A useful tool for science education, *J. Res. Science Teaching*, **27**, p. 937 (1990).
27. K. M. Markham, J. J. Mintzes and M. G. Jones, The concept map as a research and evaluation tool: further evidence of validity, *J. R. Science Teaching*, **31**, p. 91 (1994).
28. J. Turns, C. J. Atman and R. Adams, Concept maps for engineering education: a cognitively motivated tool supporting varied assessment functions, *IEEE T. Eng. Ed.*, **43**(2), pp. 164–173 (2000).
29. K. A. Ericsson and H. A. Simon, *Protocol Analysis: Verbal Reports as Data*, MIT Press, Cambridge (1993).
30. C. J. Atman. and K. M. Bursic, Teaching engineering design: can reading a textbook make a difference? *Research in Engineering Design*, **8**, pp. 240–250 (1996).
31. J. R. Chimka, C. J. Atman and K. M. Bursic, Describing student design behavior, *Amer. Soc. Eng. Ed. Conf. Proc.*, (1997).
32. K A, Ericsson and HA Simon, *Protocol Analysis: Verbal Reports as Data*, The MIT Press, Cambridge, Massachusetts, (1993).
33. C. J. Atman and K. M. Bursic, Documenting a process: the use of verbal protocol analysis to study engineering student design, *J. Eng. Ed.*, **87**(3), pp. 121–132 (1998).
34. C. J. Atman, J. R. Chimka, K. M. Bursic and H. L. Nachtmann, A comparison of freshman and senior engineering design processes, *Design Studies*, **20**(2), pp. 131–152 (1999).
35. C. J. Atman and J. Turns, in *Studying Engineering Design Learning: Four Verbal Protocol Studies, in Design Knowing and Learning: Cognition in Design Education*, C. Eastman, M. McCracken and W. Newstetter, eds., Elsevier, New York (2001).
36. M. E. Besterfield-Sacre, C. J. Atman and L. J. Shuman, Engineering student attitudes assessment, *J. Eng. Ed.*, **87**(2), pp. 133–141 (1998).
37. M. E. Besterfield-Sacre, C. J. Atman and L. J. Shuman, Characteristics of freshman engineering students: models for determining attrition in engineering, *J. Eng. Ed.*, **86**(2), pp. 139–149 (1997).
38. M. E. Besterfield-Sacre, C. J. Atman, L. J. Shuman and H. Wolfe, Three approaches to outcomes assessment: questionnaires, protocols and empirical modeling, *1997 Amer. Soc. Eng. Ed. Conf. Proc.*, (1997).
39. M. E. Besterfield-Sacre, C. J. Atman, L. J. Shuman and H. Wolfe, Development of Customer-Based Outcome Measures for an Engineering Program, *Proc. 1997 Amer. Soc. Eng. Ed. Conf.*, (1997).
40. M. E. Besterfield-Sacre, C. J. Atman, L. J. Shuman, R. L. Porter, R. M. Felder and H. Fuller, Changes in freshman engineers' attitudes—a cross institutional comparison of what makes a difference, *1996 FIE Conf. Proc.*, Salt Lake City (1996).
41. J. R. Chimka, H. Wolfe and M. E. Besterfield-Sacre, Ordered Logit Modeling of Likert Scale Indications for outcomes assessment, *Proc. Industrial Engineering Research 2000 Conf.*, Cleveland, Ohio (2000).
42. R. S. Adams, R. Nakamura, C. J. Atman, G. Kalonji and D. Denton, Assessment of an international freshmen research and design experience: a triangulation study, *Int. J. Eng. Educ.*, forthcoming.
43. C. J. Atman, R. S. Adams and J. Turns, Using multiple methods to evaluate a freshmen design course, *Proc. Frontiers in Education Conf. 2000*, Kansas City, Missouri (2000).
44. M. J. Safoutin, C. J. Atman, R. Adams, T. Rutar, J. C. Kramlich and J. L. Fridley, A design attribute framework for course planning and learning assessment, *IEEE Trans. Eng. Educ.*, **43**(2), pp. 188–199 (2000).
45. M. E. Besterfield-Sacre, L. J. Shuman, H. Wolfe and J. McGourty, Triangulating assessments: multi-source feedback systems and closed form surveys, *Proc. ASEE National Meeting*, St. Louis, Missouri (2000).
46. M. E. Besterfield-Sacre, C. J. Atman and L. J. Shuman, (1998).
47. W. G. Perry, (1970).
48. P. M. King and K. S. Kitchener, (1994).
49. R. L. Miller, B. M. Olds and M. J. Pavelich, Using computer software to assess the intellectual development of engineering students, *Proc. Frontiers in Education 1999*, San Juan, Puerto Rico (1999).
50. B. M. Olds, R. L. Miller and M. J. Pavelich, (2000).
51. J. Turns, C. J. Atman and R. Adams, (2000).
52. J. McGourty, P. Dominick, M. E. Besterfield-Sacre, L. J. Shuman and H. Wolfe, Improving student learning through the use of multi-source assessment and feedback, *Proc. Frontiers in Education 2000*, Kansas City, Missouri (2000).
53. J. McGourty, (2000).
54. J. McGourty and K. De Meuse, *The Team Developer: An Assessment and Skill Building Program*, New York: J. Wiley and Company (2000).
55. G. Rogers and T. Chow, (2000).
56. R. Hoare, M. E. Besterfield-Sacre, L. J. Shuman, R. Shields and T. Johnson, Cross-institutional assessment with a customized web-based survey system, *Proc. Frontiers in Education 2001*, Reno, Nevada (2001).
57. J. McGourty, L. J. Shuman, M. E. Besterfield-Sacre, R. Hoare, H. Wolfe, B. M. Olds and R. L. Miller, Using technology to enhance outcome assessment in engineering education, *Proc. Frontiers in Education* (2001).
58. G. L. Perez, L. J. Shuman, H. Wolfe and M. E. Besterfield-Sacre, Measuring continuous improvement in engineering education programs: a graphical approach, *Proc. ASEE National Meeting, Albuquerque, New Mexico* (2001).
59. R. Balamuralikrishna and J. C. Dugger, SWOT analysis: a management tool for initiating new programs in vocational schools, *J. Vocational and Technical Education*, **12**(2) (1999).
60. P. Kotler, *Marketing Management: Analysis, Planning, Implementation and Control*, Ninth Edition, Prentice-Hall (1996).

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