Defining the Outcomes: A Framework for EC-2000

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***Abstract*—The "new" Accreditation Board for Engineering and Technology criteria, EC-2000, has caused engineering educators to focus on 11 intentionally undefined outcomes as a necessary step in the accreditation process. As part of a large study sponsored by the National Science Foundation, a framework, based on Bloom's taxonomy, has been developed for better specifying these outcomes. Using this framework, each outcome has been expanded into a set of attributes that can then be used by engineering faculty in adapting the outcomes to their own program. Also discussed are two ways in which this characterization of outcomes can be used as part of an assessment and feedback process. These outcome definitions are considered to be in a dynamic state; i.e., they will continue to be modified and updated as more is learned about their specificity and use. Interested readers may download the most recent set of outcomes from the project website.**

***Index Terms*—Accreditation Board for Engineering and Technology (ABET), accreditation, assessment, EC-2000, outcomes.**

I. Introduction

SINCE 1995, when the "new" Accreditation Board for Engineering and Technology (ABET) criteria, EC-2000, were first proposed, there has been considerable discussion about engineering education outcomes, especially the minimum set of 11 student learning outcomes that are a major part of EC-2000 [1], [2]. While engineering educators are embracing, although often with trepidation, the substantial changes set forth by ABET, there is much concern as to how to best operationalize each outcome for use within one's own institution. By intent, the outcomes—or "3a–k," as they are euphemistically known—were left unspecified, further contributing to this sense of concern. The purpose here is to assist faculty by presenting a framework with supporting documentation that will enable individual programs to achieve specificity in an informed, systematic manner. In particular, as part of a large research study funded by the National Science Foundation (NSF), each outcome has been characterized by a set of attributes whose organization is based in part on Bloom's taxonomy [3]. This paper describes the process for arriving at these outcome specifications and provides examples of how they can be used.

In an earlier paper [4], the authors posed the following question: In the initial desire to satisfy the new criteria, have we become too captivated with the process, as witnessed by the proliferation of continuous improvement (e.g., plan–do–act–check) models that describe the "ideal" educational path [5]–[8]? Such models have exposed engineering faculty to a cycle in which the educational process is first defined, measured, compared to desired criteria or standards, and subsequently improved, and then the cycle is repeated. We asked: In rushing to adopt this "cycle," have we overlooked an important step—to comprehensively examine the meaning of these learning outcomes and hypothesize how our focus on each may result in an improved educational environment?

To date, approximately 60 engineering schools have undergone EC-2000 reviews, with the majority occurring during the 1999–2000 cycle. Clearly, it is time to establish a foundation for these learning outcomes before too many more institutions proceed through EC-2000. The purpose of this paper is to demonstrate to the engineering educational community how institutions can capitalize on EC-2000 to reform their educational process by supporting the specification of these (and other) critical learning outcomes.

Reform is not a new concept to engineering education. For the past ten years, six coalitions involving more than 60 institutions have attempted to revolutionize engineering education. Now, as the coalitions wind down their activities, a final evaluation may conclude that the desired changes in institutional culture tend to occur through evolution, not revolution. Just as educational reform takes time, developing real knowledge and competency, as denoted by the 11 outcomes, also takes time since individual intellectual growth is an evolutionary process.

II. What are Student Learning Outcomes?

Defining student learning outcomes depends on the educational perspective. The term "student learning outcome" is similar to certain constructs such as educational objectives [9], competencies [10], skills [11] or achievement [12]. The similarity of these key terms has led to confusion among faculty and administrators as they focus on such reform initiatives as "outcomes-driven assessment," "competency-based curriculum," and "ability-based learning." As a result, engineering educators have initiated reform actions assuming the nature of the construct without really exploring its underlying meaning. There are two issues to address when defining student learning outcomes: 1) the breadth of the construct and 2) the level of specificity.

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A. Breadth of Construct

One dilemma that educators have in accepting the outcomes construct is defining its limits; i.e., what it will encompass. Nichols [13] points out that the "intended educational (student) outcomes are descriptions of what academic departments (faculty) want students to know (cognitive), think (attitudinal), or do (behavioral) when they have completed their degree programs, as well as their general education or 'core' curricula." The inclusion of these three elements alone greatly increases the breadth of the construct. Here, each of these elements—cognitive, attitudinal, and behavioral—has substantial value and must be explored further.

Krotseng and Pike [14] note that most universities relate cognitive outcomes to what the student learns in general; i.e., the "core" education courses in their academic major as well as such basic skills as writing or oral communications. With the exception of these basic skills, cognitive outcomes are commonly related to knowledge acquisition. In addition, researchers acknowledge that there is increasing attention among educators (including engineering educators) to such higher ordered cognitive skills as critical thinking [15]. The 11 ABET learning outcomes appear to cut across all three elements. For example, "knowledge of contemporary issues" (outcome "j") is a straightforward reference to knowledge acquisition. "An ability to identify, formulate, and solve engineering problems" ("e") can refer to higher ordered thinking skills, while "an ability to use the techniques, skills, and modern engineering tools" ("k") directly implies a skill orientation.

The measurement of student attitudinal-related outcomes provides considerable information on the effectiveness of an academic program [16], [17]. Most attitude measurements are focused on how students' attitudes, including their state of mind and values, are related to institutional-level performance and effectiveness. This is typically accomplished using closed-form questionnaires, one-on-one interviews, and/or focus groups. The results are usually analyzed at an institutional level and are only occasionally applied at the individual or small group level. However, as Besterfield-Sacre *et al.* have demonstrated, student perceptions of their abilities can influence one's subsequent learning as well as such important institutional objectives as retention [18]. Although the EC-2000 outcomes do not explicitly incorporate the concept of "feelings" within their construction, they do advocate a need for "valuation" [19] of certain aspects of the engineering profession. This "valuation" requirement is delineated by several outcomes (e.g., "professional and ethical responsibility," "the impact of engineering solutions in a global and societal context," and "life-long learning").

Behavioral-related outcomes have become increasingly common in the classroom [20]. These can be defined as an individual's action or reaction to either an external or an internal stimulus. In the engineering context, behavior is seen as the manifestation (i.e., application) of what the student has learned through an educational intervention. In essence, behavioral aspects are those skills engineering students possess. A faculty member or co-op employer can readily observe the student's application of knowledge that has been transmitted through the educational process. By adding this element to the construct, a critical aspect is being postulated: Knowledge must not only be acquired but also be applied in relevant situations.

The integration of these three key elements (cognitive, attitudinal, and behavioral) provides a comprehensive approach to defining a specific learning outcome. Further, true learning outcomes are a demonstration that knowledge does not exist apart from application. In fact, the two are tightly coupled. The attitudinal element indicates that the individual not only is capable of doing "engineering work" but also embodies values of the profession.

B. Level of Specificity

It is proposed that student learning outcomes can be described or specified in terms of sets of attributes. However, such descriptions may vary greatly. Certain outcome descriptions are very general and holistic using such words as "understanding," "comprehending," and "applying." Others are more focused with descriptors such as "synthesizing," "organizing," and "enumerating." The EC-2000 learning outcomes meet the former criteria and, by design, appear as vaguely constructed statements to encourage each engineering program's faculty to add its own, hopefully unique specificity. This flexibility reflects a sensitivity on ABET's part to the importance of differing institutional missions and programs. Hence, the 11 outcomes serve as a foundation for all engineering programs, but each program must then define itself by adding its own specificity to the outcomes.

This lack of construct specificity poses several problems. First, faculty consensus is required if successful implementation is to follow. This consensus must encompass definitions, performance criteria, and assessment processes. Faculty consensus is also required for both vertical integration within a program and horizontal integration across all the institution's engineering programs. If faculty cannot make connections across courses, it will be difficult to transfer knowledge, behavior, and attitudes across the curriculum [21]. Second, to properly recast each outcome into measurable descriptions that will result in usable assessment results requires sufficient expertise, resources, and time. For many engineering faculty, this is often a cumbersome first step in the overall preparation for the new criteria.

Hence, an operational definition of student learning outcomes (relevant to engineering education) is needed to properly evaluate engineering programs. It is proposed that *student learning outcomes are observable and measurable manifestations of applied knowledge*. That is, true learning is reflected through the action and behavior of the individual. The cognitive processes or attitudes of individuals cannot be separated from their behavior and attitudes. In fact, true learning cannot be measured without observable behavior. Each of the EC-2000 learning outcomes must reflect the integration of the cognitive and behavioral—the knowing and doing. It is not enough to have "knowledge of contemporary issues." The individual must be able to demonstrate that this knowledge can be applied as one encounters new problems and attempts to achieve solutions (whether in engineering or in another context).

III. An Initial Step: Development of Attribute Lists

A working definition for student learning outcomes has been developed. Using this, the next step is to operationalize each EC-2000 outcome with respect to its key elements. By operationalizing the outcomes into sets of measurable attributes, engineering faculty can more systematically address curricular planning and classroom learning. However, providing construct specificity to the outcomes in this way is not straightforward. Under NSF funding the authors have begun to address this challenge by developing a set of measurable attributes for each outcome using an educational framework.

The objectives in creating the outcomes/attribute lists are twofold. The first is to develop a comprehensive list of attributes for each outcome arranged (to some extent) by desired level of student achievement. This would provide engineering educators who wish to develop specific student learning outcomes for a course or program with a "buffet" of attributes from which to choose. The second is to assure that the attributes are measurable so that they may more easily be incorporated into assessment instruments and protocols.

This section is divided into three areas. The first discusses the various literature and resources that were used to derive attributes for each of the eleven outcomes. Next, an explanation of the framework, which is based on Bloom's taxonomy in order to delineate the outcome attributes, is given. Finally, a worked example is provided to demonstrate how an outcome/attribute list was derived.

A. Outcome Research

The project team consists of researchers with a wide range of expertise in evaluation and assessment methodologies [22] as well as in engineering ethics [23], design [24], communications [25]; and multisource (self and peer) classroom feedback methods [20]. Each attribute set was first hypothesized and then refined, using the relevant literature on the particular outcome, interviews with engineering faculty and/or industry practitioners, and the collective experience of the researchers. The archival engineering education literature, related literature from other areas of education, and Web sites that focus on engineering education (e.g.; measurement of outcomes, EC-2000, etc.) were examined. In addition, traditional engineering textbooks and complementary literature were sought depending on the outcome in question. The goal of the literature review was to produce an extensive list of possible attributes. While the outcomes are considered relatively "complete" at this point, they are not static. Rather, it is anticipated that they will be updated and revised as engineering educators gain more experience with EC-2000.[1]

B. Outcome/Attribute Framework

Early on, it was apparent that the specification of the various outcomes would result in each having a large set of attributes. Hence, a consistent framework for organizing each outcome's attributes while maintaining consistency across all 11 was needed. Expanding upon Nichols' cognitive, attitudinal, and behavioral components in combination with the general taxonomy presented by Bloom formed the basis for the framework. Bloom's taxonomy is based on six levels of the cognitive domain: knowledge, comprehension, application, analysis, synthesis, and evaluation. In addition to these levels of cognition, an affective domain described by Krathwohl [19] as valuation was added. Outcome elements and associated attributes were then expanded within each of the seven levels. These seven components parallel the three broad categories specified by Nichols: 1) knowledge and comprehension (cognitive); 2) application, analysis, synthesis, and evaluation (behavioral); and 3) valuation (attitudinal). McBeath's action verbs associated with each Bloom level [26] were then used to translate the attributes into learning outcomes and thus make the attribute easier to measure. This process is defined as "characterizing the outcomes." The definitions for the cognitive and affective components of the framework along with the respective learning verbs are presented in Table I.

Caveat Emptor: The use of Bloom's taxonomy is promoted with caution since both its hierarchical and cumulative nature and its use as a learning theory have not been validated. Under the assumption that Bloom's is a learning taxonomy, a student would have to acquire all the knowledge about the outcome before he or she could apply it. However, to paraphrase a famous jazz musician, "I can recognize jazz" (comprehension) and "play jazz" (application), "but I cannot define jazz" (knowledge). Although there may be areas within an outcome where the attributes are "cumulative" in nature, such that the accomplishment of one attribute is correlated with being able to demonstrate a preceding attribute, in general, the attributes presented in the framework may be considered independent of the others. In publishing the taxonomy, Bloom and his colleagues acknowledged the possibility of ambiguities in the sequencing of categories. Hence faculty are cautioned from adopting the taxonomy without first considering its ramifications and limitations. It can provide a guide, but it should not be used to track detailed student learning across its levels. Also, note that there is not a unique mapping of action verbs into Bloom levels; consequently, certain verbs may appear within more than one level.

C. Specifying the Outcomes

As noted above, Bloom's taxonomy is used as the basis for a framework that helps describe and organize the individual attributes. The use of the Bloom's and Krathwohl's explanation of cognitive and affective domains can be very helpful in facilitating discussion among engineering educators about the outcomes and their associated attributes. In addition, there is some literature that links the Bloom's taxonomy to assessment methods. For example, one can directly measure knowledge by using true/false and multiple-choice questions on exams.

For most of the outcomes, the literature research approach was straightforward, and the outcome could be subdivided into components with minimal controversy. For example, the outcome "design and conduct experiments, as well as analyze and interpret data" was broken down into four discrete elements: "designing experiments," "conducting experiments," "analyzing data," and "interpreting data." Literature and other

[1] For the most recent set of outcomes, the reader is referred to the project Web site: www.engrng.pitt.edu/~ec2000.

TABLE I
OUTCOME/ATTRIBUTE LIST FRAMEWORK

Cognitive/ Affective Domain	Bloom and Krathwohl Definition	McBeath Action Verbs
Knowledge	Remembering previously learned information	Arrange, define, describe, duplicate, identify, label, list, match, memorize, name, order, outline, recognize, relate, recall, repeat, reproduce, select, state
Comprehension	Grasping the meaning of information	Classify, convert, defend, describe, discuss, distinguish, estimate, explain, express, extend, generalized, give example(s), identify, indicate, infer, locate, paraphrase, predict, recognize, rewrite, report, restate, review, select, summarize, translate
Application	Applying knowledge to actual situations	Apply, change, choose, compute, demonstrate, discover, dramatize, employ, illustrate, interpret, manipulate, modify, operate, practice, predict, prepare, produce, relate schedule, show, sketch, solve, use, write
Analysis	Breaking down objects or ideas into simpler parts and seeing how the parts relate and are organized	Analyze, appraise, breakdown, calculate, categorize, compare, contrast, criticize, diagram, differentiate, discriminate, distinguish, examine, experiment, identify, illustrate, infer, model, outline, point out, question, relate, select, separate, subdivide, test
Synthesis	Rearranging component ideas into a new whole	Arrange, assemble, categorize, collect, combine, comply, compose, construct, create, design, develop, devise, explain, formulate, generate, plan, prepare, propose, rearrange, reconstruct, relate, reorganize, revise, rewrite, set up, summarize, synthesize, tell, write
Evaluation	Making judgments based on internal evidence or external criteria	Appraise, argue, assess, attach, choose, compare, conclude, contrast, defend, describe, discriminate, estimate, evaluate, explain, judge, justify, interpret, relate, predict, rate, select, summarize, support, value
Valuation	Awareness and willingness to receive (awareness w/o assessment, willingness to suspend judgment); Actively respond (comply, commit, internal satisfaction); Value (acceptance of worth, preference); Organize (when values conflict)	Accept, challenge, defend, respect, question, support, enjoy

resources (including Web sites) were then consulted for each of these elements to determine suitable attributes. There were a few outcomes, however, where the meaning of the outcome, under heavy scrutiny, generated several interpretations. The two outcomes "knowledge of contemporary issues" and "a broad education necessary for understanding the impact of engineering solutions have in a societal and global context" proved to be particularly difficult to define or even separate. Indeed, for these two outcomes, multiple definitions may result, and thus different avenues of literature can be pursued. Table II provides a preamble for each outcome along with references used in developing the attribute list.

D. Outcome/Attribute List Example: "Ability to Design and Conduct Experiments"

To demonstrate how each outcome was characterized, the outcome "Ability to design and conduct experiments, as well as analyze and interpret data" is provided as an example. For this outcome, the literature review was relatively straightforward. Engineering texts that explained experimental design and laboratory procedures were reviewed to obtain an exhaustive list of plausible attributes. In addition, Web sites of programs undergoing EC-2000 accreditation were investigated in order to determine how various engineering schools were addressing this particular outcome. The outcome was then dissected into four smaller components or elements: 1) designing experiments, 2) conducting experiments, 3) analyzing data, and 4) interpreting data.

Next, each plausible attribute was assigned to a particular element of the outcome and to the appropriate level within the framework as shown in Table III, which provides an example of the operationalized outcome. The table shows the expanded elements and their definitions along with operational verbs for each particular element. It is important to note that within each element not all domains are represented. The element may be covered by another element or there may be no attribute identified for the specified domain. For a particular element, e.g., "conducting experiments," it may not be necessary to have an attribute(s) to describe the domain synthesis or evaluation, as the element of conducting experiments describes carrying out the experiment rather than requiring analysis and reflection of the work that was performed.

IV. DISCUSSION: CULLING THE ATTRIBUTES

In approaching EC-2000, one must guard against having the collection of data dominate the process, since the improvement of the educational systems remains the objective. Data collection through questionnaires, course evaluations, analysis of attributes, or direct methods such as student portfolios, focus

TABLE II
DEFINITION/PERSPECTIVE USED FOR DEFINING THE EC-2000 OUTCOMES 3A–K

	Outcome	Definition and Reference
a)	An ability to apply knowledge of mathematics, science, and engineering	Encompasses the basic mathematical, scientific, and engineering fundamental knowledge needed by engineering graduates. The emphasis is on: 1) formulation and solution of mathematical models describing the behavior and performance of physical, chemical, and biological systems and processes and, 2) use of basic scientific and engineering principles (e.g., conservation laws, rate and constitutive equations, thermodynamics, materials science) to analyze the performance of processes and systems. Characteristics of each sub-outcome are described at all six Bloom taxonomy levels and one affective level (valuation). [29-30]
b)	An ability to design and conduct experiments, as well as to analyze and interpret data	Comprises four straightforward elements: 1) designing experiments, 2) conducting experiments, 3) analyzing data and 4) interpreting data. Statistically designed experiments, laboratory based experiments and field experiments were considered. Each element was further broken down into descriptive attributes that encompass the larger element. For example, designing experiments includes setting up experiments, determining the proper models to use, considering the variables and constraints, using laboratory protocols and considering ethical issues that arise [31-35].
c)	An ability to design a system, component, or process to meet desired needs	Is based on an extensive survey of published models of design activity [36]. The design activities mentioned in each model were abstracted and organized into similar categories. The resulting categories are a representation of the primary components of design activity. Each component was also broken down into individual sub-components by further analyzing its specific contents. When expanded into the cognitive categories of Bloom's Taxonomy, the framework can provide attributes at two levels of detail, depending on whether design is described at the component level or the sub-component level. Both levels of the framework have been employed to assess and evaluate a freshman engineering design course [37].
d)	An ability to function on multi-disciplinary teams	Is divided into four behavioral dimensions found to be prevalent in successful student work teams [38]. These four dimensions are collaboration, communication, conflict management, and self-management. The specific attributes are designed to measure the occurrence of behaviors in the context of working groups. Each attribute is behaviorally described in order to provide both the feedback provider and receiver with a clear description of the behavior being measured. This allows the learner to translate feedback into developmental action and incremental improvement of the learning outcome in question.
e)	An ability to identify, formulate, and solve engineering problems	Is based on the problem solving process that has been well documented in engineering texts. The elements of the process include: problem or opportunity identification, problem statement and system definition, problem formulation and abstraction, information and data collection, model translation, validation, experimental design, solution development or experimentation, interpretation of results, implementation and documentation. Finally, as most engineers eventually learn, the problem solving process is never complete. Therefore, a final element has been included: feedback and improvement [39-44].
f)	An understanding of professional and ethical responsibility	Comprises four components: ability to make informed ethical choices, knowledge of professional codes of ethics, evaluates the ethical dimensions of professional practice, and demonstrates ethical behavior. The ability to recognize potential ethical dilemmas is emphasized, as is the relationship between cost and schedule pressures and increased risk [45-47].
g)	An ability to communicate effectively	Includes a range of communication media – written, oral, graphical, and electronic. In developing the elements of this attribute, the focus is only on these four large areas; an effective assessment program would need to develop measurable sub-elements for each. The categories are based on the process theory of writing and on widely accepted technical communication norms. Once the list of elements and attributes was developed, writing specialists, engineering educators, and practicing engineers critiqued it. [48-54]
h)	The broad education necessary to understand the impact of engineering solutions in a global and societal context	Is based on how the engineering student interpret(s) solutions in both a societal (more micro context), and global (more macro context). The societal context might be a particular community, state or even country. The global context might cover more than one community, nation, country, etc. Example impacts might include, but are not limited to, political, economical, religious, environmental, communication, and aesthetic impacts. As specific literature for this outcome is scarce, Science, Technology, and Society (STS) and Engineering and Public Policy (EPP) programs were investigated. A variety of programs (Stanford's Science Technology and Society Program, MIT's Technology and Policy Program, MIT's Science Technology and Society Program, Carnegie Mellon's Program – The Computer: Technical and Policy Issues, Simon Frasier's Center for Policy Research on Science and Technology, Virginia Tech's Science, Technology and Society Program, Berkeley's Science, Engineering, and Public Policy Program) were explored to learn about their objectives and curricula.

groups, and individual input should be used to identify areas where improvement is possible. Once identified, it is necessary to prioritize and be selective about the improvement efforts that will be undertaken since it is important for the program under review to demonstrate that the complete feedback cycle of measurement, identification, evaluation, change, and remeasurement has taken place.

In utilizing the attributes as part of this process, the first requirement is for the faculty to select the outcome or outcomes that match the program's highest priorities. This can be accomplished either through external instruments such as focus groups, student portfolios, or questionnaires or by a direct analysis of the attributes. The external instruments can help identify outcomes that are most important to a program in terms of potential improvement. For example, suppose that a departmental visiting committee identifies as potential problem areas outcomes "b" (ability to analyze and interpret data), "e" (ability to identify, formulate and solve engineering problems), and "g"

TABLE II (*Continued.*)
DEFINITION/PERSPECTIVE USED FOR DEFINING THE EC-2000 OUTCOMES 3A–K

Outcome	Definition and Reference
i) A recognition of the need for, and an ability to engage in life-long learning	One of the difficulties with developing measurable performance criteria for life-long learning is that there is no commonly accepted definition of what this concept means. Several authors have written about what it means to be a life-long learner, but little was found about what types of knowledge, skill or attitudinal sets are needed to become an effective "life-long learner." The attributes listed in this taxonomy have been developed from the listed references and will, hopefully, inspire the reader to further explore what it means for students in his/her program to recognize the need for life-long learning [55-63].
j) A knowledge of contemporary issues	This is also a difficult outcome to define, particularly relative to "h" above. Here the focus is on "knowledge" and is interpreted to mean the student's obtaining in-depth knowledge of at least one contemporary issue. Three types of examples are given – socio-economic, political and environmental. It is anticipated that faculty will develop other broad issue areas, using our three as guidelines. Specifically excluded are contemporary, technical engineering issues since these are included in outcome "k" as well as in "a."
k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Encompasses a wide range of tools and skills needed by engineering graduates including computer software, simulation packages, diagnostic equipment, and use of technical library resources and literature search tools. No attempt was made to develop an inclusive list of all skills and tools needed by graduates of all engineering disciplines, but rather a generic description of the outcome at each Bloom level (plus the valuation affective domain) was developed. This information should be flexible enough to be applied to specific disciplines by engineering faculty [64].

(ability to communicate effectively). The faculty can then select those attributes from these three outcomes that would most likely hone in on the perceived weaknesses and then develop a plan for improvement. An alternative to investigating a perceived program problem is to directly select specific attributes to examine. This would include going through the outcomes and identifying not only which attributes might represent curricular problems but also which level or levels of the attributes are not being addressed.

Regardless of how a problem area is identified, the process of narrowing in on a problem as part of the entire "feedback cycle" is the same. For example, outcome "e" has 12 elements, each of which might be evaluated. Examining each of these, two might represent specific weaknesses in the student's ability to identify, formulate, and solve engineering problems. For example, the steps selected for investigation might be "constructing a problem statement and system definition" and interpretation of results—evaluates potential solutions and selects solution." Once an element has been selected, one moves along the framework to specifically identify those attributes where improvement can be made. For instance, focusing on the first element (system definition), four levels—"knowledge," "comprehension," "application," and "valuation"—might not be viewed as problem areas. However, the level "evaluation," which contains one attribute—"appraises the problem statement for objectiveness, completeness, relevance, and validity"—might be identified as the specific problem. With this element, level, and attribute identified, improvement can begin.

The first two phases in the feedback cycle are already accomplished using the analysis of the attributes. This sets the stage for evaluation. Going back to the previous example, it is necessary to investigate the coursework, the student's experience through co-op or internship programs, and the time devoted by faculty to reinforce the importance of system definition. Once the cause of the inadequacy is identified, then changes can be proposed and implemented. At this point, faculty should also make sure that the measurements for assessing the outcome are in place. After an appropriate time period, the outcome is remeasured to determine if the implemented changes have alleviated the problem or if a reevaluation phase should be pursued. Other outcome problems identified through analysis of the attributes can be worked on subsequently. A goal might be to have such attribute analyses become a routine function of the engineering program.

V. EXAMPLES IN USE

A. *Measurement of Problem Solving, Communication, and Teamwork Skills Using the TeamDeveloper*

As discussed in the previous section, careful selection of a pertinent set of attributes is necessary if valid measurements are to be obtained. However, proper attribute selection is not the only consideration when assessing an outcome. Obtaining a metric or method that adequately measures the outcome in question may be difficult. Because many of the methods and instruments currently being used in engineering education have not been fully validated in terms of content or construct, where possible it is highly desirable to triangulate the methods/metrics. By triangulating the methods and metrics, one obtains multiple surrogates for the real measure of the outcome, thus providing both a much needed anchor measure where none exists and obtaining corroboration of measurement results.

In fall 1999, the University of Pittsburgh, Department of Industrial Engineering, began a longitudinal experiment following a cohort of approximately 50 students through a three-course sequence beginning in the first semester of the sophomore year. The purpose of this study is multifold: 1) to triangulate and verify two or more different methods for measuring outcomes and 2) to investigate how students progress toward demonstrating their abilities in selected outcomes.

For the study, three courses were chosen. The first course, *Modeling with Computer Applications*, is taken the fall 1999 and provides an introduction to mathematical modeling, problem solving, and teamwork. The second course, *Productivity Analysis*, is taken in the second semester of the sophomore year

TABLE III
CHARACTERIZED OUTCOME "b": DESIGN AND CONDUCT EXPERIMENTS, AS WELL AS ANALYZE AND INTERPRET DATA

Outcome Element	Cognitive/Affective Domain	Attributes
Design Experiments, continued	**Application**	• Can use existing theory/history to design an experiment • Chooses the measure(s) of effectiveness by which the outcome or the alternative will be evaluated – cost, quality, value, time to complete, feasibility • Formulates the control and evaluating alternatives of the experiment • Develops contingency plans • Applies constraints and assumptions into experimental design • Determines the data that are appropriate to collect • Specifies and justifies the assumptions given test conditions
	Analysis	• Predicts experimental uncertainties
	Synthesis	• Seeks information for experiment from multiple sources
	Evaluation	
	Valuation	• Accepts the limitations and extensions that an experiment built can be used to represent the system
Conduct Experiments	**Knowledge**	
	Comprehension	• Aware of measurement errors in instrumentation, human, environment • Anticipates and minimizes experimental disruptions via pilot study
	Application	• Acknowledges possible disruptions to existing surroundings and operations • Uses appropriate measurement techniques to collect data • Facilitates use of modern data collection techniques (computer for data logging) • Follows ethical protocols when collecting data • Documents collection procedures such that experiment may be repeated • Anticipates and minimizes data errors via pilot study
	Analysis	
	Synthesis	
	Evaluation	
	Valuation	
Analyze Data	**Knowledge**	
	Comprehension	• Can select and explain different methods of analysis (descriptive and inferential) and depth of the analysis needed • Can identify different audiences and their analysis/summary needs • Can identify artifacts/confounding elements that may result
	Application	• Uses appropriate tools to analyze data • Selects and uses appropriate, self-explanatory graph formats for data • Prepares analysis such that results can be replicated
	Analysis	• Can apply statistical procedures • Investigates possible artifacts with a balance of costs associated with the analysis
	Synthesis	• Organizes information into meaningful categories
	Evaluation	
	Valuation	
Interpret Data	**Knowledge**	
	Comprehension	• Can recognize how results relate or differ from theory or previous results
	Application	• Can verify and validate experimental results
	Analysis	• Questions whether constraints hold in both experiment and real world • Relates and makes a connection between the measured property and variables • Examines data WRT measures of effectiveness • Makes considerations for risk
	Synthesis	• Combines results of multiple experiments, history or data sources • Clearly presents information usable in formats (graph, numerical, text, etc.)
	Evaluation	• Considers possible extensions of results to other areas • Interprets what the results mean with respect to the assumptions and constraints • Interprets results with regards to how results relate the theoretical state of nature or system
	Valuation	• Respects and understands the need to consider results from different view points and audiences • Appraises how results can be used to make a decision • Recognizes experiment's limitations

(spring 2000) and provides an introduction to industrial engineering concepts and thought processes. The last course, *Human Factors Engineering*, is taken the first semester junior year (fall 2000) and focuses on the study of human abilities, characteristics, and behavior in the development and operation of systems designed for human use. Each course requires the use of open-ended problem solving (outcome "e"), oral and written communication skills (outcome "g"), and relies heavily on teamwork (outcome "d") in and out of the classroom. To measure these outcomes, two assessment methods were chosen: closed-form questionnaires [18], [51] and multisource feedback [7], [20]. The validated questionnaires elicit students' confidence for all outcomes. These surveys will be used in conjunction with the multisource feedback system known as the TeamDeveloper.

The outcome/attribute list was used to select the metrics for the TeamDeveloper, a feedback system where students

TABLE III *(Continued.)*
CHARACTERIZED OUTCOME "b": DESIGN AND CONDUCT EXPERIMENTS, AS WELL AS ANALYZE AND INTERPRET DATA

Outcome Element	Cognitive/Affective Domain	Attributes
Designing Experiments	**Knowledge**	• Can recognize applicable analytical models, possible simulators (e.g. physical, digital, continuous, other format), testing apparatus, databases, models, etc. • Can identify applicable theory and recognize the past history • Can describe different measurement techniques and alternatives based on cost, etc. • Gives examples of possible disruptions that may occur while conducting experiment that could affect experimental data • Can discuss laboratory/experimental protocols • Understands the need for proper units
	Comprehension	• Can indicate how existing theory/history differs/complements current question • Can select the variables in question (controllable, level of variation, impact with other variables) • Identifies the constraints and assumptions for the experiment - cost, time, equipment • Can construct an appropriate hypothesis or problem statement • Can select appropriate equipment, test apparatus, model, etc. for measuring variables in question • Aware of orderliness and integrity of data

provide their team members with meaningful feedback about each member's technical and interpersonal performances. The three instructors teaching the courses collectively selected attributes that they felt were pertinent to the objectives of the courses. For outcome "e" ("an ability to identify, formulate, and solve engineering problems"), 17 attributes were selected; for outcome "d" ("an ability to function on multidisciplinary teams"), 32 attributes were selected; and for outcome "g" ("an ability to communicate effectively"), 12 attributes were selected as applicable to the three courses.

Each of the selected attributes then formed the basis of a "statement" for inclusion with the TeamDeveloper. Only slight modifications were made from the attribute list when transferring them to the TeamDeveloper. A diskette containing the software was given to students twice during the semester, first during the middle of the semester and then toward the end of each course. Each student rated themselves and their project teammates on each of the 61 attribute based-statements on a five-point scale (1—never, 2—rarely, 3—sometimes, 4—frequently, and 5—always). The evaluation process took no more than 20 minutes of the student's personal time. The questionnaires were administered on the last day of each class.

The first set of data from the TeamDeveloper and the survey instrument is currently being analyzed. In analyzing the data, the differences in self-assessment ratings versus ratings of peers and faculty for the group projects are being investigated. In addition, differences between in-depth assessment methods like the multisource feedback and more general assessment tools such as the sophomore and junior attitude instruments will be explored. Finally, differences in the rating scales used in the two methods will be examined.

B. Development of a Questionnaire to Measure Design Abilities

At the University of Washington, the team of researchers who developed the attribute list for the outcome "c" ("an ability to design a system, component, or process to meet desired needs") used the resultant framework to help develop a systematic approach for evaluating curriculum and for assessing student learning of design knowledge and skills. The attribute framework was used in conjunction with an introductory design course. The course consisted of several hands-on design projects and introduced simple engineering analysis and communication skills. The design attribute framework was used to help develop questions for a survey instrument to assess student learning in this particular course. The fine detail of the individual attributes in the framework provided an opportunity to frame very specific questions directly from the framework. For example, a survey designer who wished to assess skill at "developing a design strategy" at the comprehension level would transform the appropriate cell directly into a survey question. Similarly, other questions may be created from other cells.

The framework was also used to obtain profiles of learning objectives for various design projects. Depending on the project different elements and attributes were highlighted. Safoutin *et al.* [3134] describe these projects in detail.

VI. CONCLUSIONS

There are many implications to consider when adopting the eleven EC-2000 outcomes. An initial, major challenge that every engineering program faces involves achieving faculty consensus on the meaning and translation of these outcomes as it applies directly to them. A second challenge is in converting the desired outcomes into useful metrics for assessment. ABET was purposefully vague when formulating the outcomes, as the intent was to be less prescriptive in the accreditation process and thus encourage individual programs to distinguish themselves by the manner in which they define their engineering education. Although this vagueness has provided engineering faculty with the needed flexibility and opportunity to meet their customers' needs, the initial task of defining the outcomes is proving to be a substantive and potentially overwhelming endeavor. The context in which each outcome is used affects its definition. Each engineering program and individual course may have different outcome interpretations depending on the perspective of the engineering educators involved and the institution's mission and program objectives.

Although institutional mission and program objectives will most probably drive local definitions, within the institution there are several advantages and synergies to be enjoyed by reaching some degree of convergence on what is meant by these eleven outcomes. The approach suggested here may assist many engineering faculty undertaking this challenge. An attempt has been made to provide order and direction to this critical initial step by thoroughly researching each outcome and by contributing an evolving framework by which engineering educators may select attributes that are suitable to their curricular needs. Thus a buffet of attributes from which educators can pick and choose and directly use in the measurement of their courses or program needs has been provided.[2]

The authors entertain any comments and improvements to the outcomes/attributes list. Since its initial inception, the document has been reviewed and commented by engineering educators attending the 1999 *American Society for Engineering Education Annual Conference* [52] and at the *Best Assessment Processes III in Engineering Education* at Rose-Hulman Institute (April 2000). Such comments have been and will continue to be incorporated into the document on a periodic basis.

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[2]The complete list of engineering outcomes and their attributes can be found at www.engrng.pitt.edu/~ec2000. Visitors to the Web site can download the outcome/attribute document in its entirety or by individual outcome. It is important to note that this list is by no means exhaustive nor is it static in nature. The attribute list should be considered a dynamic document that must be constantly reviewed and updated much like the new approach to engineering education that ABET is promoting.

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