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Approaches to Increasing the Efficiency of an Effective Outcome Assessment Process*

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We use the framework of the Electrical Engineering Program and the Computer Science Program within the Department of Electrical Engineering and Computer Science at the U.S. Military Academy at West Point to describe a systematic process to increase efficiency in assessing program outcomes while maintaining effectiveness of the assessment results. We describe two systems used in the Electrical Engineering and Computer Science Programs to reduce the number of embedded indicators and therefore the time required by faculty to accomplish program outcome assessment. We then propose an extension of the Computer Science system to formalize faculty communications to ensure the student learning model facilitates program outcome achievement. Finally, we propose a cross-correlation matrix used by both programs that eliminates redundancy of assessing a program multiple times for different accreditation sources. These approaches not only effectively monitor graduate abilities, but also provide mechanisms to monitor individual course contribution and serve as troubleshooting instruments for deficient outcome results. This process can also be extended to satisfy other institutional assessment requirements and encourages increased faculty interaction which results in improved course linkages.

Keywords: ABET accreditation; outcome assessment

INTRODUCTION

BECAUSE OF THE INCREASED FOCUS on assessment resulting from ABET EC2000, numerous articles have been published on how assessment processes can be used in the design, development, assessment, evaluation, and improvement of engineering curricula. Some articles focus on different approaches to assessment. McGorty, *et al.* [1] reported on a multi-institutional project that considered twelve different assessment methods and their application to engineering education. Wellington, *et al.* [2] addressed multiple authentic assessment methods applied to a multi-disciplinary industry project. Williams [3] described the use of engineering portfolios as an assessment vehicle. Adams, *et al.* [4] described the importance of the use of multiple methods and the triangulation of these results in assessment. Other articles have focused on the interaction between administrators and faculty in the assessment process. Nault and Hoey [5] argue that establishing a culture of trust in an organization is a necessary first step towards creating sustainable assessment systems. Still other articles addressed a variety of models that can be used in the development of a framework for assessment. Besterfied-Sacre, *et al.* [6] described the use of empirical methods that can be used to develop a model of the engineering education process. Kaw *et al.* [7], Steward *et al.* [8] and Mitchell *et al.* [9] presented innovative course-level assessment techniques. However, the effort needed to execute these processes may not be sustainable for busy faculty. Finally, Howell *et al.* [10] suggested a program assessment process that links program objectives to course objectives and educational activities. Although similar linkages are prevalent in our programs, our work takes another direction. In this paper we focus on the important issue of improving the efficiency of the outcome assessment process (reducing the burden on already-busy faculty) without sacrificing the quality of the results. We present several different techniques used in a large department consisting of Electrical Engineering and Computer Science programs.

After a program determines its outcomes, the faculty must determine how to assess and evaluate those outcomes. Here we use the ABET definitions of outcomes, assessment and evaluation. Program educational outcomes are 'statements that describe what students are expected to know and be able to do by the time of graduation [11] .' Assessment is 'one or more processes that identify, collect, and prepare data to evaluate the achievement of program outcomes and program educational objectives [11].' Evaluation is 'one or more processes for interpreting the data and evidence accumulated through assessment practices [11].'

There are many different types of measures that can be used in assessing student achievement of program outcomes. Gloria Rogers enumerates twelve and categorizes them as either direct or indirect. Direct measures generally provide stronger evidence of program outcome achievement [12]. Locally developed exams are an example of

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Table 1. USMA electrical engineering program

Sophomore 2nd Semester	Junior 1st Semester	Junior 2nd Semester	Senior 1st Semester	Senior 2nd Semester
Digital Logic	*Circuits I*	*Circuits II*	*Electronics*	*Seminar*
Engineering Math	*Signals & Systems*	*E&M Fields & Waves*	*Electronics System Design I*	*Electronics System Design II*
	Computer Arch.	Statics & Dynamics	*Solid State Electronics*	Elective
		EE Depth	EE Depth	EE Depth

direct measures that are already implemented by most courses. We define embedded indicators as specific events or graded requirements already administered in a course (direct measures) that help assess one or more program outcomes. Chosen correctly, these serve to evaluate both student performance in the course and achievement of program outcomes simultaneously. Without careful planning, use of embedded indicators can be extremely time-intensive, in spite of the fact that it does not add onto the 'grading load.' Instead, we only want to choose enough embedded indicators to assess our program properly according to our stated outcomes.

In Sections II and III we describe two different techniques for identifying a minimal set of embedded indicators that can be used to directly assess the level to which students meet a program's educational outcomes. The bottom-up approach described in Section II begins with an abundance of embedded indicators that already exist throughout a curriculum and culls out a smaller, more reasonable set of indicators that cover outcomes. We use examples from an Electrical Engineering Program to illustrate this process. Section III describes an alternative approach, in this case a top-down approach, to identifying a minimal set of embedded indicators. The top-down approach defines first a set of knowledge, skills, and behaviors we want to measure for each outcome and then identifies one or more embedded indicators for each. We use examples from a Computer Science Program to illustrate this process.

Both Approaches 1 and 2 rationally determine which embedded indicators in which courses should be used as indicators of outcome achievement, with a goal of producing the smallest set of indicators that adequately assess individual program outcomes. Approach 3 introduces the concept of assessment re-use: using the achievement of one set of academic program outcomes to satisfy assessment of similar outcomes for another assessment association.

APPROACH 1: THE COURSE-OUTCOME MATRIX

In the Electrical Engineering Program, we have developed a system for efficiently assessing program outcome achievement using embedded indicators. One can develop a matrix of program outcomes and program courses and list which embedded indicators in which courses support which outcomes. For a typical engineering program, this matrix will contain numerous embedded indicators. Assessing all of them would be impractical. The goal is to obtain a sparse matrix that contains a small set of embedded indicators that adequately demonstrates student achievement of program outcomes. The course sequence in the Electrical Engineering curriculum at West Point is shown in Table. 1. The courses in italics are those required for all Electrical Engineering majors. The Electrical Engineering Program outcomes are shown in Table 2. The nine program outcomes map directly to the ABET Criteria 3 (a–k) as shown in Table 3. Using nine program outcomes rather than the eleven defined by ABET demonstrates an additional level of efficiency that can be achieved. A complete course-outcome matrix is shown in Table 4. Notice that all graded requirements in every course could be used to assess one or more outcomes. Since most courses have three examinations and lab courses have three-to-four labs, Table 4 represents over 80 embedded indicators across 19 courses. To determine which embedded indicators in which courses are most useful, we critically assess the individual tool against the outcome criteria. First, since outcomes are what students can do *at the time of graduation*, we

Table 2. USMA electrical engineering program outcomes

Electrical engineering graduates can:

1. Apply knowledge of mathematics, probability, statistics, physical science, engineering, and computer science to the solution of problems
2. Identify, formulate, and solve electrical engineering problems
3. Apply techniques, simulations, information and computing technology, and disciplinary knowledge in solving engineering problems
4. Design and conduct experiments to collect, analyze, and interpret data with modern engineering tools and techniques
5. Communicate solutions clearly, both orally and in writing
6. Work effectively in diverse teams
7. Apply professional and ethical considerations to engineering problems.
8. Incorporate understanding and knowledge of societal, global and other contemporary issues in the development of engineering solutions that meet realistic constraints
9. Demonstrate the ability to learn on their own.

Table 3. EE program outcome to ABET a–k crosswalk

Program Outcome to ABET A-K crosswalk Strong Support = X — Electrical Engineering Program Outcomes (abbreviated)	a Mathematics, Sciences and	b Experiments, Analysis and	c Ability to Design a System	d Multi-Disciplinary Teams	e Solve Engineering Problems	f Professional and Ethical Responsibility	g Communicate	h Impact of Engineering Solutions	i Lifelong learning	j Knowledge of Contemporary Issues	k Modern Engineering Tools
1 Apply math, science and engineering	X										
2 Identify, formulate and solve problems					X						
3 Apply simulations and info technology											X
4 Experiments w/modern engineering tools		X									X
5 Communicate orally and in writing							X				
6 Work effectively in diverse teams				X							
7 Apply professional and ethical consider.						X					
8 Incorporate realistic constraints			X					X		X	
9 Demonstrate ability to learn on one's own									X		

reduce emphasis on courses early in the curriculum, unless that course is the only source of an embedded indicator for an outcome. Second, we focus on courses taken by all the students in the program, so we reduce emphasis on elective courses unless, again, they are the only source of indicators for an outcome.

After two iterations of review and evaluation by all faculty in the Electrical Engineering Program, we were able to reduce the number of courses requiring embedded indicator linkages to program assessment from 19 to eight as shown in Table 5. This represents nearly a 58% reduction in the number of courses requiring embedded indicators for assessment.

The next and final iteration of this process reduces redundancy in the number of embedded indicators considered for those eight courses by examining outcomes with similar embedded indicators and choosing a reduced number of indicators that satisfy the assessment requirements for several outcomes. Outcomes 1 and 2 both involve solving engineering problems. The examinations in the Electromagnetic Fields, Electronics and Solid State Electronics courses all require the use of mathematics to solve electrical engineering problems. Selecting one examination from each course to assess both outcomes reduces the program assessment requirement. Outcomes 3 and 4 involve simulations and laboratory exercises. In the Circuits and Electronics courses, each laboratory exercise begins with a 'pre-lab' that requires simulation of the experiment for comparison with measured results once the experiment has

Table 4. Initial course-outcome matrix

	Program outcomes								
Courses	1	2	3	4	5	6	7	8	9
Digital Logic	E, L, DP	E	L, DP	L, DP	DP	E, L, DP			
Circuits I	E, L	E, L	L	L		E, L, DP			
Signals & Sys.	E	E				E			
Comp. Architect	E	E	L, DP			E, L, DP			
Circuits II	E, L, DP	E, L	L, DP	L, DP	DP	E, L, DP			
E&M Fields	E	E				E			
Elec-tronics	E, L, DP	E, L, DP	L, DP	L, DP	DP	E, L, DP			
Elec. Sys Des I	DP	DP	L, DP	L, DP	PD, DP	E, L, DP	EQ, PD	EQ, PD	DP
Elec. Sys Des II	DP	DP	L, CD, FD, DP	L, CD, FD, DP	CD, FD, DP	CD FD, DP	EQ, CD, FD, DP	EQ, CD, FD, DP	DP
Seminar					RP	RP	RP	RP	RP
Solid State	E	E, L	L	L		E, L			
Power Eng.	E, L	E, L		L	L	E, L, DP			
Adv. Architect	E, L	E, L	L	L		E, L			
Wireless Comm.	E, L	E, L	L	L	L	E, L			
Comm Theory	E, L	E, L	L	L	L	E, L			
Micro-control	E, L	E, L	L	L		E, L			
Control Systems	E, L	E, L	L	L		E, L			
Photonic	E, L	E, L	L	L	L	E, L			
Telecom.	E, L	E, L	L	L	L, DP	E, L, DP			

CD = Critical Design Review
E = Examinations
FD = Final Design Review
PD = Preliminary Design Review
DP = Design Project Report
EQ = Ethics Quizzes
L = Laboratory Exercises
RP = Research Paper

Table 5. Course-outcome matrix after two passes

	Program outcomes								
Courses	1	2	3	4	5	6	7	8	9
Adv. Architect	E, L	E, L	L	L		E, L			
Circuits II	E, L, DP	E, L	L, DP	L, DP	DP	E, L, DP			
E&M Fields	E	E				E			
Elec-tronics	E, L, DP	E, L, DP	L, DP	L, DP	DP	E, L, DP			
Elec. Sys Des I	DP	DP	L, DP	L, DP	PD, DP	E, L, DP	EQ, PD	EQ, PD	DP
Elec. Sys Des II	DP	DP	L, CD, FD, DP	L, CD, FD, DP	CD, FD, DP	CD, FD, DP	EQ, CD, FD, DP	EQ, CD, FD, DP	DP
Seminar					RP	RP	RP	RP	RP
Elec. Power Eng.	E, L	E, L		L	L	E, L, DP			

CD = Critical Design Review
DP = Design Project Report
E = Examinations
EQ = Ethics Quizzes
FD = Final Design Review
L = Laboratory Exercises
PD = Preliminary Design Review
RP = Research Paper

Table 6. Final course-outcome matrix

	Program outcomes								
Courses	1	2	3	4	5	6	7	8	9
Adv. Architect			L3						
Circuits II			L3	L3					
E&M Fields	E2	E2							
Elec-tronics	E1	E1	L3	L3		E1			
Elec. Sys Des I						Peer, Adv	EQ	EQ,	DP
Elec. Sys Des II					CD, FD, DP	Peer, Adv	CD, FD, DP	CD, FD, DP	DP
Seminar							RP	RP	RP
Elec. Power Eng.	E1	E1		L3	L3				

Adv = Advisor Evaluation of Teamwork
CD = Critical Design Review
DP = Design Project Report
E = Examinations
EQ = Ethics Quizzes
FD = Final Design Review
L = Laboratory Exercises
Peer = Peer evaluations
PD = Preliminary Design Review
RP = Research Paper

been performed. The Circuits, Electronics and Power courses also require students to design their experiments. The Advanced Architecture course requires simulations in VHDL. Assessing student performance in the labs later in the course allow the students to demonstrate the proficiency they have developed during the course, so we select the last lab in the Electronics, Circuits II, Power Engineering, and Advanced Architecture classes. Outcome 5 requires students to demonstrate their ability to present solutions orally and in writing. The capstone design courses Electronics Systems Design I and II include three major oral presentations: the Preliminary, Critical and Final Design Reviews. Recognizing that the Preliminary Design Review is the first time the student design team presents together, we select the Critical and Final Design Reviews for assessment. The capstone design project also requires an extensive written report, which is a good opportunity to assess the students' writing skills. Finally, to give another data point for writing ability, we assess the last lab in the Power Engineering course which requires a formal lab report. In a similar fashion, we critically evaluate the remaining embedded indicators and program outcomes, again identifying opportunities to reduce the number of embedded indicators used to assess program outcomes while maintaining the integrity of the assessment. The result of this final iteration in the Electrical Engineering Program are shown in Table 6.

The final course-outcome matrix identifies a total of 16 embedded indicators across eight courses required to provide program assessment—a much more manageable load than the original 80+ embedded indicators across 19 courses.

APPROACH 2: IDENTIFYING PERFORMANCE INDICATORS

The previous section described a bottom-up approach to identifying a minimal set of embedded indicators that can be used to assess whether or not a program meets its outcomes. That approach began with a generous set of candidate embedded indicators sprinkled throughout the courses offered by the program and described how to reduce that number systematically.

In this section we describe a top-down approach that meets the same goal and show how we applied the approach in a Computer Science program.

The basic idea is to begin with the set of

Table 7. USMA computer science program outcomes

Computer science graduates can:

1. Apply mathematical foundations, algorithmic principles, and computer science theory in the modeling and design of computer-based systems in a way that demonstrates comprehension of the trade-off in the design choices.
2. Analyze a problem, and identify and define the computing requirements appropriate to its solution.
3. Apply design and development principles in the construction of software systems of varying complexity.
4. Function effectively on teams to accomplish a common goal.
5. Use current techniques, skills, and tools necessary for computing practice.
6. Recognize the need for, and engage in, continuing professional development.
7. Understand the professional, ethical, and social responsibilities expected of a computer scientist and a military officer.
8. Communicate with a range of military and non military audiences.
9. Analyze the impact of computing on Army operations, soldiers, units, and society at-large, including ethical, legal, political, and security issues.

outcomes and derive from each outcome a small set of statements that each describe a quantifiable, 'bite-sized' facet of the outcome. Each such statement is called a performance indicator. When taken together, this set of performance indicators provides total support for achieving the outcome. Unlike outcome statements, performance indicators describe the techniques, skills and behaviors that graduates should acquire in order to satisfy that program outcome. A well formulated performance indicator is a statement that will naturally be able to be assessed in a number of courses.

Once performance indicators are established, the assessment process then identifies embedded indicators by linking each performance indicator with an appropriate course and finding a single graded event in that course that can be used to demonstrate the level of achievement for that performance indicator.

With this approach, the total number of embedded indicators is dependent on the number of performance indicators. A goal in designing performance indicators is to establish as few performance indicators as is necessary to 'cover' an outcome. The competing goal, however, is to make each performance indicator simple enough that a number of course directors will be happy to claim it as something that they develop in their students.

Efficiency is gained by carefully analyzing the constituent elements that comprise an outcome once. These performance indicators are fixed, whereas an embedded indicator could change from course offering to course offering. We came up with between two and six performance indicators for each outcome, with a total of 36 performance indicators. With an assessment cycle of two years, this comes to approximately nine performance indicators to be assessed each semester.

The Computer Science Program assessment process illustrates this top-down process of identifying a minimal set of embedded indicators. The Computer Science Program outcomes are shown in Table 7.

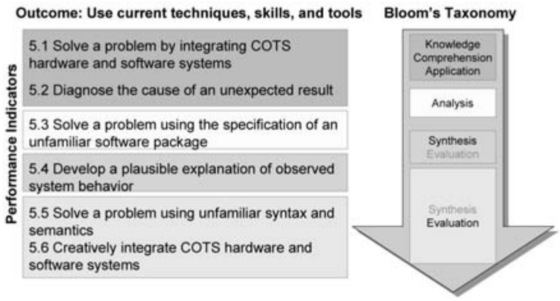

Fig. 1. Scaffold for performance indicators

We developed performance indicators that are scaffolded based on Bloom's Taxonomy of Cognitive Domains [13], and hence are distributed among various levels of thematic mastery. For example, outcome number 5 led to the six performance indicators shown in Fig. 1. We further used Bloom's Taxonomy as a guide in defining four levels of performance indicators. Every performance indicator is then associated with one of the four levels.

To facilitate assignment of performance indicators to courses, we associate each course in the curriculum with one of the four levels. Figure 2 shows the organization of our required courses for the Computer Science Major. It is the set of courses in a particular course group that are candidates for claiming the corresponding performance indicators. For example, in the Knowledge–Comprehension–Application level, the Digital Computer Logic course director was happy to claim performance indicator 5.1, and used his final course project as the embedded indicator to demonstrate that at the end of the second semester in the program the level at which students solve a problem by integrating COTS hardware and software systems is acceptable.

For each course group, there is a course monitor team (CMT) drawn from members of the faculty who are stakeholders for one or more courses in the group. The CMT plays a key role in engaging course directors during the assessment cycle to

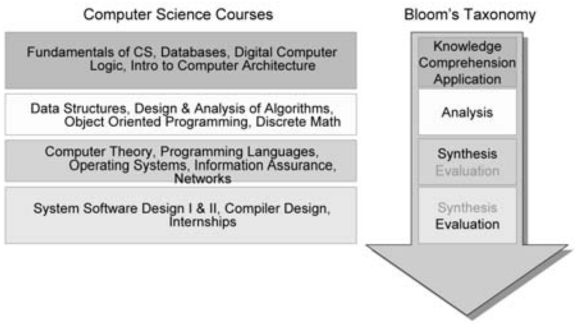

Fig. 2. CS course mapping to Bloom's Taxonomy

ensure proper performance indicator coverage in their courses.

The use of stakeholders on a CMT formalizes common informal communication channels. In most programs there is an informal line of communication among course directors. We call these 'water-cooler' meetings. Commonly, the conversation is between one faculty member who is the course director of a course that is a pre-requisite to a course the second faculty member teaches. These conversations can be quite fruitful. The course director of the pre-requisite or *producer* course can get first-hand insight on the expectations and needs of his/her client: the course director of the *consumer* course. We found this interaction so valuable that we formalized it within our assessment process.

As mentioned previously, the CMT is made up of stakeholders. In particular, the faculty members on the CMT normally course direct a course that is a *consumer* of the courses monitored by the CMT. Accordingly, these CMT members have a vested interest in how well students are able to achieve the performance indicators at the end of the prerequisite courses.

Given these parts, the assessment process formalizes communication links between course directors and stakeholders. Figure 3 shows the flow of communication throughout a semester. At the end of every semester, the course director prepares a summary of the course that he or she has just taught. Just before the start of the next time the course is taught, the course director reviews the previous course summary, discusses the course with the CMT and Program Director and produces a proposal for the course he or she is about to teach. The Program Director approves the finalized course proposal. The CMT makes a contract with the course director identifying which embedded indicator (i.e., graded event) that course will use to demonstrate achievement of a performance indicator. The CMT is responsible for ensuring that all performance indicators are evaluated at least once in a two-year cycle. During the semester, the course director collects assessment data and at the end of the semester produces a new course summary that is reviewed by the CMT and the Program Director. Any changes to the course are discussed and the CMT and Program Director oversight ensures that changes in one course do not adversely affect another course (for instance by eliminating coverage of a topic that is considered pre-requisite knowledge by a follow-on course). Likewise, the CMT might recommend changes to a course based on their experience with a consumer course, since the members of the CMT are typically the course directors of these consumer courses. This formal process promotes increased intra-program awareness and increased longitudinal curricular integration [14].

APPROACH 3: THE OUTCOME CROSS-CORRELATION MATRIX

Many programs are faced with conducting additional assessments to satisfy several different accrediting agencies, for instance ABET, an institutional review committee, and a state or regional association such as the Middle States Association of Colleges and Schools. It would be most efficient to have a single process that satisfies all the accrediting agencies. One way of achieving this goal is to have a cross-correlation matrix among the outcomes required for one agency and the outcomes for the other agencies. This can be accomplished by developing an assessment and evaluation process that satisfies the most stringent set of program outcomes and then mapping those results to demonstrate the assessment and evaluation of the other outcomes. For example, our institution currently has six ABET-EAC accre-

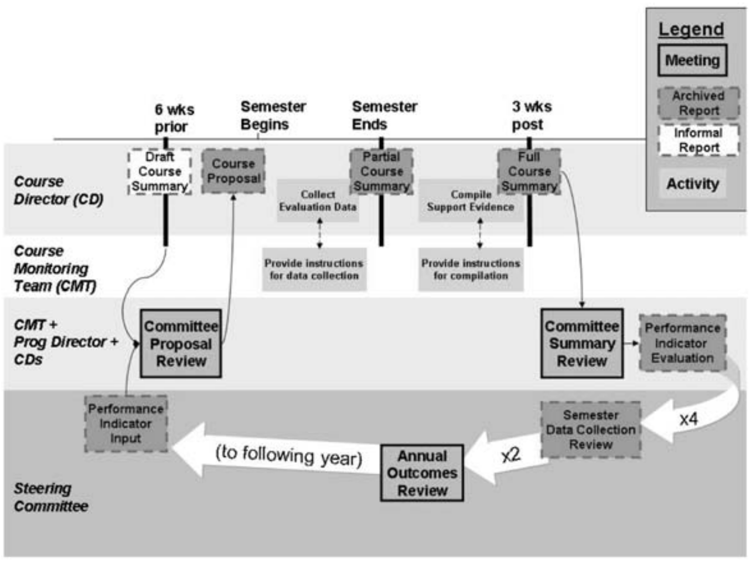

Fig. 3. Program assessment process using course monitor teams

Table 8. Cross-correlation matrix between ABET Criterion 3 (a–k) and USMA Engineering and Technology Goal outcomes

1-Poor Mapping, 5-Excellent Mapping		ABET										
		a	b	c	d	e	f	g	h	i	j	k
Engineering and Technology Goal Standards ⇩		Mathematics, Sciences and	Experiements, Analysis and	Ability to Design a System	Multi-Disciplinary Teams	Solve Engineering Problems	Professional and Ethical Responsibility	Communicate	Impact of Engineering Solutions	Lifelong learning	Knowledge of Contemporary Issues	Modern Engineering Tools
1	In changing environment, identify needs					5						
2	Define political, social, economic dimension					3			3		5	
3	Gather info and make assumptions					5						
4	Apply design process and use technology	5		5		5						5
5	Demonstrate creativity in forming solutions			5		5						
6	Apply math and science to analyze	5	5	4		5						3
7	Effective teamwork to solve problem				5	3						
8	Plan implementation							5				
9	Communicate solution to various							5				
10	Assess effectiveness of a solution								5			
11	Technical proficiency	5	5	5		5						
12	Self learn technologies and concepts	2				3				5		5

dited engineering programs and an ABET-CAC accredited Computer Science Program. The West Point academic program has ten institutional goals that describe what graduates can do at the time of graduation [15]. At the institutional level, teams of senior faculty members drawn from several departments assess each institutional goal. One of these goals is an Engineering and Technology Goal that applies to all students, regardless of major. Clearly, Engineering and Computer Science students in an ABET-accredited major will more than satisfy the Engineering and Technology Goal requirements that apply to, for instance, a History major. Rather than assess our programs twice, the members of the Engineering and Technology Goal Team developed cross-correlation matrices that show that the Engineering and Technology Goal is, in fact, a subset of the ABET program outcomes and therefore our assessment and evaluation processes for ABET can be applied to satisfy our institution's Engineering and Technology Goal. Table 8 shows the mapping of the ABET EAC Criteria [a]-[k] to the institutional Engineering and Technology Goal Standards and Table 9 shows a similar mapping to the ABET CAC attributes. All institutional outcomes are well mapped by at least one ABET.

CONCLUSION

This paper has presented three independent approaches drawn from various stages in the assessment process that will help programs increase the efficiency of their assessment processes. We have shown two different approaches used by the Electrical Engineering Program and the Computer Science Program in our department to reduce the burden of assessment on an already busy teaching faculty. One approach used a bottom-up review to

Table 9. Cross-correlation matrix between ABET CAC outcomes and USMA Engineering and Technology Goal outcomes

Engineering & Technology Goal Outcomes \ ABET-CAC CS Required Attributes	Apply foundations in choosing design	Analyze requirements	Design and develop software	Effective teamwork	Prof, ethical, social responsibilities	Communicate w/ range of audence	Impact of computing	Continue prof. development	Use current tools and techniques
In changing environment identify needs		5	3	2	4	3	5		
Define political, social, economic dim.	3	3	3		3		5		
Gather info & make assumptions	5	5	5						5
Apply design process & use technology	5	5	5						5
Demonstrate creativity in forming sol.	5	5	5						5
Apply math & science to analyze	5	5	5						5
Effective teamwork to solve problem				5	3	4	4		
Plan implementation	4	5	5						5
Communicate solution to various						5	4		
Assess effectiveness of a solution	4	4	5				5		5
Technical proficiency	5	5	5						5
Self learn technologies and concepts	4	4	4					5	5

systematically reduce the number of embedded indicators used to assess outcomes. The other performed a top-down review and defined a small set of performance indicators that are independent of particular courses. We have also shown how to formalize inter-faculty communication that already occurs in order to help ensure pre-requisite courses meet the needs of follow-on courses. Finally, we have demonstrated an approach to satisfying multiple assessment agencies with a single assessment process. We have found that the reduced overhead of these approaches not only reduces costs associated with assessment but also provides an increased faculty buy-in of the assessment process. Other benefits include increased longitudinal curricular linkages [4] and providing program and institutional leadership with a better sense of outcome achievement.

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