

Assessing and Developing Program Outcomes through Workplace Competencies*

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The College of Engineering at Iowa State University (ISU) partnered with constituents and assessment professionals to identify and validate 14 observable and measurable competencies necessary and sufficient to measure program outcomes. Constituents identified the engineering and experiential workplaces as settings most likely to develop and demonstrate the competencies, and the traditional classroom as least likely. Engineering students in the experiential workplace are assessed on the competencies by their supervisors, providing feedback for curricular change. These results confirm that we must re-examine how we use the classroom to educate engineers and our belief that experiential education is critical to students' success.

Keywords: assessment; ABET; competencies; workplace assessment; internships

INTRODUCTION

MANY ENGINEERING PROGRAMS are well on their way to adopting the outcomes-based ABET Criteria 3, now well known as the 'ABET (a–k) Outcomes' [1]. Eight of the eleven Outcomes address 'an ability to . . .'; two address 'understanding'; and only one addresses 'knowledge.' The direct measurement of 'an ability to . . .' presents challenges very different from those of measuring knowledge and understanding. George Peterson, ABET Executive Director, stated, ' . . . evaluating their outcomes are sophisticated activities with which most engineering educators have had little or no experience' [2].

There is no universal approach to implementing and assessing the ABET outcomes-based criteria. Each program must interpret the criteria as they fit for them. A cursory examination of the literature reveals numerous different approaches to implementing ABET criteria [3–5].

Mentkowski *et al.* [6] state:

- Abilities are complex combinations of motivations, dispositions, attitudes, values, strategies, behaviors, self-perceptions and knowledge of concepts and of procedures.
- A complex ability cannot be observed directly, it must be inferred from performance.

At Iowa State University (ISU), we realized that we did not know how to directly assess 'an ability'. We hypothesized that each of the Outcomes are multi-dimensional and represent some collection of workplace competencies necessary for the practice of engineering at the professional level.

We define workplace competencies as the application of knowledge, skills, attitudes and values,

and behaviors, as identified by Ewell [7], in the engineering workplace. They are 'the result of integrative learning experiences in which skills, abilities and knowledge interact' to impact the task at hand [8]. As such, competencies are directly measurable through actions or demonstrations of the existence of those competencies in the individual.

The 2005–2006 ABET Engineering Criteria [1] confirm our hypothesis by stating that the program outcomes 'relate to the skills, knowledge, and behaviors that student acquire in their matriculation through the program.'

A list of such competencies could be endless. Which are the most important for students to become successful engineers? Rogers [9] stated that ' . . . faculty must determine what competencies that the student must demonstrate in order to know that they have achieved the outcome.' She also stated that 'key stakeholders need to be involved in determining which competencies should be the focus from all the possible competencies for any given outcome.' We could not agree more.

Employers of Iowa State University graduating engineers are relying on behavioral-based interviewing in the recruitment, screening and selection processes of new hires. They seek to assess whether a student has demonstrated a specific set of competencies, the definition of which is based on the analysis of the successful practice of engineering in specific engineering positions. These screening criteria often contain a minimum set of competencies, such as communication, teamwork and continuous learning.

In Spring 1999, the Iowa State University College of Engineering and Development Dimensions International, Inc. (DDI), a global provider of competency-based performance management

* Accepted 6 July 2005.

tools and services [10], collaborated to identify workplace competencies that were linked to Criterion 3 Outcomes and Assessment.

IDENTIFYING WORKPLACE COMPETENCIES

Our initial objective was to create a set of repeatable and reproducible measurements for the ABET (a–k) Outcomes that could be applied across the broad spectrum of the engineering experiential education workplace. This process was previously reported by Hanneman *et al.*, [11] and is summarized here.

Experiential education can be broadly defined as a philosophy and methodology in which educators purposefully engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, and clarify values [12]. In the College of Engineering at Iowa State University, we use a much narrower definition for engineering experiential education. For us, it is work experience in an engineering setting, outside of the academic classroom, and before graduation. Iowa State engineering students work in either a cooperative education program (alternating periods of full-time academic college training and full-time work experience of approximately equal length) or an internship (a single work period of institutional supervised full-time employment of a summer or at least one semester) [13]. Thus, the experiential workplace for us is where students are working when on an internship or participating in a cooperative education program. Typically, over 80% of graduates of our accredited engineering programs have participated in engineering experiential education before they graduate. An internship or cooperative education experience is not required at ISU in our engineering programs, but is strongly encouraged by faculty and advisors.

It was desired that measurements of the ABET (a–k) Outcomes should be applicable across all ten of our accredited programs and across the two forms of experiential education offered by the college. Additionally, we wanted the measurements to be clearly and independently defined, readily observable, immediately measurable, consistent with the visions and missions of our college and university, and aligned with existing employer assessment, development and performance management practices. The competencies were to be uniquely ISU's.

Over two hundred constituents (stakeholders) were invited in 1999 to participate in a process to create and validate metrics for the experiential education workplace. These constituents included representation from these groups:

- employers (supervisors, managers, practicing engineers, recruiters, and human resource, education, training and development representatives);

- faculty, staff, and administrators; alumnae/i;
- students who participated in experiential education; parents;
- international faculty from partnering institutions.

Significant effort was made to ensure that each accredited program in the college received appropriate representation from each of the stakeholder groups and to ensure a broad, diverse representation from the employer community. The group ultimately consisted of 212 stakeholders.

The constituents participated in DDI-facilitated focus sessions, using a 'Critical Incident' data gathering technique, following the DACUM strategy [14]. In these sessions, constituents provided hundreds of examples of successful and unsuccessful demonstrations of the eleven ABET (a–k) Outcomes by engineering students and graduates. DDI professionals analyzed these 'critical incident' stories and extracted fourteen dimensions or workplace competencies necessary and sufficient for the successful demonstration of the eleven Outcomes:

Engineering Knowledge	General Knowledge	Continuous Learning
Quality Orientation	Initiative	Innovation
Cultural Adaptability	Analysis & Judgment	Planning
Communication	Teamwork	Integrity
Professional Impact	Customer Focus	

Note that these are 'ISU Competencies' that resulted from dialogue with *our* constituents. Other programs or institutions might develop a different set of competencies.

Based on their experience, DDI provided definitions for each competency. Each definition is clear, concise and independent of all others. Specific to each definition is a set of observable and measurable Key Actions that a student may take that demonstrates their development of that ISU Competency. A complete listing of the ISU Competencies and Key Actions can be found at <http://learn.ae.iastate.edu/assessment/competency-definitions.pdf>. An example of one ISU competency, Continuous Learning, is given in Table 1.

This process resulted in a mapping of the fourteen ISU Competencies to the ABET (a–k) Outcomes. The matrix of this mapping is given in Table 2. In each cell with a number, a competency is mapped to a specific Outcome. The numbers refer to constituent ranking of each competency–outcome combination (see the following section on Validation). There is no mapping of a competency to an Outcome where there were no supportive 'critical incident' stories, despite the temptation to assign such a relationship.

This matrix confirms our hypothesis that the outcomes are multi-dimensional and complex. For example, 'Initiative' is linked to each Outcome with 'an ability'. Outcome (c), 'an ability to design a system . . .', requires the greatest

Table 1. The Continuous Learning workplace competency

Definition	Actively identifying new areas for learning; regularly creating and taking advantage of learning opportunities; using newly gained knowledge and skill on the job, and learning through application.
Key Actions	<ol style="list-style-type: none"> 1. Targets learning needs — Seeks and uses feedback and other sources of information to identify appropriate areas for learning. 2. Seeks learning activities — Identifies and participates in appropriate learning activities (e.g., courses, reading, self-study, coaching, experiential learning) that help fulfill learning needs. 3. Maximizes learning — Actively participates in learning activities in a way that makes the most of the learning experience (e.g., takes notes, asks questions, critically analyzes information, keeps on-the-job application in mind, completes required tasks). 4. Applies knowledge or skill — Puts new knowledge, understanding, or skill to practical use on the job; furthers learning through trial and error. 5. Takes risks in learning — Puts oneself in unfamiliar or uncomfortable situation in order to learn; asks questions at the risk of appearing foolish; takes on challenging or unfamiliar assignments.
Representative Career Activities	<ul style="list-style-type: none"> • Participating in applied projects that require new knowledge • Designing and/or performing experiments that require new knowledge • Designing products that require engineers to learn new subject areas • Questioning ethical professional responsibility when undertaking sensitive tasks • Engaging in discussions on professional responsibility • Taking courses outside of the ‘hard sciences’ while in the workplace • Using feedback from ‘customers’ to learn new material that will improve a product • Reading non-assigned books to learn new topics • Attending conferences and seminars • Learning local, state, and federal laws to understand impact on engineering practices • Learning new software programs to design a product or solve a problem • Participating in experiential education opportunities
Off-Key Actions	<ul style="list-style-type: none"> • Lets others determine learning goals and needs • Allows barriers and obstacles to interfere with learning • Only targets low-priority or current needs • Ignores own preferences, strengths, or developmental needs • Doesn’t practice, reinforce, or apply learning
Over Actions	<ul style="list-style-type: none"> • Sets unrealistic goals or overextends • Over-emphasizes future needs and excludes current needs • Is overly confident or independent

Table 2. Matrix of ABET (a–k) Outcomes vs. ISU Competencies*

ABET Criterion 3 Outcomes	ISU Competency													
	Engineering Knowledge	General Knowledge	Continuous Learning	Quality Orientation	Initiative	Innovation	Cultural Adaptability	Analysis & Judgment	Planning	Communication	Team-work	Integrity	Professional Impact	Customer Focus
(a) An ability to apply knowledge of mathematics, science, and engineering	4.8		3.8		3.5			4.3						
(b) An ability to design and conduct experiments, as well as to analyze and interpret data	4.4		3.6	4.3	3.7	4.0		4.5	4.1		3.4			3.4
(c) An ability to design a system, component, or process to meet desired needs	4.4		3.8	4.1	3.9	4.3	3.0	4.5	4.2	4.0	3.8			4.2
(d) An ability to function on multidisciplinary teams					4.0		4.3	3.6	3.8	4.7	4.9	4.3	3.9	3.7
(e) An ability to identify, formulate, and solve engineering problems	4.7		3.8	3.9	4.1	4.2		4.4		3.7	3.6			3.6
(f) An understanding of professional and ethical responsibility		3.8	3.6	3.3			3.7	3.5				4.7		
(g) An ability to communicate effectively		3.8			3.7					4.9			4.2	4.0
(h) The broad education necessary to understand the impact of engineering solutions in a global & societal context	3.4	3.9	3.9				4.1	3.5						
(i) A recognition of the need for, and ability to engage in, life-long learning			4.6		4.1									
(j) A knowledge of contemporary issues		3.7	3.8				3.8	3.1						
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	4.3		4.2	3.6	3.7		2.6	4.0						

* Numbers refer to the average rating by constituents of the importance of the competency to demonstrating the outcome (5 = essential; 4 = very important; 3 = important; 2 = useful, but not essential; and 1 = unnecessary.) No rating was made for any competency-outcome combination where there was no ‘Critical Incident’ story.

Table 3. Constituents' view of the probability (%) that students/graduates will have the opportunity to develop and demonstrate competencies in various settings.

Setting	ISU Competency														Average
	Engineering Knowledge	General Knowledge	Continuous Learning	Quality Orientation	Initiative	Innovation	Cultural Adaptability	Analysis & Judgment	Planning	Communication	Teamwork	Integrity	Professional Impact	Customer Focus	
Engineering Workplace	88	71	87	87	92	78	73	89	87	90	90	90	92	88	86
Co-op/Internship Workplace	73	62	76	76	82	63	63	76	69	80	76	80	83	66	73
Classroom Capstone Design	76	47	69	72	73	63	55	73	75	71	75	72	60	53	67
Extracurricular Activities (Engineering Profession Related)	47	54	67	45	70	52	59	59	55	69	68	68	66	50	59
Classroom (Laboratory)	71	32	60	67	57	43	46	59	63	55	61	65	41	30	54
Extracurricular Activities (Non-engineering profession related)	25	69	56	35	63	44	59	49	51	65	64	66	60	47	54
Classroom (Traditional)	64	40	62	51	51	35	43	51	56	50	42	59	41	27	48

number of ISU Competencies. The 'Continuous Learning' and 'Analysis and Judgment' competencies are the most highly leveraged (associated with the greatest number of Outcomes) to the successful demonstration of the Outcomes.

VALIDATING THE RELATIONSHIP BETWEEN WORKPLACE COMPETENCIES AND ABET OUTCOMES

To validate the ISU Competency Matrix, a survey was sent to each of the original constituents. In this survey, we first asked them to carefully read the competency definitions and Key Actions and then to rate how important each competency is to a student's or a graduate's successful demonstration of each of the ABET Outcomes to which that competency is linked. The rating was on a Likert scale (5 = essential; 4 = very important; 3 = important; 2 = useful, but not essential; and 1 = unnecessary.)

Of the 212 constituents mailed a survey, 67 responded, a 32% return rate. The respondents represented industry and faculty from each of the engineering disciplines in the college. Each accredited program within the college had a minimum of six respondents that identified with the degree. Thirty-six percent represented faculty, fifty-eight percent of whom are Iowa State alumni. Sixty-four percent of respondents represented industry; sixty-nine percent of whom are Iowa State alumni. The results of their ratings are given in Table 2.

All competencies received an average rating of 3 (important) or better, confirming that the associations between the competencies and the Outcomes were valid. The only exception was the rating of Cultural Adaptability in its relationship to Outcome (k): 'an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.' That relationship received an

average rating of 2.6. After review by the Employer Advisory Board for the ISU Engineering Cooperative Education, Internship and Summer Programs, the decision was made to keep this association at least through the initial pilot applications and analysis.

Finally, we asked of the constituents the degree to which the 14 ISU Competencies collectively cover ABET Criterion 3 Program Outcomes (a-k) and the degree (from 0 to 100%) to which all of the ISU Competencies cover the practice of engineering at the professional level. Coincidentally, the response average to both questions was 89%, from which we conclude that the ISU Competencies are sufficient for measuring our program outcomes.

This process resulted in a set of constituent-created and -validated, competency-based, ABET-aligned assessment tools for the engineering experiential education workplace. These tools will serve as the foundation for assessing our program outcomes.

CONFIRMING THE IMPORTANCE OF EXPERIENTIAL EDUCATION

As part of the validation survey, we asked that, after considering the Key Actions, constituents offer their assessment of the probability that a student and/or graduate would have the opportunity to take those actions to develop and demonstrate that competency in various settings. The settings were: the full-time engineering workplace, the cooperative education/internship workplace (experiential education); the traditional classroom, the classroom laboratory, the classroom capstone design, extracurricular activities (engineering profession related), and extracurricular activities (non-engineering profession related). The results are given in Table 3. The result for the Communication Competency is illustrated in Fig. 1.

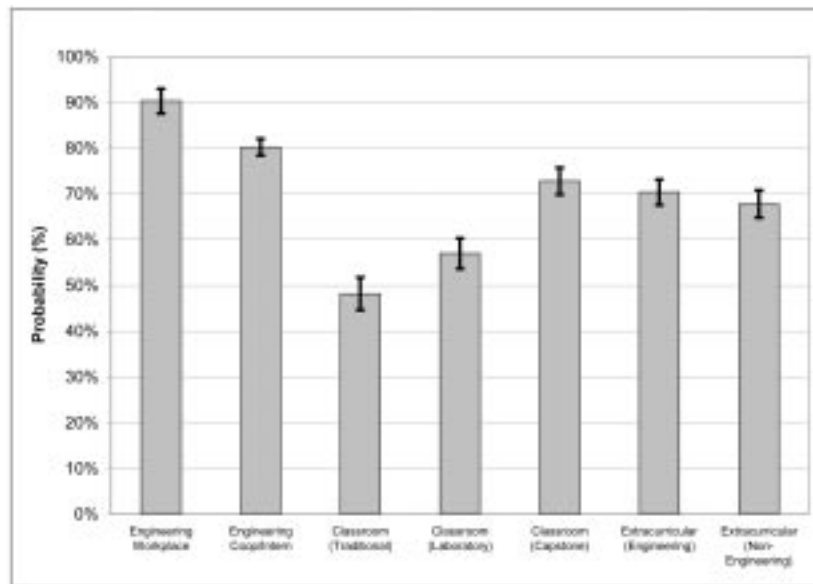


Fig. 1. Constituents' view of the probability (%) that students/graduates will have the opportunity to develop and demonstrate the Communication Competency in various settings.

For most of the competencies essential to the professional practice of engineering, the engineering workplace ranked the highest as the place best to develop and demonstrate the competencies, followed by internships. The classroom consistently ranked last. Engineering students spend a large portion of their academic experiences in the classroom, the least likely place for them to develop the skills, attitudes, values and behaviors necessary to be successful engineers, according to the constituents.

Competency assessment in experiential education

Engineering experiential education programs, such as cooperative education and internships, present the best place to directly observe and measure students developing and demonstrating competencies while engaged in the practice of engineering at the professional level. Measurements made by employers of student competencies present the best opportunity for feedback and curricular change with a cycle time that can address rapidly changing employer needs and expectations. Thus, engineering experiential education can and should be integral to the curricular continuous improvement process.

The ISU College of Engineering, through the office of Engineering Career Services, has implemented competency-based assessment tools for the engineering experiential education workplace, using Online Performance and Learning (OPAL™) [15]. OPAL™ is DDI's web-based competency development and performance management software that provides assessment, development, coaching and learning tools. OPAL™ was customized to present the ISU Competencies, corresponding Key Actions, and assessment surveys. To receive academic credit for their work experience, each student is required to complete the standard self-assessment and to

ensure that their supervisor completes the same assessment of the student. This system has been in place since the fall of 2001. Over 90% of the ISU engineering students in the experiential workplace are evaluated by their supervisors.

A standard assessment survey consists of rating the student on the following question: 'When given the opportunity, how often does this individual perform the action?' The rating for each Key Action is on a Likert scale (1 = never or almost never; 2 = seldom; 3 = sometimes; 4 = often; 5 = always or almost always). A total of 61 Key Actions must be rated in the survey, which takes about 10 minutes to complete.

For each accredited engineering program in the College, the average value of each Key Action is computed from the student's self-assessment and separately from the supervisor's assessment. A ranking of the fourteen competencies (1 = highest mean score value, 14 = lowest mean score value) are made for students in each program. DDI recommends that individual departments look more carefully at patterns than a mean value. The overall results for the college [16] and one program [17] have been reported elsewhere.

The implementation of such an assessment system in a large practice-oriented engineering college presents an outstanding opportunity to collect very large volumes of competency-based assessment data and to study the correlation of these data to curricular processes and to the success of our graduates.

IMPLICATIONS FOR ENGINEERING EDUCATION PROGRAMS

There are number of important implications for engineering educators at Iowa State. Constituents

believe that the classroom is the least likely place to develop competencies necessary for the successful practice of engineering at the professional level. We must re-examine how we use the classroom in educating future engineers, broadening our focus to include competency development. Additionally, these results confirm our belief that experiential education is critical to students becoming successful in the engineering workplace. Finally, the engineering cooperative education and internship workplace provides a superb venue in which to assess student development and demonstration of the ISU Competencies and Criterion 3 Outcomes.

If competencies are the lens through which we view student learning outcomes, competencies must be integral to our engineering education programs. Competency-based learning involves redefining program, classroom, and experiential education objectives as competencies or skills, and focusing coursework on competency development. 'Competencies can have a stronger impact on student learning when they are linked and embedded within specific courses and across both general education and academic majors' [18]. Competencies are transparent; that is, all participants in the learning process can readily understand the learning goals. Competencies provide students with a clear map and the navigational tools needed to move expeditiously toward their goals [19].

At Iowa State University, some engineering programs are implementing competency-based learning and assessment. For example, the Department of Agricultural and Biosystems Engineering is implementing a competency-based education and assessment strategy [20], focused on student attainment of the Competencies, as demonstrated through portfolios and experiential education. They have identified the degree to which all engineering courses they offer address the 14 ISU competencies. The results of these assessments are being used to make curricular changes as part of their continuous improvement process.

CONCLUSIONS

Iowa State University's College of Engineering constituents helped us create and validate the use of workplace competencies to assess ABET Criterion 3 (a-k) Outcomes. Eight of the eleven Outcomes are directly stated as ability-based

outcomes. Abilities are highly complex, multi-dimensional variables that cannot be measured directly and must be inferred from performance by direct observation. We re-defined the Outcomes as a collection of independent workplace competencies with measurable Key Actions.

Measuring the Outcomes as single variables can only provide information confirming that the demonstration of an Outcome is at a specified level, or whether the demonstration has improved or declined from a specified level. Measuring the Criterion 3 Outcomes with competencies provides specific information on what needs to be improved to enhance demonstration of specific Outcomes. This provides programs with specific, focused information on where and how to apply resources and, therefore, significantly enhances efficiency and efficacy of the curriculum continuous improvement process.

The experiential workplace (cooperative education and internships) provides a unique setting where the actions that define performance and competencies can be assessed while the student is actually engaged in the practice of engineering at the professional level.

The constituent-created ISU competencies provide the basis for an on-line measurement system that is well aligned with performance management and professional development systems in common practice in the engineering workplace. This system presents minimal burden to supervisors and mentors of engineering students and requires little education and training of the users.

The use of an on-line competency-based assessment system, such as OPAL™, provides large volumes of data to each program and to the college each semester, with little or no demand on faculty resources. A broad and representative sampling of student competency development is assured because of the high degree of student participation in experiential education and resulting supervisor assessment. Faculty can focus on data analysis, design and implementation of curricular changes, and analysis of the results of those changes.

Understanding the importance of developing workplace competencies in students provides an opportunity to re-invigorate and re-invent the engineering education process. Competencies provide students with a clear map and the navigational tools needed to become successful engineers and have a strong impact on student learning.

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