AC 2007-1737: STUDENT OUTCOME ASSESSMENTS METHODOLOGY IN MECHANICAL ENGINEERING

Anne Spence, University of Maryland-Baltimore County

ANNE M. SPENCE is an Assistant Professor of Mechanical Engineering at UMBC and holds a Ph.D. in Aerospace Engineering. During her thirteen years as an engineering educator, she has developed curricula, directed programs to increase the recruitment and retention of women in engineering, and developed hands on engineering programs designed to foster an interest in engineering among elementary, middle and high school students. She manages a number of NSF grants related to engineering education.

Liang Zhu, University of Maryland-Baltimore County

LIANG ZHU is an Associate Professor of Mechanical Engineering at UMBC and holds a Ph.D. in Mechanical Engineering. Her research focuses on the effects of vascular geometry and blood perfusion on local heat transfer in microcirculation and the simulation of temperature fields in tissue during hyperthermia and hypothermia treatment for various diseases. Dr. Zhu was actively involved in the ABET data collection and analysis process.

© American Society for Engineering Education, 2007

Student Outcomes Assessment Methodology in Mechanical Engineering

Introduction

For many years, mechanical engineering departments around the country have prepared for visits by the Accreditation Board for Engineering and Technology (ABET). Typically, the preparation for these visits and accompanying reports could be generated quickly and often by a single individual. The data that was collected was often referred to as "bean counting" as the number of credits in mathematics, physics, design, thermodynamics, etc. were simply counted and entered on a form. The evolution of the ABET 2000 Criteria has forced mechanical engineering departments to reconsider the age-old methods of evaluating the education that is provided to their students.

According to Lohmann[1], one of the most important pieces of the process is to gather large amounts of data from a variety of sources. This provides a means to cross-check the outcomes. The United States Military Academy uses a Course Assessment Plan to collect and analyze data.[2] This system relies on surveys and end of course grades to provide qualitative and quantitative assessments. Felder[3] suggests that there are many ways to assess student learning and, ultimately, program outcomes, but both qualitative and quantitative methods should be employed. With all of these recommendations in mind, the Department of Mechanical Engineering at UMBC, developed a process to assess program outcomes that reinvigorated the course delivery and assessment process.

Methodology

As the reality of ABET 2000 criteria began to set in, the department began discussions centered around the mechanical engineering program outcomes – what students are expected to know and be able to do by the time of graduation. Old criteria simply required students to complete courses in specific areas, new criteria requires departments to identify specific outcomes related to the program. It was critical at this step to identify outcomes that could be both measurable and assessable. After much discussion, faculty chose to approve the outcomes identified by ABET as a-k and mechanical engineering outcomes l-o.

ABET Outcomes

Our Mechanical Engineering graduates will have:

(a) An ability to apply knowledge of mathematics, science, and engineering
(b) An ability to design and conduct experiments, as well as to analyze and interpret data
(c) An ability to design a system, component, or process to meet desired needs
(d) An ability to function on multi-disciplinary teams
(e) An ability to identify, formulate and solve engineering problems
(f) An understanding of professional and ethical responsibility
(g) An ability to communicate effectively

(h) The broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) A recognition of the need for, and an ability to engage in life-long learning
(j) A knowledge of contemporary issues
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

ME outcomes

(l) Knowledge of chemistry and calculus-based physics with depth in at least one
(m) The ability to apply advanced mathematics through multivariate calculus and differential equations
(n) Familiarity with statistics and linear algebra
(o) The ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems.

Upon identification of these outcomes, the arduous task of outcomes measurement and assessment began. Course work is the mechanism used to produce the program outcomes. Students take courses in four broad areas:

1. General Foundation Courses (30 credits, 10 courses)
   These courses in the Arts and Humanities, Social Sciences, and Language and Culture form the primary basis for achieving the **outcomes g, h, and j. Secondarily, they contribute to achieving outcomes i and o.**
2. Science and Mathematics (36 credits, 10 courses).
   These courses insure that students achieve **outcomes a, b, l, and m**.
3. Engineering Science and Fundamentals (47 credits, 16 courses).
   These courses insure that students achieve **outcomes a, b, d, e, f, g, i, k, m, n, and o.**
4. Engineering Design (15 credits, 5 courses).
   These courses insure that students achieve **outcomes b, c, d, e, f, g, i, k, o.**

Faculty then began to identify the outcomes that were addressed in the individual courses. Often courses provided a thorough view of the topic and, in other cases, it was simply an introduction or brief discussion of the outcome. Table 1 shows the mapping of each course to the expected a-k outcomes addressed.

Table 1. Mapping of Courses to ABET Criteria

	ABET Criteria										
Course	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
ENES101	X		X	X	X		X				X
ENES110	X				X		X				X
ENES220	X		X		X						X
ENES221	X				X		X				X
ENME204	X		X	X	X		X				X
ENME217	X				X						
ENME301	X	X	X	X	X	X	X	X	X		X
ENME303	X				X						X
ENME304	X	X	X	X	X	X	X	X	X	X	X
ENME320	X		X		X					X	
ENME321	X	X			X		X				X
ENME332L	X	X	X		X		X				X
ENME360	X	X	X		X						X
ENEE302	X	X	X		X						X
ENME403	X		X	X	X						X
ENME432L	X	X	X	X	X	X	X	X	X	X	X
ENME444	X	X	X	X	X	X	X	X	X	X	X
ENME482L	X	X	X	X	X		X				X
Technical Electives											
ENME412	X	X	X	X	X		X	X	X		X
ENME423	X		X		X	X			X	X	X
ENME465	X	X	X		X						X
ENME471	X	X	X		X	X	X	X	X	X	X
ENME475	X	X	X		X		X				X
ENME489B	X		X		X	X	X			X	
ENME489C	X	X	X		X	X	X	X	X	X	X
ENME489F	X				X					X	X
ENME489G	X		X		X	X	X			X	X
ENME489H	X	X		X	X		X				X
ENME489J	X	X	X	X	X	X	X	X	X	X	X
ENME489L	X	X	X	X	X	X	X	X	X	X	X
ENME489M	X		X		X	X	X		X		X
ENME489N	X	X	X		X						X
ENME489Q	X	X	X	X	X		X	X	X		X

Having identified the outcomes that are addressed in each of the courses, the faculty began to create assessment tools that would allow them to evaluate progress toward achieving the outcomes. Prior to ABET 2000, the primary methods used to evaluate student learning were final grades and university generated course evaluations. Final grades provide an overall view of student achievement but are unable to drill down to determine if students have met course outcomes. Course evaluations did not always provide the data that was needed. With this in mind, the faculty began to identify course outcomes and develop assessment tools.

The first thing that became clear in this process was that many courses did not have clearly defined outcomes. To resolve this, faculty met within their thematic areas to take a close look at the outcomes for each course and how those outcomes fit in to the overall thematic area outcomes. The following thematic areas were identified: Thermal/Fluids (THFL), Design/Manufacturing and Systems (DEMS), and Solid Mechanics and Materials (SMMS). The result of this exercise was a Course Outcomes Worksheet (COW). Each course has a COW that identifies course outcomes, relates the outcome to ABET outcome, describes the activities used to convey the course outcomes, and defines the basis for the assessment. Two sample COWs for a sophomore level design course and a junior level engineering mathematics course are included in Tables 2 and 3 below. After identifying course outcomes for all courses, the faculty moved on to assessment tools.

Table 2. Sample COW for ENME204: Introduction to Engineering Design with CAD

Course Outcomes	**Supports ABET Outcomes**	**Activity**	**Basis for Assessment**
Each student will be able to identify and use sources of information.	i(0)	Lecture, visit to the library	Laboratory assignment, design project
The student will be introduced to the product development process, which includes: sources of information, needs identification, project definition and planning, objective trees, Quality Function Deployment (QFD), functional analysis, materials selection, concept generation, embodiment design and cost analysis. Each team will be required to design, construct, evaluate, test and present (written and orally) their product.	a(*), b(0), c(*), d(*), e(*), f(0), g(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, instructor assessment, graded homework, quizzes, design project, and exams
Each individual student will develop their specific design analysis and computer skills including applications software (Microsoft Word and Microsoft Excel) and graphics (ProEngineer).	a(*), b(0), c(*), e(*), i(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, instructor assessment, graded homework, quizzes, design project, and exams

Course Outcomes	**Supports ABET Outcomes**	**Activity**	**Basis for Assessment**
By the end of the course, the student will have had opportunities to further his/her professional development through working in teams, practicing written, oral and graphical communication skills, using modern computer tools and acquiring an appreciation to engage in life-long learning.	c(*), d(*), e(*), f(0), g(*), h(0), i(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, instructor assessment, graded homework and exams

Note: (*) indicates a heavy coverage and (0) indicates a moderate coverage of the outcome.

Table 3. Sample COW for ENME303: Topics in Engineering Mathematics

Course Outcomes	**Supports ABET Outcomes**	**Activity**	**Basis for Assessment**
The student will be able to solve linear algebraic equations numerically	a(*), b(0), e(*), g(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, and exams
Each individual student will learn numerical methods to fit curves to data.	a(*), b(0), e(*), g(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, and exams
Students will find roots of equations numerically.	a(*), b(0), e(*), g(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, and exams
The student will learn to evaluate integrals and differentials numerically.	a(*), b(0), e(*), g(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, and exams
Students will solve differential equations numerically.	a(*), b(0), e(*), g(0), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, and exams
Students will learn Matlab programming skills.	a(*), e(*), k(*)	Lecture, in class examples, discussion session assistance, homework, exams	Student assessment, and exams
Students will apply the engineering code of ethics to case studies.	f(0)	Homework	Homework

The next tool developed was the Course Outcomes Survey (COS). Initially, the COS asked students to assess the knowledge that they gained in the areas of the ABET a-k outcomes in a given course. While this provided broad data, it was not the best way to perform the evaluation since it would be difficult to identify exactly why students were not “gaining experience in applying mathematics, science and engineering.” When this tool was developed five years ago, faculty compared the results of the COS of students with their own assessment of the achievement of course outcomes. Again, this exercise was useful in identifying strengths and weaknesses in the course, but it did not provide a quantitative measure of course outcomes. Since then, the COS has evolved into a tool that requires students to rate how well the instructor met the stated Course Outcomes using the following scale: (E=Excellent, V=Very Good, G=Good, F=Fair, P=Poor). The students are also given an area to provide general comments on the strengths and weaknesses of the course. An example COS for the engineering mathematics course is included in Table 4.

Table 4. Sample COS for ENME303: Topics in Engineering Mathematics

Course Outcomes:	**E**	**V**	**G**	**F**	**P**
Students will be able to solve linear algebraic equations numerically					
Students will learn numerical methods to fit curves to data.					
Students will find roots of equations numerically.					
Students will learn to evaluate integrals and differentials numerically.					
Students will solve differential equations numerically.					
Students will learn Matlab programming skills.					
Students will apply the engineering code of ethics to case studies.					

Initially, these surveys were completed with paper and pencil during class time. However, a couple of years ago, the survey was moved to Blackboard and the students completed the assessment online. The students received homework credit for completing the survey by a given due date. The most remarkable thing about the transition to the online version was that students gave significantly more comments when they were allowed to complete the survey on their own time schedule. The Blackboard survey tool indicated if a student had completed the survey and gave a summary of results. This also streamlined the data analysis process.

In order to provide quantitative data related to the course outcomes, the Quantitative Assessment of Course Outcomes (QuACO) was developed. This tool identifies the instructor's detailed assessment of the student achievement of course outcomes. The analysis goes far beyond giving a course grade. It entails the detailed evaluation, in light of the course objectives and the ABET outcomes addressed by this course, of some or all of the work upon which a student's grade is based. These works include homework assignments, quizzes, tests, exams, project reports, presentations, and demonstrations. Since different courses emphasize different experiences, most courses will include only a subset of the above items. Furthermore, the department does not want to restrict any course instructor in the way the course is delivered and graded. This results in some variation in the student work materials that are used for the outcomes assessment. For example, one of the course outcomes in the sophomore design course is "an understanding of the design process". In order to assess this in a quantitative fashion, the instructor developed a laboratory assignment that targeted the design process. The grade on this assignment paired with the grade on the design process section of the final design report, comprise the quantitative assessment of student progress in the outcome identified above. This process has proved to be valuable as it requires instructors to insure that they have not only defined their course outcomes, but are also measuring them in some quantitative fashion. After collecting the data for all students in each course, the course outcomes are mapped to the ABET outcomes and a quantitative value is obtained indicating success in achieving the ABET outcomes. An example QuACO for the engineering mathematics course is given in Table 5.

Table 5. Sample QuACO for ENME303: Topics in Engineering Mathematics

Course Outcome	Basis for Assessment
The student will be able to solve linear algebraic equations numerically	One final exam problem
Each individual student will learn numerical methods to fit curves to data.	Three final exam problem
Students will find roots of equations numerically.	One final exam problem
The student will learn to evaluate integrals and differentials numerically.	One final exam problem
Students will solve differential equations numerically.	One final exam problem
Students will learn Matlab programming skills.	One final exam problem
Students will apply the engineering code of ethics to case studies.	One homework

The assessment tools identified above are valuable in evaluating the program outcomes. The methods are quite extensive and allow the department to determine if (a) ABET outcomes are at an acceptable level, (b) the assessments are indicators of strength and weaknesses in curriculum objectives, and (c) the assessment results provide the basis on which all constituents, especially the faculty, can base action items for changes in the program. The metrics used to insure that students meet the competency level in each outcome required to meet the program outcomes is based on a very detailed analysis of students' work in each course. It is expected that students will attain at least a 70% level of achievement for each activity associated with each ABET outcome.

Results

Data was collected for all courses during the 2004-2005 academic year. While this represented a significant workload, it did provide valuable baseline data for the department's first evaluation under the ABET 2000 criteria. Table 6 shows the results of the COS for ENME303 in the Fall 2004 semester. Course outcomes survey ratings of excellent or very good by over 70% of the students represents an acceptable level. This level was met in all but two of the outcomes – Matlab programming skills and the application of the engineering code of ethics to case studies. This would indicate that a different approach should be used to deliver these outcomes or more time should be spent on these outcomes in future delivery of the course.

Table 6. COS Results for ENME303: Topics in Engineering Mathematics in Fall 2004

(Reported values represent the number of students choosing the rating, n =50)

Course Outcomes:	**E**	**V**	**G**	**F**	**P**
Students will be able to solve linear algebraic equations numerically	27 (54%)	16 (32%)	6 (12%)	1 (2%)	0 (0%)
Students will learn numerical methods to fit curves to data.	20 (40%)	23 (46%)	7 (14%)	0 (0%)	0 (0%)
Students will find roots of equations numerically.	22 (44%)	21 (43%)	6 (12%)	1 (2%)	0 (0%)
Students will learn to evaluate integrals and differentials numerically.	28 (56%)	16 (32%)	5 (10%)	1 (2%)	0 (0%)
Students will solve differential equations numerically.	21 (42%)	20 (40%)	9 (18%)	0 (0%)	0 (0%)
Students will learn Matlab programming skills.	5 (10%)	10 (20%)	21 (42%)	11 (22%)	3 (6%)
Students will apply the engineering code of ethics to case studies.	13 (26%)	14 (28%)	18 (36%)	4 (8%)	1 (3%)

Note: Numbers in (%) represent the % of students reporting in that category.

Table 7 shows the results of the QuACO for the engineering mathematics course. More than 70% of the students achieved a grade of 70 or better on their ability to solve linear algebraic equations numerically, find roots of equations numerically, evaluate integrals and differentials numerically, solve differential equations numerically, learn Matlab programming skills, and apply the engineering code of ethics to case studies. Students fell well short of expectations on their ability to learn numerical methods to fit curves to data. The instructor resolved to spend more time helping students to identify the differences between curve fitting and least squares regression. Clearly, there were deficiencies in the students' ability to program in Matlab since 37% performed at an unacceptable level. To resolve this, the instructor will spend more time introducing students to Matlab in the discussion period. In addition, a Matlab text will be required for the course.

Table 7. QuACO Results for ENME303: Topics in Engineering Mathematics in Fall 2004

(Reported values represent the number of students with grades in the given range, n = 55)

Course Outcomes:	**90-100**	**80-89**	**70-79**	**60-69**	**59 and below**
Students will be able to solve linear algebraic equations numerically	53 (96.4%)	0 (0%)	0 (0%)	1 (1.8%)	1 (1.8%)
Students will learn numerical methods to fit curves to data.	12 (21.8%)	2 (3.6%)	15 (27.3%)	9 (16.4%)	17 (30.9%)
Students will find roots of equations numerically.	45 (81.8%)	1 (1.8%)	9 (16.4%)	0 (0%)	0 (0%)
Students will learn to evaluate integrals and differentials numerically.	45 (81.8%)	1 (1.8%)	1 (1.8%)	2 (3.6%)	6 (10.9%)

Course Outcomes:	**90-100**	**80-89**	**70-79**	**60-69**	**59 and below**
Students will solve differential equations numerically.	34 (61.8%)	16 (29.1%)	0 (0%)	0 (0%)	5 (9.1%)
Students will learn Matlab programming skills.	25 (45.5%)	3 (5.5%)	11 (20.0%)	1 (1.8%)	15 (27.3%)
Students will apply the engineering code of ethics to case studies.	31 (56.5%)	8 (14.5%)	6 (10.9%)	2 (3.6%)	8 (14.5%)

Note: Numbers in (%) represent the % of students achieving grades in the given range.

Tables 6 and 7 are representative of the qualitative and quantitative data that was collected for each course. After instructors collect the data, they identify strengths and weaknesses, make observations and identify actions to be taken. Faculty then meet in thematic areas to discuss the broader findings of courses. This is a critical piece to the continuous improvement process since instructors for courses might change each semester. This enables faculty who take over a course to be appraised of the deficiencies and take steps to improve the course when they teach it. These thematic area meetings also provide the opportunity to determine how topics should be distributed throughout the courses.

After COS and QuACO data has been collected for each course, the task of mapping course outcomes to ABET criteria begins. The COW is used to identify the weighting that course outcomes receive as they are mapped to the ABET criteria. The summary of that mapping is presented in Tables 8 and 9. Table 8 shows the summary of the QuACO data for the Fall 2004 semester. The table shows that most of the ABET criteria are met at an acceptable level. The overall averages for each criteria meet the 70% level that the department identified as an acceptable level. Courses that do not meet the 70% level are identified for improvement within the thematic areas.

Table 8. Fall 2004 QuACO Summary

(Reported values represent %-level out of a maximum of 100)

	Quantitative Assessment of ABET Outcomes													
Course	**a**	**b**	**c**	**D**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**
ENES220	80		76		76						76			
ENME301	71	73	73	73	71	72	72	71	71		70			
ENME303	84	84			84		84				84		86	94
ENME332L	75	74	75	75	74	75	74	75	75	75	74			
ENME489C	63	66	63		63	70		70	72	70	63			
ENME489L	92	87	92	92	92	94	92	92	92	92	92			
ENME204	78	84	85	87	95	88	83	91	90					
ENME304	75	75	75	84	75	84	84		79	79	75			
ENME360	76	76	82		82		82				76			
ENME403	79		79	82	79						79			
ENME444	77	81	75	74	75	79	80	77	80	79	78			
ENME217	72				73									

Course	Quantitative Assessment of ABET Outcomes													
	a	**b**	**c**	**D**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**
ENME320	74	78			74					85				
ENME321	66	91		91	83		97				91			
ENME432L	86	86			86	99	87				87	80	80	
Average	***77***	***80***	***78***	***82***	***79***	***83***	***84***	***79***	***80***	***80***	***79***	***80***	***83***	***94***
Metric	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Difference	**+7**	**+10**	**+8**	**+12**	**+9**	**+13**	**+14**	**+9**	**+10**	**+10**	**+9**	**+10**	**+13**	**+7**

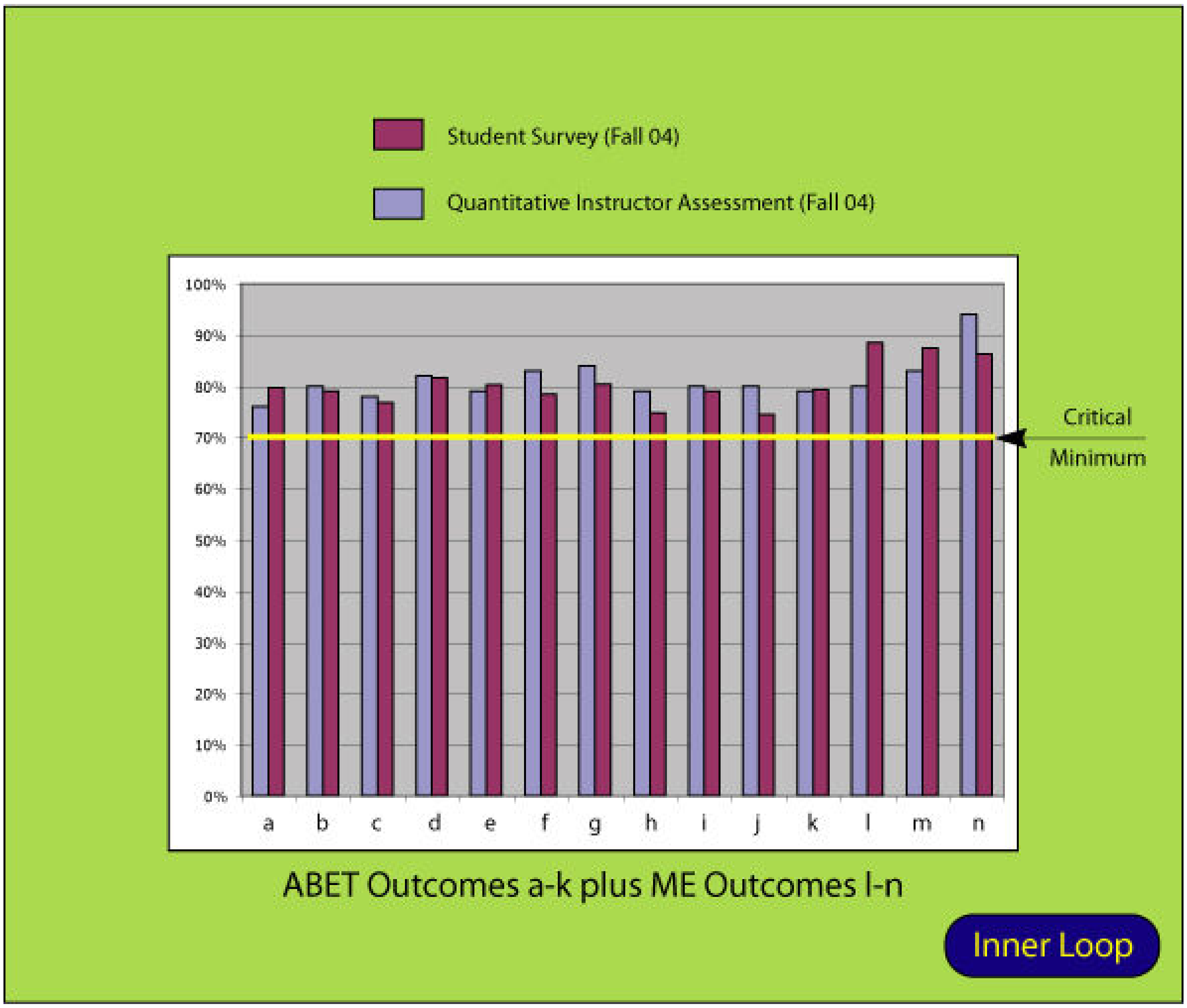
Table 9 shows the summary of the COS data for the Fall 2004 semester. The table shows that most of the ABET criteria are met at an acceptable level. The overall averages for each criteria meet the 70% level that the department identified as an acceptable level. Courses that do not meet the 70% level are identified for improvement within the thematic areas. Finally, Figure 1 provides a graphical comparison of QuACO and COS results for the Fall 2004 semester.

Table 9. Fall 2004 COS Summary

(Reported values represent %-level out of a maximum of 100)

Course	Qualitative Assessment of ABET Outcomes													
	a	**b**	**c**	**D**	**e**	**f**	**g**	**h**	**i**	**j**	**k**	**l**	**m**	**n**
ENES101	73	67	70	76	72	63	65	61	66	54	63			
ENES220	67		70		67						70			
ENME301	87	64	64	65	87	78	70	82	83	85	74			
ENME303	81	81			81		81				81		86	86
ENME332L	78	80	78	78	74	75	74	75	75	75	74			
ENME489C	76	73	76		76	87		87	79	87	76			
ENME489L	67	80	78	81	75	70	80	64	79	62	70			
ENME204	81	87	93	93	83	80	80	83	90	74	91			
ENME304	82	82	81	85	82	85	85		81	83	82			
ENME360	88	87	88		90		86				88			
ENME475	79	70	70		80			70			80			
ENME320	78	76			78					76				
ENME321	92	93		93	91		93				93			
ENME432L	89	89			89	89	90				90	89	89	
Average	***80***	***79***	***77***	***82***	***80***	***78***	***80***	***75***	***79***	***75***	***79***	***89***	***87***	***80***
Metric	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Difference	+10	+9	+7	+12	+10	+8	+10	+5	+9	+5	+9	+19	+17	+16

Figure 1. Comparison of QuACO and COS Results for the Fall 2004 Semester



The results indicate that all of the program outcomes are meeting the critical minimum of 70%. In general, however, students perform as well as or better than their own self-evaluation. It is difficult to determine if this is a true self-reflection or if students are simply "hedging their bets." Students seem to over-predict their abilities in outcomes (a) An ability to apply knowledge of mathematics, science, and engineering, (l) Knowledge of chemistry and calculus-based physics, and (m) The ability to apply advanced mathematics through multivariate calculus and differential equations. There are very few data points for (l), (m) and (n) so the results may not be as robust as those for other outcomes.

The data does show that the student's ability to apply knowledge of mathematics, science and engineering is at a lower level than most of the other outcomes. To remedy this situation, the department is placing more effort into developing relevant problems and projects that require students to apply their knowledge.

Conclusions

The department entered into the ABET 2000 process with the goal of reevaluating the undergraduate curriculum and the way that program outcomes were developed. Faculty worked through their thematic areas to develop course outcomes and map them to program outcomes. The COW, QuACO and COS were developed to provide an operating framework as well as to allow both the qualitative and quantitative assessment of program outcomes. Although the process is labor intensive initially, adoption of the course outcome philosophy helps faculty to streamline course delivery and assessment. Results of the initial implementation of the process have identified areas of improvement.

The Department of Mechanical Engineering at UMBC was granted full ABET accreditation.

---

[1] Lohmann, J., "EC2000: The Georgia Tech Experience", *Journal of Engineering Education*, July 1999, pp. 305 – 310.
[2] Bailey, M., Floersheim, B. and Ressler, S., "Course Assessment Plan: A Tool for Integrated Curriculum Management," *Journal of Engineering Education*, October 2002, pp. 425 -434.
[3] Felder, R., and Brent, R., "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria," *Journal of Engineering Education*, January 2003, pp. 7 – 25.