All, Most or Some: Implementation of Tiered Objectives for ABET Assessment in an Engineering Program

Elliott B. Slamovich and Keith J. Bowman
Purdue University, elliotts@purdue.edu, kbowman@purdue.edu

Abstract - **The Purdue School of Materials Engineering's successful ABET assessment in 2007 relied in part on an innovative approach to setting course objectives set at levels based on the performance expected for all students, most students and some students. By not relying merely on averages and variability or some scaling based on percentiles, faculty may match exam questions and written laboratory report content to a set of tiered objectives. Using the all, most, some system facilitates a systematic approach to document student performance across the curriculum and provides a context for multiple instructors responsible for specific courses to discuss the course objectives and student success in meeting them.**

Index Terms – ABET, assessment, Bloom's Taxonomy, tiered course objectives.

INTRODUCTION

The Purdue School of Materials Engineering (MSE) radically changed the direction of its undergraduate curriculum in 1989 to serve better students destined for a broader range of future employment and research directions across the realm of metals, ceramics, polymers and electronic materials. This was accomplished by developing a broader consideration of phenomena that span or impact materials no matter the specific category. This change was concurrent with the National Academy of Engineering report addressing competitiveness [1], and resulted in dramatic changes in course content or creation of new courses throughout the Purdue MSE curriculum. Specific attributes that came about through 1995 included stronger inclusion of ceramics and polymers in introductory courses and also in courses on mechanical properties, thermodynamics, transport phenomena and solid state physics of materials. Laboratory courses were also expanded and broadened to truly reflect considerations of this expanding realm for practitioners of materials science.

One important theme that arose has been described as the "Generic Materials Processing Curriculum," which through National Science Foundation support [2] enabled development of courses based specifically on materials processing. The laboratory course truly engaged students in processing of metals, ceramics and polymers wherein the laboratory exercises possessed sufficient flexibility for students to learn through failure as well as success. This change in the curriculum and the integration and interdependence of coursework along with a strong component of true team teaching in many of these courses led to a culture of reflection and innovation on how well MSE students could be served by course improvements. Missing however through the first decade of steady changes, which also included a turnover of nearly two thirds of the faculty, was a satisfactory approach for integrating course objectives and student outcomes necessary to establish a process of continuous improvement.

Prior to 2001, outcomes assessment was based solely on student feedback about a course and course instructor *via* end-of-semester course evaluations. While the faculty examined homework, lab reports, exams, and written reports, there was no systematic documentation of student performance. Associated with the ABET visit of the 2001-02 academic year, a system of outcomes assessment was initiated based on qualitative and quantitative measures. The evolution of the ABET a-k criteria over the following years led to major changes in the outcomes assessment process initiated in 2001.

OUTCOMES ASSESSMENT 2005-2006

An important change made in the 2005-2006 academic year to simplify assessment was to modify Purdue MSE Program Outcomes to mirror the ABET a-k Outcomes [ABET a-k]. Purdue MSE outcomes c, d, f, g, h, and i are identical to the ABET a-k, and outcomes a, b, e, j and k have been modified slightly to emphasize the materials engineering content of the curriculum. During this time period the Purdue MSE faculty also grew substantially with the net change between 2003 and 2006 being from 14 to 20 faculty full time equivalents. By the end of this academic year most of the new hires began to be integrated into roles teaching parts of the undergraduate curriculum through a program substantially comprised of team teaching fundamental courses or laboratories. This necessitated a great deal of discussion and reflection as to the purpose of course objectives and the design of outcomes assessment.

The MSE faculty determined how each course in the MSE curriculum related to the MSE Program Outcomes, and for each course developed appropriate Course Objectives that reflected course content. The development of Course Objectives was discussed at faculty meetings so the instructors of every course could receive input from the entire faculty. The Course Objectives are typically generic, thereby providing instructors a great deal of flexibility when formulating tasks to achieve a given objective. For example, Objective 1C for MSE 230 "Structure and Properties of Materials" states: "Recognize the effect of composition and microstructure on material properties". An example of a task related to this objective is an exam question about the Hall-Petch effect in polycrystalline metals. Objective 2C, states: "Assess the interplay of two material properties." In this case an example task is an exam question related to the effect of atomic bond strength on Young's modulus, the coefficient of thermal expansion and the melting temperature of a material. To facilitate assessment the Course Objectives associated with each course in the MSE core curriculum are mapped to the MSE Program Outcomes.

The second change in the assessment system of 2005 was to replace the hypothetical "average" student with the recognition that a student population is better described by a distribution reflecting the significant variability in performance for a given group of students. Although approaches for designing teaching to correspond to ABET criteria have been described [3-6], a coupled approach prioritizing objectives that can be coupled to assessment is heretofore unavailable. Purdue MSE thereby defined three categories for Course Objectives that would enable a coupled approach by creating tiers of success for student outcomes. The first category consists of objectives that an instructor believes "all" students should achieve, the second category consists of objectives that "most" students should achieve, and the third category consists of objectives that "some" students should achieve. The three levels of Course Objectives are distinguished by number with "all" students objectives labeled as 1A, 1B, 1C, etc.; "most" student objectives labeled as 2A, 2B, 2C, etc. and "some" student objectives labeled as 3A, 3B, 3C, etc. Examples of level 1 and 2 Course Objectives were provided above. One of the level 3 examples from MSE 230 "Structure and Properties of Materials" states: "Describe a processing sequence to produce materials with specific microstructure and/or properties".

Although during this time period Purdue MSE faculty utilized no specific guidelines differentiating between "all", "most" and "some" course objectives besides the meanings of each word, "all" objectives typically involve information processing with little analysis, "most" objectives require information analysis and some synthesis relating data to physical phenomena or interrelating physical phenomena and "some" student objectives require the application of information in a different context from where the information was initially gleaned with emphasis on synthesis and evaluation. Tiered objectives could be related to Bloom's Taxonomy and descriptions used in engineering [e.g. see 7], but Purdue MSE faculty consciously chose to limit the number of tiers for assessment of educational accomplishment as a materials engineer to three rather than the more extended and complex challenge of relating course objectives to the six learning levels commonly used for Bloom's Taxonomy [8]: knowledge (1), comprehension (2), application (3), analysis (4), synthesis (5) and evaluation (6).

In practice, the "all" objectives used by Purdue MSE generally fall across the levels 1-4 of Bloom's Taxonomy, the "most" objectives span levels 3-5 and the "some" objectives typically fall into levels 5 and 6. Because materials science education engages a higher emphasis on explaining and describing complex interactions related to fundamental science and has a somewhat lesser emphasis on problem solving than engineering disciplines such as chemical engineering, mechanical engineering and electrical engineering, enabling the instructors to think more broadly of how important the objectives are relative to student performance has several advantages. First it enabled a team of instructors who may team teach or alternate the teaching of a course to have a simple context for deciding what expectations they have for student performance and how well particular editions of the course content, course materials and teaching approaches enable students to meet expectations. Second, it also enables clear and coherent explanation of the course objectives to colleagues who teach related courses or who may also be interested in program objectives. And, lastly, it makes assessment more tractable and less daunting for faculty.

The tools used to assess success in achieving the MSE Program Outcomes included: examination questions, rubrics and a survey completed by the sponsors of our senior design projects. In the case of midterm and final examinations the link between a specific question and one or more Course Objective(s) (and thereby one or more of the ABET a-k Outcomes) is straightforward. Linking tasks in a laboratory report or a technical paper requires more forethought on the part of the instructor to ensure that the overall score in an assignment can be parsed to reflect the contributions of components of the assignment that correspond to different Course Objectives and ABET Outcomes, a-k. Developing scoring guides (often referred to as rubrics) to evaluate student performance based on several performance criteria was helpful in many cases. Further, the need to parse an assignment into its components provided instructors with the opportunity to reflect on the goals of the individual tasks and make refinements. A survey completed by the industry sponsor of each group senior design projects diversified the assessment input beyond the faculty. Surveys were also used to address outcomes that were most challenging to obtain from direct measures.

OUTCOMES ASSESSMENT 2006-PRESENT

The outcomes assessment process outlined above enabled direct mapping of course tasks to the ABET a-k Outcomes, but included no specific metric goals. Another improvement in the Purdue MSE assessment process was the development and implementation of metric goals.

Student performance on Course Objectives associated with each MSE Program Outcome is used as a direct measure of student achievement. Two sets of Course Objectives are assessed. The first set corresponds to Course Objectives we expect "all' students to satisfy. Because "all" students likely perform differently on different days and a great deal of coursework and laboratory work involves partial credit a threshold for performance is used for assessing student performance on "all" objectives. For any individual to satisfy a given "all" Course Objective he or she must achieve a score of at least 60% of the possible points on the associated task (e.g., exam question, lab report section). For a class to satisfy the Course Objective, 70% of the students in the class must satisfy the 60% threshold. If a class does not reach the 70% threshold, the instructors comment in their course assessment addressing the nature of the deficiency (e.g., was the task too difficult or does the instructor need to take steps to reinforce the material?) and a remedy (such as revisiting the concept(s) in question, and/or suggesting improvements for the next course cycle). The second set corresponds to Course Objectives "most" students are expected to satisfy. For a class to satisfy the Course Objective, 50% of the students in the class must meet or surpass the 60% threshold. Class goals are not strongly emphasized for level 3 or "some" objectives because these are based on expectations for the most talented and best prepared students. Because few tasks are assigned with the expectation that only "some" students will be successful, all of the assessment effort has been directed towards the "all" and "most" Course Objectives. However, defining "some" objectives is useful to ascertain whether the brightest students are challenged in their coursework. Feedback from students in course evaluations or during senior exit interviews (conducted by the Head of School) provides feedback mechanisms to help instructors develop "some" objectives where beneficial.

Implementation of the assessment scheme described above required the collection of appropriate data, viz., the distribution of scores on a given task rather than the average score. The class average is a reasonable reflection of overall class performance, but the distribution provides a better reflection of individual performance.

APPLYING ALL-MOST-SOME TO ASSESS AN INDIVIDUAL COURSE

Once the grading of an exam or assignment is complete, the student scores associated with each task in the exam or assignment are collected. Data collection from the graded exams is usually performed by an administrative assistant, although some of the faculty prefer to do this themselves. Due to the workload involved, data are typically collected from "major" assignments like examinations, technical papers and formal lab reports, but not from homework assignments, or quizzes. The performance of the class is assessed from the distribution of scores on a given task. Typical sample sizes are from 25-35 students. All of the students' scores are included in the process for smaller classes, but for large classes like the introductory course (with an enrollment of approximately 200 students per semester) a representative sample of the students is used for assessment purposes. When the number of MSE students in such courses are sufficiently large, their exams are separated from the rest of the class to obtain the sample. When MSE student enrollment is small, a random sampling from all of the students is used.

In the Fall of 2006 Purdue MSE began to use these metric goals for measurable tasks (e.g., tasks that are given a score in some form). The relationship between assessing individual tasks, courses and the curriculum described below is summarized in Figure 1.

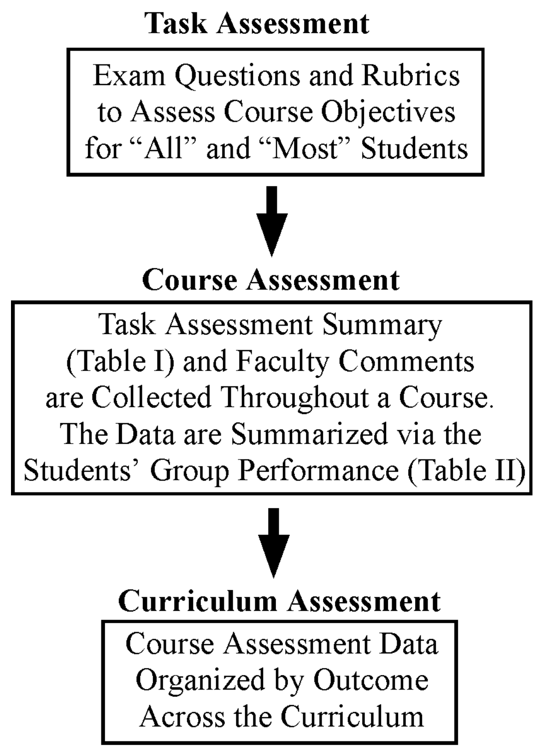

Figure 1: Relationship between assessment at the task, course and curricular levels.

A standard format called the Assessment Summary was adopted to communicate to the instructor the class performance on a group of tasks. The scores from an exam or lab report were collected by the instructor or an administrative assistant, the data was processed to determine the scoring distribution on each task, and the summary data was returned to the instructor. The instructor assigns the appropriate Course Objectives to each task, comments as needed on goals that were not reached or anything else the instructor considers relevant.

An example of an Assessment Summary for a midterm examination is provided below for MSE 235 Materials Properties Laboratory (Table I), a course offered in the fall semester of the sophomore year. The summary lists the

TABLE I: EXAMPLE OF AN EXAMINATION ASSESSMENT SUMMARY

Ques.	Course Objec.	ABET Outcome	Avg. Score	% of sample over 60%	Class Goal Reached?
1a	1C	a,k	5.0/5	100	Y
1b	1C	a,k	4.6/5	93	Y
1c	1C	a,k	4.5/5	100	Y
1d	1C	a,k	6.5/10	45	N
2a	1D	a,b,k	14.0/15	95	Y
2b	1D	a,b,k	9.4/10	93	Y
3a	1D	a,b,k	11.6/12	93	Y
3b	2B	b,e	7.1/12	51	Y
4a	1C	a,k	3.7/5	78	Y
4b	1C	a,k	9.1/10	90	Y
4c	1C	a,k	6.1/10	56	N

specific task (exam questions in this case), its associated Course Objective and ABET a-k Outcome, the average score for the sample, the percentage of students scoring greater than 60% of the possible points on the task (determined from the distribution of scores), and whether the class goal was reached (70% for level 1 or "all" student objectives, 50% for level 2 or "most" student objectives). The instructor provides written comments to complement the numerical data. The commentary accompanying Table I was as follows: "The assessment of the midterm exam indicates that some of the class goals have not been reached. Problems 1d (involving the symmetry in crystal structures) and 4c (Euler angles) deviate the most from expectations based on class objectives. Although these problems are included in an "all students" objective of the course they involve some of the most advanced mathematical concepts covered in the class, and it is the first time our students are exposed to these ideas (that are reinforced later in other MSE classes); the assessment results reflect this. The lab where these concepts are introduced are already challenging and lengthy. Simplifying the lab and focusing more on concepts may prove beneficial. An additional way of helping students grasp these complex concepts is with more emphasis on the connections between the different labs in the class; for instance, crystal symmetry can be reinforced in the XRD lab. Student performance in problem 3b (involving XRD of a sample with few grains) was also slightly below ideal. We believe this is because the XRD lab is performed before the microstructure one and concepts of grain size are not emphasized strongly enough. Again emphasizing the relationship between the various labs may prove beneficial here. After the students obtain micrographs from various samples with different microstructures they can be asked to explain what XRD diffraction patterns they expect."

At the end of the semester, the data from any Assessment Summaries performed during the semester are compiled to reflect student performance in the course. An example of a summary from MSE 235 Materials Properties Laboratory, consisting of tasks from the midterm and final examinations and a formal laboratory report, is provided in Table II.

The total number of evaluations (e.g., the total number of tasks evaluated) for the semester, listed by Course Objective and ABET a-k Outcome, is provided along with the number of times the group metric is achieved. In most cases a Course Objective addresses more than one ABET a-k Outcome thereby making the number evaluations for a given ABET a-k Outcome greater than the number of evaluations for a given Course Objective. The summary data are used to identify outliers and alert the instructor to deficiencies in a particular Course Objective or ABET a-k Outcome. From the example above, a high percentage of the "all" students Course Objectives achieved their goal while there was less success in achieving the goals for the outcomes directed towards "most" students. This suggests to the next instructor teaching this course that the current approach is effective at addressing "all" student Course Objectives and that their

TABLE II: EXAMPLE OF STUDENT GROUP PERFORMANCE

Course Objective	# of Evals.	Times Goal Achieved	ABET Outcome	# of Evals.	Times Goal Achieved
1A	4	4	a	15	13
1B	3	2	b	12	12
1C	7	5	e	3	2
1D	8	8	g	7	7
1E	3	3	k	21	19
1F	4	4			
2A	4	1	a	6	2
2B	8	3	b	12	5
2C	2	1	e	12	4
2D	2	1	g	0	0
			k	2	1

time is best spent examining means by which better performance at the "most" student Course Objectives could be achieved. At the end of the semester, the summary data is used along with other inputs to prepare a course summary.

A course summary is used to communicate assessment results and ideas for course improvement, and to document the continuous improvement process. In the first section the instructor addresses overall performance on Course Objectives and ABET Outcomes as summarized by the Student Group Performance (Table II). Next, any assessment summaries assembled during the course of the semester are added so all relevant information is in the same document. Following the summary data, the instructor is asked to document any attempts to address problems that were observed during the course of the semester, and efforts to address suggestions for improvement from assessments of the same course in previous years. These are both variations of the loop closing process essential to continuous improvement. The instructor is also asked to comment on the student evaluation feedback. Student evaluations provide tabulated scores (1-5 scale) to a series of questions, along with written comments and primarily address the instructor's performance rather than the course content Finally, the instructor is asked to suggest improvements to benefit the course in the future.

After completion, course summaries are forwarded to the Undergraduate Committee that reviews the summary for completeness using a course summary check sheet. Incomplete assessments are returned to the course instructor with recommendations for improvement. If the assessment is considered complete (e.g., instructor comments address goals not reached, recommendations for improvement included, etc.) one copy of the assessment is forwarded to members of the relevant course team, and the assessment is archived on a server accessible to all faculty members. A course team consists of a group of faculty who take turns leading a given course. Course teams tend to be larger for MSE 230, a course offered every semester, and for laboratory courses that typically have either two or three instructors. As discussed above, the next instructor or group of instructors is obligated to incorporate recommendations from the previous assessment into their course, or explain why this was not done.

APPLYING THE ASSESSMENT RESULTS FOR PROGRAM IMPROVEMENT

The process described above facilitates continuous improvement at the course level. The data may also be used to assess how the curriculum as a whole addresses the ABET a-k Outcomes. This requires the data from individual courses to be organized by outcome rather than by course. An example of how this is applied to ABET Outcome b is provided in Table III. Viewing the data by outcome allows one first to identify outliers of superior or inferior student performance among the courses, and second to identify outcomes that may be under or overrepresented in the curriculum. Regarding underrepresented outcomes, the Purdue MSE curriculum addresses Outcome c related to open-ended problem solving only in the capstone senior design sequence. If the faculty perceives outcome c to be underrepresented relative to its importance this may be remedied by modifying other core courses to include appropriate tasks.

TABLE III: CURRICULUM-WIDE OUTCOME b PERFORMANCE

MSE Course No.	No. of "All Students" Evaluations	Times Goal Achieved	No. of "Most Students" Evaluations	Times Goal Achieved
235	12	12	12	5
335	6	6	-	-
367	3	3	3	3
430	3	3	-	-

ENABLING PROGRAM IMPROVEMENT THROUGH ASSESSMENT: IMPLEMENTING NEW ASSESSMENT PRACTICES

To place the assessment results in perspective it is worth noting the changes made by the MSE faculty in how students are assessed, thereby enabling the collection of appropriate data to perform an assessment. Generating the data necessary to implement the all, most, some assessment process required major changes in scoring practices, and the detail with which scores are documented. This clearly has had an impact on scoring of exams, lab reports, presentations and written papers and has fostered greater discussion among faculty of how assignments are written and scores are determined.

The main challenge generating assessment data arose from the need to associate each task with a Course Objective for subsequent mapping to a ABET a-k Outcome. This is fairly straightforward when assessing an exam. However, careful planning is required to assess assignments like written presentations and laboratory reports in order to deconvolute scores associated with particular Course Objectives from one another. For example, in 2005-06 oral presentations in the group senior design project were awarded a single overall score. In 2006-07 the scoring was divided into sections for "Technical Mastery", "Organization", "Presentation Style", and "Graphics". This not only allowed one to separate out grading components associated with outcome g, but also provided students with feedback having greater clarity regarding the strengths and weaknesses of their performance. The laboratory instructors invested a significant amount of time developing appropriate rubrics for their courses. This facilitates laboratory assignment grading, and by sharing the rubric with the class the students have a much better understanding of the instructor's performance expectations.

Collecting the data presents its own challenge because the overall score on an assignment or exam is usually meaningless in the context of outcomes assessment. Instead, every score on every question, laboratory report section, or communication assignment section must be collected. At first this appears to be a daunting task. However, support staff have been very effective in assisting with the data collection, and the faculty have worked with them to develop approaches to document grading that make it relatively easy to extract the needed information from a given assignment.

CONCLUSIONS AND PERSPECTIVES ON TIERED ASSESSMENTS

In seeking to engage current expectations of the ABET accreditation process, the Purdue MSE faculty have designed an approach for tiered assessments that reflect expectations of student accomplishment across a broad spectrum of graded assignments and tasks. The "all", "most" and "some" objectives employed by the Purdue MSE faculty have enabled discussion of course improvement and curriculum change to take place in the context of expectations for graduates from our program. Although details of the approach are also subject to further improvement, the current implementation of tiered objectives has enabled the faculty to focus on how course content and course assignments are related. A successful ABET review in 2007 and a suprisingly painless consensus of the Purdue MSE faculty to major changes in course offerings and arrangement within our curriculum pending in 2008-2009 no doubt were related to the common understanding of objectives for Purdue MSE graduates.

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AUTHOR INFORMATION

Elliott Slamovich Professor, School of Materials Engineering, Purdue University, elliotts@purdue.edu

Keith Bowman, Professor and Head, School of Materials Engineering, Purdue University, kbowman@purdue.edu.