AC 2009-902: IMPROVING AN ABET COURSE ASSESSMENT PROCESS THAT INVOLVES MARKER PROBLEMS AND PROJECTS

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Improving an ABET Course Assessment Process That Involves Marker Problems and Projects

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Abstract
One recognized goal of engineering education is to provide society with well-educated and technically-competent engineering leaders. As a means to that goal, ABET mandates the establishment of a process of continuous improvement of the quality of graduates of accredited undergraduate engineering programs. Part of this process is the ABET requirement for assessment of outcomes and demonstration of improvements in outcomes based on that assessment. Marker problems and marker projects can be used as a measure of outcomes. Establishing a system that monitors student performance on these problems and projects has been underway for eight years in the Mechanical Engineering Department at Binghamton University. This paper will outline the system. A curriculum matrix corresponding required courses with ABET requirements (3a-k) is used. Marker problems are identified and tracked for the relevant courses. Faculty report results at semi-annual curriculum review meetings. The system has been reviewed during two ABET evaluation visits. Difficulties with the system and proposals for improvement are discussed.

Introduction

We will begin with a description of the design sequence in the mechanical engineering curriculum at Binghamton University. The process that we have developed in the department for continuous improvement (Departmental Course Review Process and ABET Accreditation) will be presented next. Following this we will describe an example of the application of the process for a single course and how it fits into the overall departmental review process.

In the second section, the assessment approach using marker problems will be introduced. An example of a marker assignment in the selected course will be described. In addition, the rubric used to evaluate students' work on the assignment will be shown.

The results of the marker assignment for six semesters (2002-2007) are shown. The process by which these results are evaluated for improvement of the course and the curriculum are described in the next section.

The paper will conclude with a discussion of the benefits and problems with this system.

The Design Curriculum

Students are introduced to design and solid modeling in the first-year, introductory engineering courses. In these courses, Solid Edge[1] is used. First-year students are also introduced to the design process through two projects. In the first semester, they perform a reverse-engineering team project and, in the second semester, there is a team conceptual design project.

In the curriculum of the Department of Mechanical Engineering, the Computer-Aided Engineering course (ME 481) was a technical elective until 2004-2005. The course is now required in the first semester of the third year. This course is the initial course in an upper-division, four-semester design sequence. It is followed in the second semester of the third year by the course Mechanical Engineering Design (ME 392) and, in the senior year, by the two-semester capstone design sequence (ME 493/ME 494).

Departmental Course Review Process and ABET Accreditation

ABET requires that accredited engineering programs show that their graduates attain certain abilities, understandings, knowledge and recognitions. These characteristics are listed in the document *Criteria for Accrediting Engineering Programs*[2] and are commonly referred to as "3(a-k)." As stated in the criteria:

"Engineering programs must demonstrate that their students attain:

(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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
(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, economic, environmental 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; and
(k) an ability to use the techniques, skills and modern engineering tools necessary for engineering practice."[3]

In the Department of Mechanical Engineering, we have structured our curriculum, specifically the sequence of required courses, so that each criterion is included in more than one course and in such a way that the course instructors assigned responsibility for assessment of specific student accomplishments are clearly identified. This structure is shown in a matrix (Table I). In the matrix, shaded cells indicate that the instructor is required to collect data for ABET files. The numbers in the cells indicate the degree to which the course provides examples of student learning with respect to the ABET criteria. This could also be described as the "focus" of the course: primary, secondary, etc. For example, in ME 481, the "4" in the last, "k," column indicates that a primary focus and assessment area in the course is to evaluate a student's "ability to use modern engineering tools." The fact that it is shaded means that assessment documentation should be collected, stored and be made available during the ABET accreditation review.

Required Course	Course Emphasis (ABET Criteria 3)										
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
WTSN 111/112. Exploring Engineering I/II			2	4	2	2	4		2		3
ME 271. Engineering Mechanics	4	1			2		2		2		
ME 311. Mechanics of Deformable Bodies	4	1	1		2				2		
ME 302. Engineering Analysis	4		2								4
ME 331. Thermodynamics	4	1			2	1	1	2	2	2	1
ME 273. Science of Engineering Materials	4	2					4			2	
ME 481. Computer-Aided Engineering	4	1	4		3		3		1	1	4
ME 303. Computational Methods	4										4
ME 351. Fluid Mechanics	4				2			1			1
ME 372. Project Management	4			4	3	3	3		2	1	1
ME 392. Mechanical Engineering Design	4	2	4		3	2	4	2	1	1	
ME 421. Mechanical Vibrations	4	3	3		4	2	2		2	2	3
ME 441. Heat Transfer	4		1		2	1	1	2		1	1
ME 491. Instruments & Measurements Lab	4	4		3	2	4	4		2	2	4
ME 424. Control Systems	4	1				1	1				2
ME 493/494. Senior Project I/II	2	1	4	3	4	3	3	2	2	1	3

Legend:

4	*Primary focus of course; ample evidence of student achievement*
3	*Secondary focus of course; good evidence of student achievement*
2	*Minor focus of course; small amount of evidence of student achievement*
1	*Very minor coverage in the course; little or no evidence of student achievement*

Table I. Mechanical Engineering Department ABET Criteria Matrix

ABET Documentation

Four documents are required in the system developed by the Department of Mechanical Engineering for ABET for each offering of a course. These four documents are: (1) a course description that includes a list of objectives of the course, (2) a list of marker problems with the relevant ABET 3(a-k) requirements identified, (3) a summary of course marker problem grades and (4) a list of actions based on course assessment. These documents are prepared by the instructor of record of the course each time it is offered. At the beginning of the following semester, the documents for the required courses taught in the previous semester are presented by the instructor to the department faculty at a review session. Once the review is completed, it is the responsibility of the Undergraduate Studies Committee of the department to coordinate recommendations concerning each course and its prerequisite courses. This process provides the necessary documentation to show how well the stated objectives and outcomes for each course are being achieved. The documents listed above as well as samples of student work are then stored on the department server for use in preparation of the ABET self-study report.

The Computer-Aided Engineering Course (ME 481)

The CAE course described here provides an example of how this process is conducted. The details of the course, as well as lectures and videos, have been described in a previous paper.[4]

In summary, the learning objectives of the course (as stated in the syllabus and the department course description documentation for ABET) are that the student should:

(I) develop a proficiency in solid modeling using Pro/Engineer;
(II) develop the ability to use Pro/Engineer as a design tool;
(III) be able to perform dynamic simulation using Pro/Mechanism;
(IV) understand the theoretical basis of finite element analysis (FEA) and perform limited, simple analysis with Pro/Mechanica Structure;
(V) demonstrate the integration of the elements of modeling and analysis in a CAE design project; and
(VI) prepare a complete design project report.

Three projects are the heart of the course, comprising 54% of the grade. This paper focuses on Project #3 because it provides a good example of a marker assignment and its assessment. It is a complete engineering detail design project.[5] This final project is worth 22% of the semester grade.[6] Each semester, a landing gear mechanism is selected for design and analysis.[7] Typically, the landing gear includes a hydraulic cylinder and three links with selected contact points on the fuselage. The landing gear for fall 2007 is shown in Figure 1. The landing gears selected can always be analyzed as four-bar linkages. Landing gear mechanisms have been used since fall 2002. An example assignment is given in the next section.

The Marker Assignment Approach

The landing gear project is used as a marker problem. A marker assignment, or assignment, is used specifically to evaluate an outcome based on a course objective. A marker assignment can be a quiz, exam problem, homework problem or project assignment that is used to evaluate an outcome. The same or similar assignment is used each time the course is taught to provide longitudinal assessment of student learning. In a simple case, it is a single problem. For example, in a statics course, a course objective might be “Students should be able to create and use free-body diagrams.” The marker problem could be an assignment explicitly to draw a free-body diagram of a loading situation. The loading situation is changed each year, attempting to keep the degree of difficulty roughly the same. If a problem on an exam or homework is used, student performance on that one problem is tracked separately from the composite homework score. The score on this one problem is then used to evaluate and track student learning. In cases where multiple outcomes are included in the solution of the problem, a grading rubric can be used where each of the items in the rubric can be paired with one of the course objectives.

In the case presented here, the marker is not an individual problem but a project assignment. Here the scoring on individual items in the rubric is used to evaluate student learning. These items are matched to corresponding course objectives that are stated on the syllabus. The assignment and the grading rubric are presented below.

Marker problems provide a direct measurement of student learning. Marker problems are used in all of the courses in the Department of Mechanical Engineering in which collection of assessment data is required by our ABET Criteria Matrix (Table I).

The ME 481 Project #3 Assignment (Marker Problem)

As an example of a marker, the project assignment for fall 2007 is given here:

"Design and analyze the landing gear assembly shown in Figure 1.

1. Create the components as parts using Pro/E.
2. Create the assembly in Pro/E.
3. Create the Pro/E material files.
4. Build a motion simulation model using Pro/Mechanism. (a) Determine the forces at the pins and axle. (b) Check your work.
5. Perform finite element analysis using Pro/Mechanica Structure: (a) Determine the maximum stresses and give the associated factors of safety of each pin, and (b) perform convergence analysis and verification/validation.
6. Submit a <u>formal</u> report."[8]

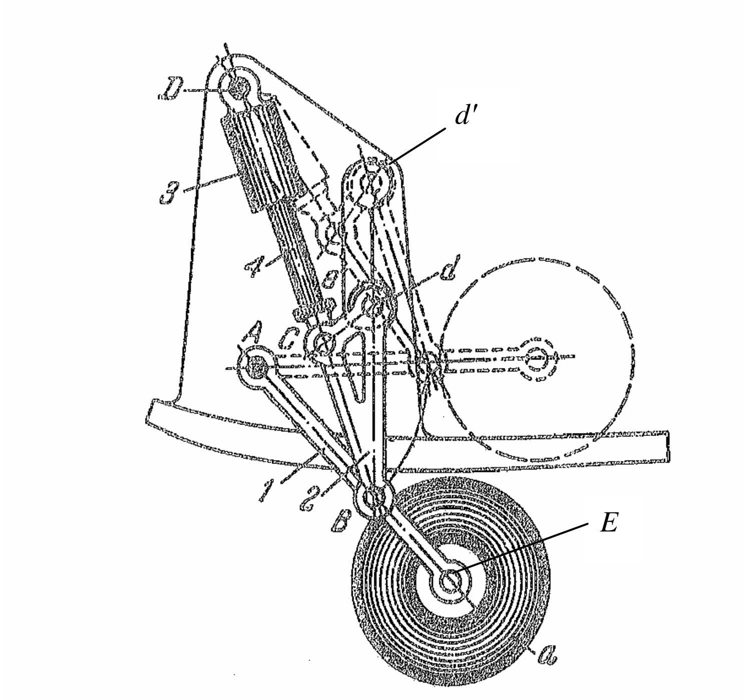

Figure 1. Landing Gear 2007

As can be seen, there are many tasks involved in this design project. A grading rubric is used to identify the items to be evaluated based on the assigned tasks. This rubric relates the individual items to course objectives. The grading rubric is shown as Table II. This rubric has been employed since the 2004 offering of the course.

Two areas of the assignment have been selected for presentation in this paper. One is the report itself, identified in the rubric in the engineering communication section. As shown in the rubric, this corresponds to course objective VI (Prepare a complete design project report). The other area is FEA. There are three items involving FEA: FEA of Stress, FEA Convergence and FEA Validation. One point of emphasis during lectures is the notion that "FEA makes a good engineer better, and a poor engineer dangerous."[9] In addition to the contour plots of the von Mises stress on the pins in the mechanism, students are required to create convergence diagrams, using strain energy as the measure, for each of their stress analyses. Lastly, because simulations are models and involve many simplifications and assumptions, the requirement that they must verify FEA results with experimental examples is emphasized. In this case, because they do not have access or time to perform full-scale or laboratory tensile tests, they must perform a "validation study" in which they create an additional finite element analysis of one of their pins using a loading for which they can hand-calculate the stress results. These must then be compared to the FEA results from Pro/Mechanica. These three items (plots, convergence, validation) are used to evaluate course objective IV (Understand the theoretical basis of finite element analysis and perform limited, simple analysis with Pro/Mechanica Structure).

In terms of our ABET Criteria Matrix (Table I), data collection is required in this course for two of the ABET a-k abilities: (c) - an ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability) and (k) - an ability to use the techniques, skills and modern engineering tools necessary for engineering practice). As this is a design project, the overall score on the project can be used as an indicator of design ability ABET (3c). To reinforce this data, in addition to providing a direct measure of ABET 3g (an ability to communicate effectively), the score on the report itself (under Engineering Communication in the rubric) is used as an indicator of design ability.

Finite element analysis using Pro/Mechanica Structure is one of the tools available to contemporary engineers. To evaluate student ability to use modern engineering tools (3k), the items involving FEA are examined.

	Item	Objective Number	Max. Points	Points Given
Solid Model and Motion Simulation	Parts Complete	I	10	
	Mechanism Execution	III	10	
	Interferences	II	5	
Engineering Analysis	Design Detail	I	5	
	Motion Driver Specification	III	5	
	Graphs (Force vs. Displacement)	III	5	
	Four-bar Linkage Analysis	V	10	
	FEA of Stress	IV	5	
	Loads and Constraints Appropriate	II	5	
	FEA Convergence	IV	5	
	FEA Validation	IV	5	
	Factors of Safety	II	5	
Engineering Communication	Report	VI	10	
	Drawings	I	5	
Overall Evaluation	Discretionary		10	

Table II. Project #3 Grading Rubric

Each student's project is graded using this rubric and the scores are entered in a spreadsheet. The scores for all students are then analyzed. The achievement of course objectives is traceable based on this analyzed data. This analysis is used in the course evaluation feedback process to identify where improvements are needed and to make any identified changes. These are documented and reviewed by the faculty at a course review session during one of the department meetings during the semester following that in which the course was offered. Results are presented and the process is described in the next section.

Results of Student Performance and Discussion

Data from six semesters (2002-2007) of the course is shown in Table III. Use of the grading rubric described above was begun in 2004. Only required courses are included in the departmental ABET criteria matrix. This course was made a required course in 2005. Prior to and including that year, the course was a senior elective. As can be seen from the row in the table labeled "Level," in 2005, seniors took the course as an elective and juniors took it as a required course. Their results are presented separately, although no distinction during the course offering was made. In the six years the course has been offered, two versions of Pro/E have been used: Pro/E 2001 was used 2002-2005. Wildfire 3.0 has been used since 2006. The arithmetic average, sample standard deviation and median are reported for the overall score in the course, the landing gear project score, the written project report score and the three FEA rubric items (stress contour plots, convergence and validation).

		Year	2002	2003	2004	2005		2006	2007
		Enrollment	31	33	43	24	74	96	84
		Level	SR	SR	SR	SR	JR	JR	JR
		Pro/E Ver.	2001	2001	2001	2001		WF3	WF3
Course Score (100)		Avg.	89.30	87.90	85.10	83.95	75.80	82.50	83.70
		Std. Dev.	3.60	5.10	6.30	7.39	13.28	11.60	11.40
		Median	89.30	89.20	85.90	83.66	77.00	85.70	86.00
Project #3	Project Score (100)	Avg.	84.80	85.40	80.40	68.34	74.73	74.10	81.20
		Std. Dev.	8.50	9.90	16.40	18.37	15.98	20.40	24.36
		Median	85.00	88.00	84.00	62.00	77.00	77.00	87.00
	Report Score (10)	Avg.			4.50*	6.26	6.24	6.24	6.15
		Std. Dev.			3.10*	2.95	2.43	2.75	1.84
		Median			5.00*	7.00	7.00	6.00	7.00
	FEA Stress (5)	Avg.			4.12*	4.35	4.33	4.68	4.61
		Std. Dev.			1.71*	1.39	1.50	1.13	1.38
		Median			5.00*	5.00	5.00	5.00	5.00
	FEA Conver. (5)	Avg.			2.58	3.91	3.96	4.67	4.69
		Std. Dev.			2.00	1.42	1.21	1.20	2.81
		Median			2.45	5.00	5.00	5.00	5.00
	FEA Valid. (5)	Avg.			0.81	1.00	1.52	2.80	3.69
		Std. Dev.			0.00	1.77	1.80	2.29	2.21
		Median			1.87	0.00	0.00	2.00	5.00

Table III. Data: ME 481 Course and Project #3
(* These scores were extrapolated from a preliminary rubric that is not identical to Table II.)

Analysis of Project Scores and Report Scores

The Project Score and the Report Score are used as indicators of student ability to design a mechanism, in this case, the landing gear. These scores are presented in Figure 2. The scores are presented separately for juniors and seniors. The Project Scores for seniors show a slight drop in the third year that the course was offered and a drastic drop for the fourth year (2005). We believe this is due to both the quality of students (note the slight drop in course average for seniors compared to previous years), as well as the mixed junior-senior class that year. The Project Scores for juniors show a slight drop in the second year and marked improvement for the third year (2007). Report scores for both the seniors and juniors are relatively unvarying for the four years of data shown.

As the trends for the two measures (Project and Report) are different, the question becomes which is the better indicator of design ability. The unchanging report scores indicate that students' writing ability has remained constant. The increasing scores for the project, it is believed, represent an improvement in design learning.

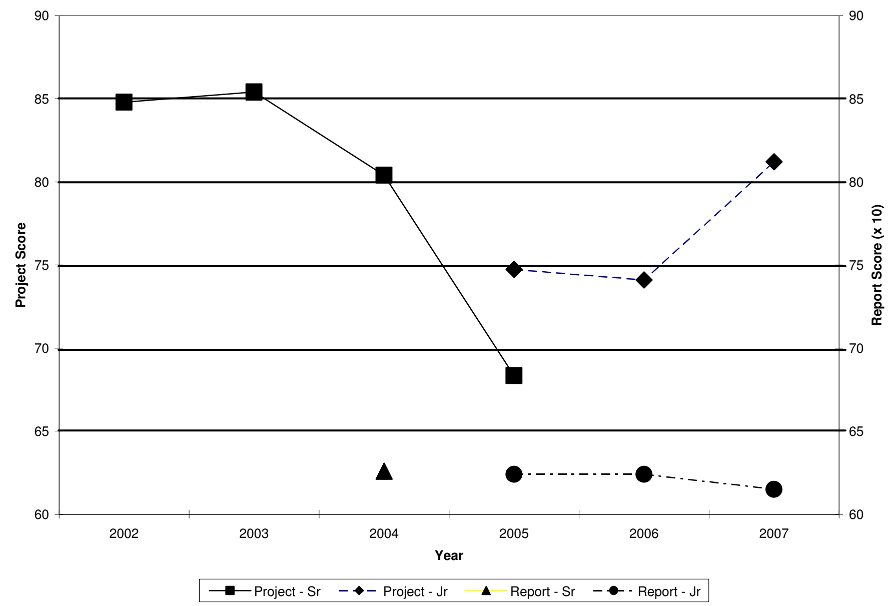

Figure 2. Project Scores and Report Scores

Analysis of FEA Scores

Figure 3 shows the trends in the scores on the FEA items in the rubric. As there is not a significant difference in 2005 between junior and senior scores on these items, they have been averaged for the figure.

From Figure 3, it can be seen that from the time the course was first taught, students had little trouble creating contour plots. It is also apparent that there was poor understanding on the part of students regarding both convergence and validation. In subsequent years, changes were made in both the content and emphasis of the FEA lectures and, also, the requirement for convergence analysis and validation were made more explicit in the wording of the project assignment. These changes resulted in improved student performance, although further improvement is still required.

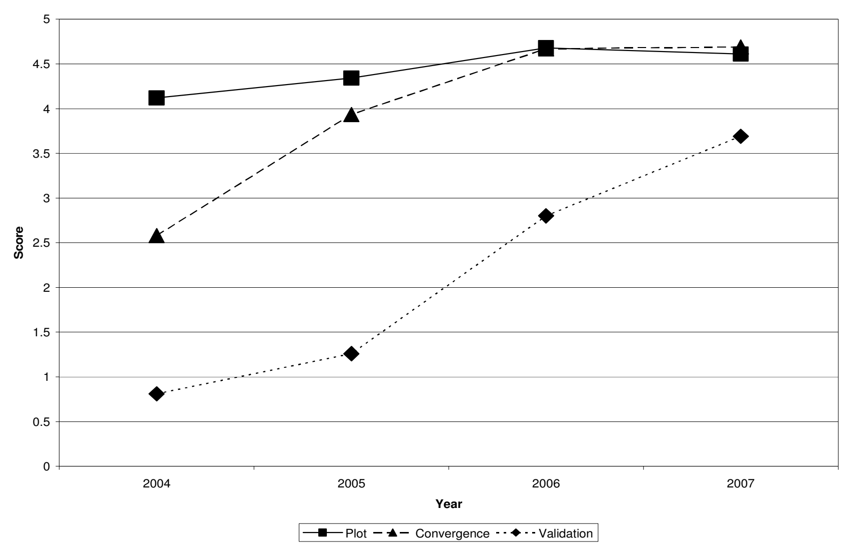

Figure 3. FEA Scores

This marker project assignment provides a useful measure of student learning and a reference for gauging the effect of any changes that are made. Figure 4 shows the documentation of grading based on the rubric in Table II. These scores are normalized on a 0-3 point scale to

ME 481 Computer-Aided Engineering Course Review – Fall 2006

Grading: 3.0 = Problem done correctly; no or one minor error
2.6 = Correct methodology but with some minor errors
1.5 = Difficulties with using the correct methodology, major errors
0 = Did not attempt or wrong methodology

Target: (2.6)
Minimum: (2.0)

Marker Problem and Description	Program Objective	Average Class Grade and Comments
3) Project #3 Interferences Convergence Validation	3(e) an ability to identify, formulate and solve engineering problems	**Grade:** **2.9** much improved performance by students on review dimensions of solid models **2.8** Convergence is still not grasped by students. **1.7** Improvement, but students do not understand the need for validation analysis.
4) Project #3 Report	3 (g) ability to communicate	**Grade: 1.88** **Mediocre** Continued poor performance on writing project reports. No improvement over previous years.

Figure 4. Documentation: Course Marker Problem Grades

facilitate comparison between different courses in the curriculum. In addition to providing a means of assessment, the assignment is used as part of the documentation for ABET. A record is kept of previous and proposed changes to the course. An example is shown in Figure 5. The example shown in the figure is part of the document from fall 2006. In the figure, the portion for 3(k) is not shown but those results are described with 3(c). The instructor each time a course listed in the Department of Mechanical Engineering ABET Criteria Matrix is offered completes one of these documents.

The documentation for each course for every semester that it is offered is stored electronically in a separate file on a server. In addition to the four documents described here, representative samples of student work are scanned and retained as supporting documents. Each instructor summarizes the results from the assessment process in a short presentation to the department faculty in one or two sessions held at the beginning of the following semester. Once the review sessions are completed, the final step of the process is for the Department Undergraduate Studies Committee to review the results and assure that all of the required documentation has been provided. The committee determines whether any further recommendations or actions are required beyond those determined in the departmental review session.

The process in place provides the required information to assess the outcomes of the courses and the overall curriculum and make adjustments as indicated to either a specific course or the prerequisites. Any assessment process requires attention and commitment by the instructor. In developing the quantitative system described here, a primary consideration was to make the process straightforward for the instructor in order to have uniform compliance. Owing to the many and varied responsibilities of faculty, challenges remain in this regard. Once the marker tasks are well-defined for a given course, compilation of the data is the primary effort required. Much of this work can be performed by teaching assistants assigned to the course.

Conclusion

The assessment process used by the Department of Mechanical Engineering has been illustrated using one course in the design sequence of the curriculum. For the CAE course, the characteristics of the landing gear project make it especially useful as a marker assignment. The arrangement of the components is different each year, providing an interesting and challenging project for students. The grading rubric is well-structured and easy to use.

ME Actions Based on Course Assessment
ABET Course Documentation

ME 481 Engineering Mechanics Semester: Fall 2006 Instructor: McGrann

The program outcomes for this course emphasize student learning in:	**Actions taken in response to previous assessments**	**Recommended changes based on end-of-semester assessment**
c) an ability to design a system, component, or process to meet desired needs	No changes.	
e) an ability to identify, formulate and solve engineering problems	More emphasis was given to convergence and validation.	More emphasis needed on validation.
g) an ability to communicate effectively	Did not implement previous suggestion. Keep as suggestion.	Include a short formal lab report prior to the Project #3 report.

Figure 5. Documentation: Actions Based on Course Assessment

The assessment process implemented in the Department of Mechanical Engineering at Binghamton University links the ABET 3(a-k) criteria to courses using the Department ABET Criteria Matrix (Table I). The course objectives from the syllabus of each course are then tied to this matrix. Any required documentation is also identified in the matrix. Marker problems (such as Figure 1) map directly to course objectives. Student performance on these marker problems is recorded (Table 2 and Figures 2 and 3) and evaluated by the instructor and the department faculty each semester. Changes to the course based on assessment are documented (Figure 5). This process provides a structure to identify problems of student learning and eases the preparation of documentation for ABET accreditation. The continuous improvement process of assessment using a direct measure of student learning, feedback adjustment and re-assessment has been implemented using a marker assignment. The marker problems discussed in this paper are repeatable assignments that provide a consistent basis for longitudinal evaluation of the effectiveness of design education and that are used to satisfy ABET requirements.

[1] Siemens Product Lifecycle Management Software Inc., http://www.plm.automation.siemens.com/en_us/products/ velocity/solidedge/index.shtml, accessed 10 February 2008.
[2] ABET Criteria for Accrediting Engineering Programs: Effective for Evaluations during the 2008-2009 Accreditation Cycle, http://www.abet.org/Linked Documents-UPDATE/Criteria and PP/E001 08-09 EAC Criteria 11-30-07.pdf, accessed 10 February 2008.
[3] Ibid, p. 2.
[4] McGrann, R.T.R., "Enhancing Engineering Computer-Aided Design Education Using Lectures Recorded on the PC," *Journal of Educational Technology Systems*, Fall 2006
[5] Dym, op. cit., p. 111
[6] The percentage of the semester grade that is allocated for this project has changed in the six years the course has been offered. When the course was an elective course (2002-2004) there was an additional Project #4 that was an individual project usually tied to the capstone project that students took at the same time as this course.
[7] Artobolevsky, Ivan I., *Mechanisms in Modern Engineering Design, Vol. II, Lever Mechanisms, Part 1*, trans. Nicholas Weinstein (Moscow: Mir Publishers, 1976)
[8] ME 481 Syllabus, Fall 2007
[9] Toogood, Roger, *Pro/Engineer Wildfire 3.0 Mechanica Tutorial (Structure/Thermal),* (SDC Publications, 2006).