# AC 2011-117: LEARNING ASSESSMENT IN A DESIGN-THROUGHOUT-THE-CURRICULUM PROGRAM

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# Learning Assessment in a Design-Throughout-the-Curriculum Program

**Abstract:**

At our institution, the Biomedical Engineering Department implements design throughout the curriculum using six sequential, client-driven design courses. This affords us unique opportunities and challenges to assess student achievement of our educational outcomes. We have devised a novel assessment strategy that quantifies sophomore-, junior- and senior-level student achievement of nine educational outcomes, which are well aligned with ABET criteria. We now have five years of experience with this assessment strategy and five years-worth of data on student learning in our curriculum. In this paper, we present our strategy and a summary of our data to date. We also describe the process by which we make improvements to our curriculum through the assessment process. Finally, we suggest aspects of our approach that may be useful in more traditional BME curricula.

**Introduction:**

In the United States, accreditation is a non-governmental, peer-review process that is designed to assure the quality of higher education programs. The Accreditation Board for Engineering and Technology, Inc. (ABET) is the organization responsible for monitoring, evaluating and certifying the quality of engineering, engineering technology and engineering-related higher education programs in the United States[1]. In 2000, new outcomes-based criteria were established called EC2000 or EC. As a condition for accreditation, which is entirely voluntary, the EC require all programs to demonstrate that they produce 11 specific learning outcomes (ABET criterion 3 outcomes a-k) listed in Table 1[1]. These outcomes are specific skills, knowledge areas and values that all students should possess upon completion of the undergraduate engineering program. Furthermore, programs seeking accreditation must demonstrate practice of continuous improvement with input from stakeholders, a focus on educational and assessment processes, and outcome and assessment linked to educational objectives. In particular, the assessment process should provide quantitative feedback that can be used to identify strengths and potential areas of improvement of the program and track the impact of changes to the curriculum[2].

In addition to the 11 criteria listed in Table 1, Biomedical Engineering (BME) programs must also demonstrate that graduates have an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science and engineering to solve the problems at the interface of engineering and biology; the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living systems [1].

In order to meet ABET criterion 3 outcomes tailored to BME curricula, the BME department at our institution established the 10 educational program outcomes listed in Table 1. An Assessment Committee was formed in 2006 and charged with developing a continuous improvement process linked to educational objectives that could provide quantitative feedback on strengths and potential areas of improvement of the program and assess the impact of changes to the curriculum.

Our curriculum is unique nationwide. Design courses throughout the curriculum form a unique feature of the BME undergraduate degree program[3, 4]. Every BME student registers for a design course and works on a client-based design project every semester for six consecutive semesters. These design courses are supervised by faculty advisors and meet for two hours per week. Therefore, every BME student has access to a faculty member through their design course at least once per week. Part of the two-hour design course lab time is relatively unstructured so that students can have the opportunity to seek advice on the curriculum, career counseling, or any other matter of interest to them. These courses allow the faculty access to all of the students in our department, providing an effective means to make announcements or discuss issues pertaining to the whole student body. Design courses also provide a platform for professional communication throughout the curriculum[5], and a relevant structure to discuss other professional topics such as intellectual property, professionalism, engineering ethics, and the need for lifelong learning. Some of these topics are taught via short video tutorials[6] including: 1) team dynamics, 2) intellectual property, 3) FDA medical device regulations, 4) human subjects research, 5) impact of engineering solutions in a global and societal context, and 6) and engineering ethics. All students also complete the university's on-line human subject research tutorial and individually receive human subjects training certification.

This implementation of design throughout the curriculum affords us unique opportunities and challenges to assess student achievement of our educational outcomes. In this paper we describe our methods of assessment and results over the past five years including recommended changes to the curriculum. Finally, we suggest aspects of our approach that may be useful in other BME curricula.

**Methods:**

Since all undergraduate students in the BME department are enrolled in a BME design course every semester, student work output from these design courses captures all students and also can provide a window into the progression of student achievement of educational outcomes. Also, potential areas of improvement identified by the assessment process can be addressed by implementing changes in the design course.

Our method of assessment is as follows. The group of faculty teaching the BME design courses in the fall makes up the BME Assessment Committee with the first author (NCC) as chair.

Assessment is performed on student work output from the prior semester, which ensures that the Assessment Committee is not identical to the instructor group responsible for grading the student work output. The Chair randomly selects team project reports from each course level (201=sophomores, 301=juniors, 400/402=seniors) and assigns them to multiple committee members for review, making sure that no reviewer was also an instructor for that group in the prior semester.

The Committee begins by reviewing one randomly selected project report to calibrate the Committee to the scoring system (1 through 5: 1=Poor, 2=Fair, 3=Good, 4=Very Good, and 5=Excellent) for student work as it pertains to achievement of each educational outcome. Then, each reviewer scores each outcome for their assigned project reports. At least two reviewers review each report. Reviewers report their scores to the Committee Chair, who compiles scores for review by the Committee. In a second meeting, the Committee reviews the results and attempts to identify strengths and potential areas of improvement in the educational program. Subsequent to this discussion, the Chair prepares an Assessment Committee report for approval by the entire BME department faculty.

It is important to note that the assessment process itself is also assessed for strengths and potential areas of improvement. Several changes have been implemented in the assessment process since its initiation in 2005. The most important of these are summarized below:

- Outcome 2 should be read broadly as the ability to apply *relevant* knowledge of advanced mathematics, sciences, and/or engineering to solve problems at the interface of engineering and biology and to model biological systems. If advanced mathematics are not required to meet the client's need but advanced sciences are, and the ability to apply advanced mathematics is demonstrated by student work, this should be taken as evidence of having achieved this educational outcome. However, the demonstration of knowledge of advanced sciences that is not relevant to the engineering design solution is not considered evidence of having achieved Outcome 2.
- We acknowledge that BME design course final reports are not well suited to demonstrating the achievement of Outcome 10. In lieu of other assessment materials, we do not assess this outcome.
- All reports are assessed using the same scale. While we may expect scores to increase from the sophomore to junior to senior level teams, reviewers should attempt to blind themselves to level during the review process. In 2010, an assessment rubric was created (See Table 1) for more consistency in assessment scores among reviewers.
- Since the BME 402 final report is required to be in journal article format, we assess senior level teams with all available information including the final report from BME 400 (the first semester course) as well as the journal article from BME 402 (the second semester, senior-level course).
- Self-peer evaluations are required to evaluate student achievement of Outcome 6
- In 2007 we noted that not all projects provide equal opportunity for all students to demonstrate mastery of each educational outcome. Therefore, a "potential" score for each project and for each outcome can be noted by reviewers. These are not used to

score student work but to provide feedback to faculty for future project selection.  All student work is scored from 1 to 5 regardless of the potential score.

Table 1. ABET criteria for engineering programs, UW-Madison BME program educational outcomes and evidence required for a score of Excellent (5/5) in the assessment process.

| ABET EC 2000 | UW-Madison BME Educational Outcomes | Rubric created in 2010 to clarify evidence required for 5/5 |
|---|---|---|
| | 1: Understanding of biology and physiology as related to biomedical engineering needs | • Clearly communicates all of the relevant biology/physiology<br>• Problem description is appropriately motivated by relevant biology/physiology<br>• Does not "fill" intro with irrelevant biology/physiology |
| a): An ability to apply knowledge of mathematics, science and engineering<br><br>k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. | 2: Ability to apply knowledge of advanced mathematics (including differential equations and statistics), sciences, and engineering to solve problems at the interface of engineering and biology and to model biological systems | • Uses appropriate statistical analysis<br>• Uses all relevant advanced mathematics, sciences and engineering<br>• Calculations predict and are compared to experimental results or are used to optimize final design |
| b) An ability to design and conduct experiments, as well as to analyze and interpret data | 3: Ability to design and conduct experiments, including making measurements and interpreting experimental data from living systems and addressing the problems associated with the interaction between living systems and non-living materials and systems. | • Experimental approach leads to design improvements or new approaches<br>• Data are used to assess all relevant PDS criteria<br>• Sources of error are identified and methods to reduce error are discussed |
| e) An ability to identify, formulate and solve engineering problems | 4: Ability to identify, formulate and solve biomedical engineering problems | • Final design works as intended<br>• Design alternatives provide evidence of multiple viable approaches<br>• Several criteria are evaluated in a design matrix for each design alternative<br>• Design problems are identified and solutions logically presented |
| 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 | 5: Ability to design systems or processes to meet desired needs | • Final design meets or exceeds client-specified criteria |

| | | |
|---|---|---|
| d): An ability to function on multidisciplinary diverse teams | 6: Ability to function on diverse teams and provide leadership | • Positive peer evaluations<br>• Clustered “bonus” scores<br>• Identifiable individual contributions in team output<br>• Team leader mentioned<br>• No non-contributors |
| f) An understanding of professional and ethical responsibility<br><br>and<br><br>h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context | 7: Understanding of professional and ethical responsibility and the impact of engineering in our global society | • Ethical considerations are clearly identified and addressed<br>• No research ethics violations<br>• Design concepts credited appropriately<br>• Text references and figures cited appropriately |
| g) An ability to communicate effectively | 8: Ability to communicate by oral, written and graphic modes | • Virtually no errors in spelling or grammar<br>• Layout enhances readability<br>• Clear problem statement<br>• Design matrix categories are justified and scores explained<br>• Experimental methods are clearly described and are appropriate to results reported<br>• Effectively uses graphics to illustrate key points<br>• Data appropriately presented (e.g., labeled axes, SI units) |
| i): A recognition of the the need for and an ability to engage in life-long learning | 9: Recognize the need for and engage in life-long learning | • Several references (typically 20+) of multiple types (articles, books, websites, patents, personal communications, etc)<br>• Reference material enhances the paper/presentation<br>• Reference material is in context when cited – uses multiple references for key points. |
| j) A knowledge of contemporary issues | 10: Knowledge of contemporary issues | • NA |

**Results:**

Student work from core BME design courses was reviewed for poor (score = 1), fair (score = 2), good (score = 3), very good (score = 4) or excellent (score = 5) demonstration of achievement of each of nine (of ten) of the BME department's educational outcomes (Table 1) each year for 5 years. At least two reports from the team-based design projects were reviewed from the sophomore, junior and senior level course each year. Also, at least two reviewers assessed each report. Mean scores (±SD) for selected sophomore, junior and senior level design teams for each outcome in 2006, 2007, 2008, 2009 and 2010 are shown in Figure 1. Cumulative results averaged over multiple years (2006 through 2010) are shown in Figure 2.

Based on these assessment results, recommendations were made each year to address average educational outcome scores less than 4, "very good" in senior teams. For example, in 2006 the average scores for outcomes 6 and 7 in senior teams (n=3) were 3.5 and 3.2, respectively. In response, the following recommendations were made:

- Direct additional curricular efforts toward effective team building. There already exists a team-building lecture in the BME design core curriculum but this was found to be insufficient [based on poor achievement of Outcome 6]. We recommend augmenting end-of-term assessments with mid-term self and peer evaluations of team function, and providing feedback directly to students to improve ability to function on diverse teams.
- Consider additional means of measuring student achievement of Outcome 7, such as student essays from BME design course case studies in ethics.

In 2009, average scores for outcomes 2, 7 and 9 in senior teams (n=5) were 3.5, 3.75 and 3.5, respectively. The Assessment Committee recommendations to the faculty were:

- Design advisors keep overall educational objectives in mind when suggesting directions for projects. For example, advisors should encourage teams to consider how mathematics and statistics could be used to improve their project designs [to address Outcome 2].
- Design advisors and other faculty should make students aware of professional codes of ethics (see http://www.nspe.org/Ethics/CodeofEthics/index.html and http://www.nspe.org/Ethics/CodeofEthics/Creed/creed.html, for example) and other resources related to professional and ethical responsibilities of engineers [to address Outcome 7].
- Students should be made more aware of BME departmental educational learning outcomes by putting a link on our design course syllabus to the department's mission web page [to address Outcome 9].
- The Committee should explore additional strategies for improving consistency in outcome assessment (i.e., scoring) from year to year.

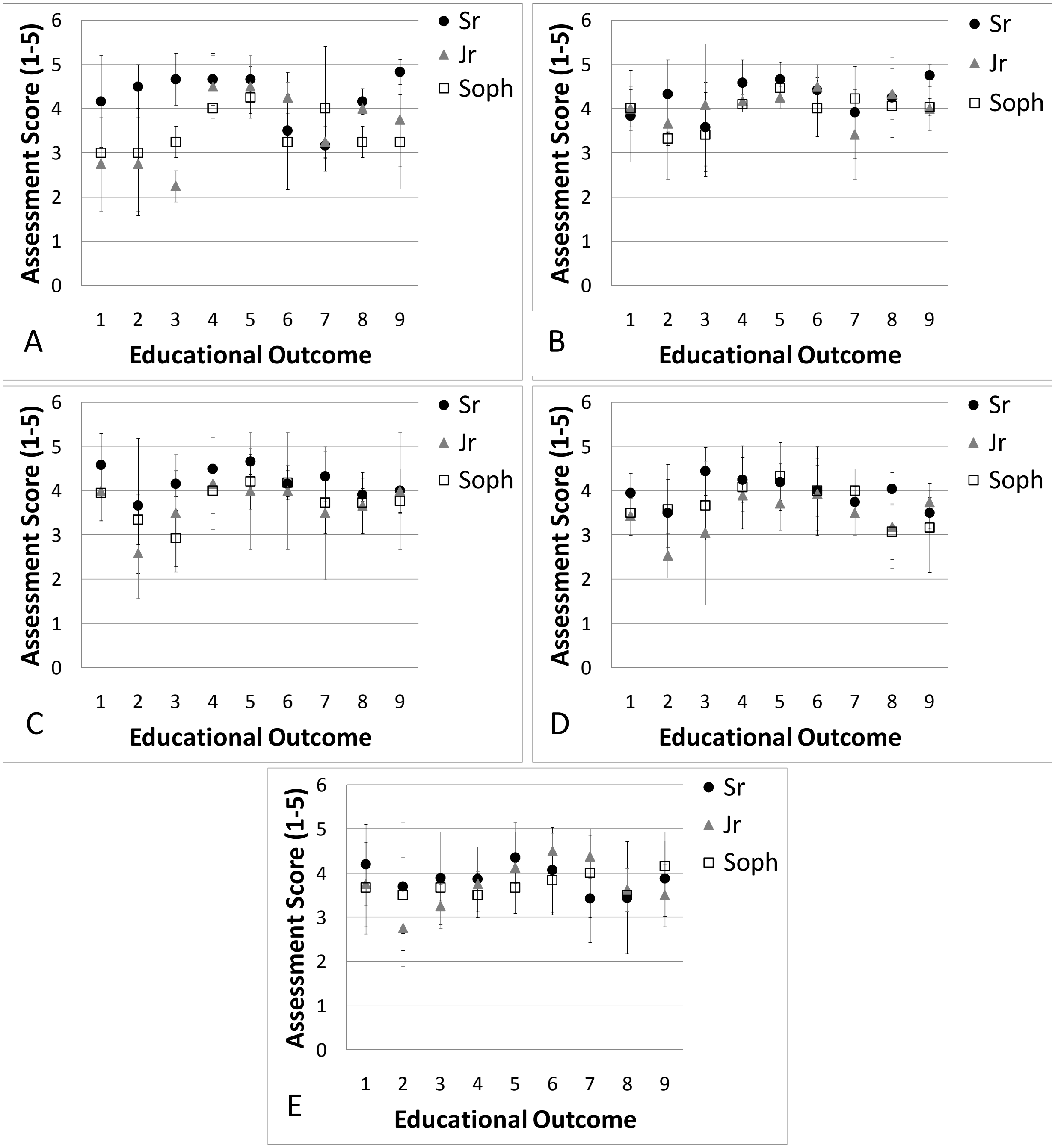


Figure 1. Results for each educational outcome scored (1 through 9 only). 1=Poor, 2=Fair, 3=Good, 4=Very Good, and 5=Excellent. Data presented as means with error bars indicating standard deviations. (A) 2006 data; Soph: n=2, Jr: n=2, Sr: n=3. (B) 2007 data; Soph: n=3, Jr: n=3, Sr: n=3. (C) 2008 data; Soph: n=3, Jr: n=3, Sr: n=3. (D) 2009 data; Soph: n=3, Jr: n=3, Sr: n=5. (E) 2010 data; Soph: n=3, Jr: n=4, Sr: n=4.

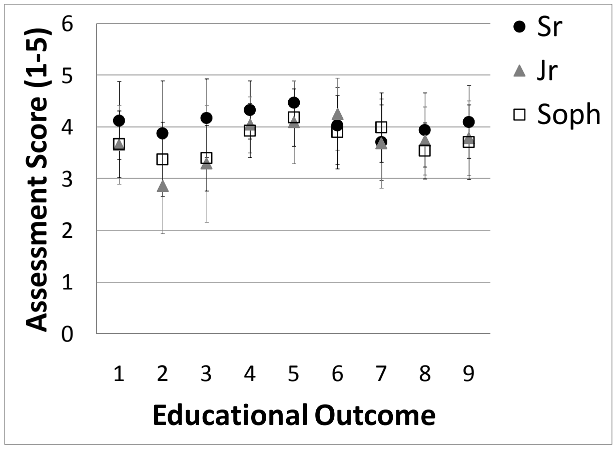


Figure 2. Cumulative results from 2006, 2007, 2008, 2009 and 2010 by class for each educational outcome scored (1 through 9 only). Data presented as means with error bars indicating standard deviations. 1=Poor, 2=Fair, 3=Good, 4=Very Good, and 5=Excellent. Mean and standard deviation shown (Soph: n=14, Jr: n=15, Sr: n=18).

A statistical analysis was not performed because of the large and overlapping standard deviations between levels (sophomore vs. junior vs. senior) and years (2006 vs. 2007 vs. 2008 etc.). In Fall 2010 we created a rubric for project design report assessment with explicit requirements for scores of 1 through 5 for each of the educational outcomes (requirements for a score of 5 are listed in Table 1), which we anticipate will increase inter-reviewer agreement.

As demonstrated by these examples, recommendations related to curricular change and the approach to assessment are typical. Both types of recommendations are followed to the extent possible.

Finally, since the Assessment Committee recommendations are brought to the entire faculty, potential areas of curricular improvement identified by this process can be discussed and, if appropriate, addressed via changes in courses other than the design sequence or a more comprehensive curricular change. As an example of the latter, in 2010, two BME courses were modified to address low average Outcome 7 score in senior teams identified in the 2009 Assessment Committee report.

**Discussion:**

As of January 2011, our department has five years of experience with this continuous improvement process, which is focused on educational and assessment processes and outcome and assessment linked to educational objectives. Several curricular changes have been implemented as a result of the assessment process. However, since we do not make changes one at a time, and since students, design projects, design advisors and Assessment Committee members are not constant, the impact of these individual changes is difficult to ascertain.

An important limitation of our assessment process is that we evaluate the work output of student teams, not individual students. This limitation is not unique to our process however. Many programs that use capstone senior design projects for ABET assessment are limited to team-based assessment[7, 8]. An advantage of this practice is that we sample a larger proportion of the student body. A disadvantage is that team achievement of educational outcomes is assessed rather than individual achievement.

Another limitation is that we do not assess all teams. In successive years we have increased the number of project teams evaluated. However, as a department we decided that the cost in terms of faculty time and effort to assess the work output of all teams outweighs the potential value of the additional data. Similarly, to date we have only evaluated student work output in the BME design sequence. Additional, valuable data could be obtained by assessing student work output from other core courses in our curriculum. This process would generate course-specific data for students at various years as opposed to our process which generates year-specific data for students who have taken various courses.

An additional limitation is that variability in scores has limited our ability to identify statistically significant differences between levels or with curricular changes from year to year, such as implementing mid-term self and peer evaluations of team function based on the 2006 Assessment Committee report. Obvious strategies for decreasing variability will increase reviewer workload. That is, we could increase the number of reviewers for each report or increase the number of reports reviewed, but these actions would also increase the workload on each reviewer and potentially reduce the quality of the review process. Using additional reviewers would decrease workload but could increase variability. In Fall 2010 we developed a rubric for scoring achievement of educational outcomes with explicit requirements for each score for each outcome. Future assessments are required to assess the impact of this strategy on scoring consistency.

**Conclusions:**

In traditional BME curricula, a similar assessment process could be implemented in a core sophomore level course, a core junior level course and/or a core senior level course. While the student work product evaluated in each of these courses would likely be different, if the same committee evaluated all products, a similar and comparable result could be obtained. In general, we recommend that the Assessment Committee sample student work instead of evaluating every student or team output simply to avoid overburdening faculty.

Ideally, the assessment process would yield more statistically compelling data regarding the impact of curricular changes on student achievement of educational outcomes. It is unclear to how to do so without extensive longitudinal data and an unchanging assessment team. In our opinion, rotating members of the assessment team has significant advantages. First, we keep more faculty members engaged in the assessment process. Second, by rotating membership, we keep the workload reasonable, ensuring quality assessment and high levels of compliance. We believe that by engaging faculty members in an assessment process that is not onerous, we increase the likelihood of having vigorous and productive discussions of curricular strengths and potential areas of improvement, and subsequently developing and implementing curricular reforms, which are the desired end-results.


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**References:**


1. Website www.abet.org, accessed January 19, 2011.
2. Enderle, J., Gassert, J., Blanchard, S., King, P., Beasley, P., Hale, P., and Alldridge, D., "The ABCs of Preparing for ABET," *IEEE Engineering in Medicine and Biology Magazine*, July/August 2003, pp. 122-132.
3. Tompkins, W.J., D. Beebe, J.A. Gimm, M. Nicosia, N. Ramanujam, P. Thompson, M.E. Tyler, and J.G. Webster. "A design backbone for the biomedical engineering curriculum," *Proc. of the 2nd Joint Conference of the IEEE Engineering in Medicine and Biology Society and the Biomedical Engineering Society*, 2002, pp. 2595-2596.
4. Tompkins, W.J. "Implementing design throughout the curriculum," *Proc. Annual Conference of the Biomedical Engineering Society*, Chicago, 2006, pp. 35.
5. Tompkins, W.J., Block, W.F., Chesler, N.C., Masters, K.S., Murphy, W.L., Tyler, M.E., and Webster, J.G. Development of Professional Communication Skills Throughout the BME Curriculum. *Proceedings of the American Society of Engineering Education Conference*. Hawaii, 2007.
6. Cadwell, K.D., Zenner, G.M., Chesler, N.C. and Crone, W.C. Developing undergraduate student design skills using online video modules and active learning exercises. *Proceedings of the American Society of Engineering Education Conference*. Austin, 2009.
7. Hazelwood, V., Valdevit, A., and Ritter, A. "A model for a Biomedical Engineering Senior Design Capstone Course, with Assessment Tools to Satisfy ABET 'Soft Skills'," *Proceedings of the Capstone Design Conference*, Boulder, 2010.
8. McKenzie, L.J., Trevisan, M.S., Davis, D.C., Beyerlein, S.W., "Capstone Design Courses and Assessment of ABET EC2000: A National Survey," *Proceedings of the American Society of Engineering Education Conference*. Salt Lake City, 2004.