A HARD JOB: ASSESSING “SOFT” OUTCOMES

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Abstract: Under criterion 3 of the Engineering Accreditation Commission (EAC) of ABET, engineering programs are required to have eleven documented student outcomes[1], commonly referred to as “a through k.” Five of these student outcomes represent technical attributes that engineering educators are familiar with teaching and assessing. However, six of these student outcomes are, for many faculty members, difficult and purportedly subjective to assess. To add to the difficulty, programs are expected to use “direct assessment” for all student outcomes. This means that assessment should be based on actual student work or performance. Measurement of the kinds of competencies in these six outcomes seems to be difficult, especially to instructors in engineering and natural sciences. However, this type of measurement is familiar to instructors in the humanities and social sciences. This paper will discuss approaches to direct assessment of these student outcomes and make the case that these assessments need not be difficult, and have the potential to significantly improve student learning.

Introduction:

Under criterion 3 of the Engineering Accreditation Commission (EAC) of ABET, engineering programs are required to have eleven documented student outcomes [1], commonly referred to as “*a* through *k*.” Five of these student outcomes represent technical attributes that engineering educators are familiar with teaching and assessing. However, six of these student outcomes are, for many faculty members, difficult and purportedly subjective to assess. These include:

- (d) An ability to function on multidisciplinary teams
- (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

To add to the difficulty, programs are expected to use “direct assessment” for all student outcomes. This means that assessment should be based on actual student work or performance. Measurement of the kinds of competencies in these six outcomes seems to be difficult, especially to instructors in engineering and natural sciences. However, this type of measurement is familiar to instructors in the humanities and social sciences. This paper will discuss approaches to direct assessment of these student outcomes and make the case that these assessments need not be difficult, and have the potential to significantly improve student learning.

Accreditation, Outcomes and Assessment:

Accreditation is a peer-review process for assurance of quality. Engineering programs in the U.S. need to be concerned with two kinds of accreditation: regional and ABET. A major difference is that regional accreditation accredits the entire institution, whereas ABET accreditation accredits individual engineering programs. Regional accreditation in New Jersey and nearby states, plus Puerto Rico and the U.S. Virgin Islands, is conducted by the Middle States Commission on Higher Education (MSCHE).

MSCHE accreditation[2] requires evaluation of 14 "standards," whereas ABET accreditation is based on evaluation of eight "criteria." Both include requirements that programs define learning outcomes at several levels (e.g. course-level and program-level) and demonstrate that students achieve those learning outcomes. Learning outcomes are defined by ABET as [1]:

> Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviors that students acquire as they progress through the program.

ABET Criterion 3 requires that programs that they accredit demonstrate that students achieve eleven outcomes, known as the "*a* through *k*," in addition to any other outcomes specified by the program.

MSCHE requires of all educational offerings (in standard 11) [2]:

- program goals that are stated in terms of student learning outcomes;
- periodic evaluation of the effectiveness of any curricular, co-curricular, and extra-curricular experiences that the institution provides its students and utilization of evaluation results as a basis for improving its student development program and for enabling students to understand their own educational progress

ABET distinguishes between assessment and evaluation. In simple terms, assessment is the collection of data demonstrating achievement of outcomes; whereas evaluation the interpretation of the data and other evidence that result in decisions and actions for making improvements to the program.

Both MSCHE and ABET further require that institution and programs, respectively, demonstrate that the results of assessment and evaluation are used to produce improvements. This is referred to as "closing the loop."

Direct assessment

MSCHE standard 14 describes what is meant by direct evidence for use in assessment [2]:

> "Tangible examples of student learning, such as completed tests, assignments, projects, portfolios, licensure examinations, and field experience evaluations, are direct evidence of student learning. Indirect evidence, including retention, graduation, and placement rates and surveys of students and alumni, can be vital to understanding the teaching-learning process and student success (or lack thereof), but such information alone is insufficient evidence of student learning unless accompanied by direct evidence."

ABET does not require direct assessment explicitly. However, program evaluators (PEVs) are trained to question whether assessment that does not include direct assessment has adequately demonstrated that students are actually achieving the learning outcomes.

Thus, direct assessment is a necessity. But direct assessment for the outcomes described here is also a stumbling block for many programs. Being outside the technical "box" that engineering instructors sometimes confine themselves to, assessing these outcomes requires a little creativity. This paper proposes approaches that would satisfy the need for direct assessment of these kinds of student learning outcomes.

Criterion 3-*d*: An ability to function on multidisciplinary teams

This criterion may be interpreted in different ways. Some programs consider this to require actual participation in multidisciplinary design projects. This would require projects, such as capstone design, incorporating elements outside the specialty. Some programs try to create capstone projects that involve students from multiple engineering disciplines. While this can satisfy the requirement, a closer reading yields both a different interpretation and an approach to assessment: Students can demonstrate the ability required by criterion 3-*d* by showing their understanding of what information they need to share with other specializations as part of the design process. For example, plants designed by chemical engineers or environmental engineers require data from laboratory-scale tests, and their design specifications are in turn used by civil engineers and power engineers, among others, to complete the project. Many product designs require interaction between mechanical and electronic engineers.

This interpretation does not require that capstone design projects actually be multidisciplinary. Although that would be desirable, it would be impracticable to make this a requirement. This serves the need for an interpretation that could apply to all projects.

Direct assessment of this capability could be done by requiring students to include a section in their capstone design report that lists engineering disciplines other than their own that they would interact with, and what kinds of information would be exchanged. Specifically, they would have to describe the information that they need from other disciplines, and what information would other disciplines need from them. A grade on that specific section of the report would then serve to provide data for assessment of this criterion.

Criterion3-*f*: An understanding of professional and ethical responsibility
Criterion 3-*h*: The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
Criterion 3-*j*: A knowledge of contemporary issues

These three outcomes can be dealt with similarly to each other. Even before these became required outcomes, programs often would mention such outcomes as being important. But equally often, they were incorporated into curricula only as presentation items, if covered explicitly at all. In any case, students were not being required to do any related work. It is well-recognized, however, that students learn best when they have to do something themselves.

Therefore, programs must ensure that there are discrete modules covering these topics somewhere in their curriculums, and preferably in multiple contexts. For example, an introductory course could include a lecture on the regulatory environment affecting the field. Then, the capstone design report could require a discussion of regulatory issues, if any. Contemporary issues, societal issues, etc., certainly are easily fit throughout the curriculum. Besides preparing the students for their profession, these can also make the subjects more interesting to them.

Ethics can be presented in two ways: general ethics and professional ethics. For the latter, all engineering professional societies have a code of ethics. Most are based on the NSPE code of ethics [3]. These tend to be rule-based and prescriptive, and do not provide a wide basis for moral reasoning. However, they are valuable as a starting point. There are many web-based resources available to assist in teaching professional ethics and that provide exercises for students and other resources [4-9]. Beyond the issues raised by the professional codes are workplace issues, such as dilemmas between an individual's responsibility to their employer versus responsibility to the public, issues of fairness in treatment of employees, whistle-blowing, etc. These can be folded into the professional ethics modules.

Besides professional and workplace ethics, it would be beneficial for the student to be introduced to general principles of ethical reasoning and bases of ethical principles (e.g. utilitarianism, pragmatism, rule-based, etc.) and to assign students a homework problem in applied ethics.

Some fields may have particular ethical principles, such as bioethics for bioengineering and environmental ethics for environmental engineering (or, actually, any engineering discipline). These could form a third ethics topic in those fields.

Student work related to ethics will likely take the form of a writing assignment. It could be a paper describing principles of ethics, or an assignment to analyze an ethical dilemma in one of the categories just described. Of course, including an assignment immediately solves the problem of direct assessment, as long as the assignment is graded.

For writing assignments for Criteria 3-*h* (impact of engineering) and 3-*j* (contemporary issues), there is a convenient source of information that will also contribute to students' learning in Criterion 3-*i* (life-long learning). This is the utilization of the professional literature. Professional societies publish magazines (as opposed to their research journals) that are an excellent source of information on current issues, controversies, societal impacts both on and by engineering, etc. An example of an assignment utilizing this resource would be to require students to write a three-page critical analysis of a magazine article from the professional society magazine for their field. The same assignment could require the students include separate sections in the paper (distinguished by separate headings) that address the impacts described in Criterion 3-*h* and 3-*j*.

Criterion 3-*g*: An ability to communicate effectively

It has become a stereotype of engineers that they are not effective communicators. Yet employers consistently tell us that the capability of graduating engineers that most needs improvement is not their technical competency, but their ability to communicate. If an engineer is unable to communicate their results well, it may be said that the job has effectively not been done at all. Communications for an engineer means not only narrative prose, but graphical communications and presentation of computations.

The separate writing assignments previously described for outcomes related to ethics, societal context and contemporary issues could also receive a broken-out grade for writing and organization. The same can be applied to the capstone design report. Many institutions have organized groups in their humanities departments or student services to help students in other programs with their writing assignments.

Furthermore, graphical and computational problem presentation should also be given a broken-out grade in some of the traditional technical assignments, and used to contribute to direct assessment of this criterion.

Sometimes, programs "offload" the teaching and assessment of communications to instructors in other programs, such as in the humanities. Ideally, however, instructors will take it upon themselves to model these competencies by making them part of the education that they provide themselves.This also enables them to tailor the requirements to those needed and used by engineers. Humanities writing assignments may lack many of the attributes of technical report writing needed by engineers.

Criterion 3-*i*: A recognition of the need for, and an ability to engage in life-long learning

An appreciation of life-long learning has often been cited as a goal of higher education programs across the board. However, it was often aspirational. The curriculum in such cases was not explicitly designed to impart it, and it was not measured as a student outcome. It could be said that, since instructors themselves may exemplify this attribute, they hoped to impart it by example. However, ABET now requires that it be incorporated in curriculum design and that it be measured.

Life-long learning has become the prototypical example for many instructors of an unmeasurable outcome. Part of the problem is the perception that it cannot be measured until a student exhibits the behavior after graduation. However, the criterion does not require that a student actually engages in life-long learning. It requires two separate things. The first is that the student should recognize the need for life-long learning. The second is that the student demonstrates the ability to engage in it. Both of these can be demonstrated within an engineering program.

Consider how professionals continue to learn after their formal education is complete. How do they do that? Examples include the following:

- Participation in professional society activities such as by attending conferences or making presentations to fellow professionals at conferences
- Read the professional literature, whether trade journals (magazines) or research journals
- Obtain and read books, even textbooks, to learn new skills on their own that could help them in their jobs
- Subscribe to web-based newsletters in their field
- Conduct internet searches for topics relevant to their field

These are all activities that students may also engage in, *exclusive of course requirements*.

The next step is to determine how this can be incorporated into the design of the curriculum. The answer to this is, at several points in the program, students should be incouraged to become student members of their professional society, be active in the student chapter if there is one, and then do the other things described.

Finally, we need to directly assess student performance. Here, in contrast to most other outcomes, we may directly assess performance with a survey. It is direct if the survey is asking for factual information, not judgements or opinions.

A good place to do such a survey is in the senior exit interview. For example, one of the commercially-conducted exit survey products [10] asks the following questions:

- I have a good understanding of the professional opportunities offered by my chosen major.
- I am planning to obtain an advanced degree in my field within the next 5 years.

This same product allows the institution to add custom questions which can further explore Criterion 3-*i*. Example questions that could be used include:

- What materials related to your profession have your read, other than those that were part of your curriculum? How many?
- Have you joined any professional societies? Which one(s)? Have you attended any conferences?
- Did you join the student chapter of the professional society in your field?
- Have you attended any professional presentations (e.g. seminars) on or off campus other than those required by courses?
- Do you subscribe to any professional journals, magazines, newsletters, whether via web, email, or hardcopy?

These measurements are easy to conduct (even without the use of the commercial survey product), and would provide the information needed to determine the degree to which students are achieving the curriculum. If student achievement in these areas is not satisfactory, then the progam would need to intensify its efforts to promote them (e.g. by providing free food at student chapter events!).

Using complex assignments for multiple outcomes

Often, as was mentioned above, the best place to measure some of these “soft” outcomes is in design reports, such as for the capstone design experience. Table 1 shows such a breakout for a junior-level design course designed as a preliminary capstone course. In this course the students work individually, to prepare them for the team-based senior design course the following semester. All grades are given on a 0.0 to 4.0 scale, with the usual interpretation.

The grade in this course has three main components: homework problems, the written design report (with individual sections written and submitted at intervals during the semester), and the oral presentation.

Note that the homework section includes several of the essay assignments such as are described in this paper. Each of those papers is judged by several broken-out criteria. For example, Table 2 shows the grading break-out for a writing assignment on environmental law given to students in a sophomore-level introductory course in environmental engineering.

Table 1 – Grading spreadsheet for multiple outcomes

Criteria	Weight		Student 1	Student 2	Student 3	Student 4	Student 5
TOTAL GRADE			**3.50**	**3.55**	**3.73**	**3.70**	**3.40**
Homework	30%		3.80	3.40	3.60	3.70	3.60
Written Design Report	50%		3.31	3.58	3.84	3.84	3.23
Oral Presentation	20%		3.50	3.67	3.67	3.33	3.50
HOMEWORK (30%):			**3.8**	**3.4**	**3.6**	**3.7**	**3.6**
Magazine article review			4	3.5	3	4	4
Technical paper review			3.5	4	3.5	3.5	3.5
Ethics paper			3.5	3.5	3.5	3	3.5
System mass balance problem			4	2	4	4	3
Pump curve problem			4	4	4	4	4
PID control simulation							
Activated sludge optimization							
ORAL PRESENTATION (20%)			**3.5**	**3.7**	**3.7**	**3.3**	**3.5**
Technical content/clarity			4.0	3.0	3.5	3.5	3.5
Visual presentation			3.5	4.0	4.0	3.0	3.5
Oral presentation			3.0	4.0	3.5	3.5	3.5
WRITTEN DESIGN REPORT (50%)			**3.31**	**3.58**	**3.65**	**3.84**	**3.23**
Writing	**15%**		3.0	3.5	3.5	3.8	2.5
Report organization *	**15%**		4.0	3.5	3.2	4.0	3.0
Introduction	**10%**		**2.60**	**2.10**	**3.70**	**4.00**	**2.40**
Goals/scope			4.0	3.5	4.0	4.0	3.0
Regulations & Standards			3.0	3.0	4.0	4.0	3.0
Multidisciplinary factors			0.0	0.0	3.0	4.0	3.0
Alternatives			3.0	0.0	4.0	4.0	3.0
Other factors **			3.0	4.0	3.5	4.0	0.0
Technical Design	**35%**		**3.58**	**3.78**	**4.00**	**3.63**	**3.33**
Flow diagram			4.0	4.0	4.0	4.0	4.0
Mass balance			4.0	4.0	4.0	3.5	3.0
Unit process design			4.0	3.7	4.0	4.0	4.0
Layout			3.5	4.0	4.0	3.0	3.0
Hydraulics			3.0	4.0	4.0	3.8	3.0
Pumping and Power			3.0	3.0	4.0	3.5	3.0
Controls (optional)							
Economics	**25%**		**3.00**	**4.00**	**3.50**	**4.00**	**4.00**
Cost estimation			3.0	4.0	3.5	4.0	4.0
Optimization (extra credit)							

*** Organization: Executive summary, headings, references, etc.**
**** Other factors: Ethical, social, political, public**

Table 2 – Grading table for essay on environmental law

Items	**Weight**	**Grade**
Writings and References	15%	
Summary of Legislative History	15%	
Summary of Major Provisions	15%	
Description of a Case History	15%	
Discussion and Conclusions	40%	
FINAL GRADE	**100%**	

Returning to Table 1, the grading break-out can be seen for the project written design report. Writing quality and organization separately count for 15% of the grade on the report. Separate items are graded for regulations and standards, which counts towards Criterion 3-*h*. Students are required to include a section on multidisciplinary factors as described above, in support of Criterion 3-*d*. The technical design section, of course, is also used to support Criterion 3, although not one of the factors we are concerned with here. Finally, the section on economics is broken out, and this grade is used to support the outcome in Criterion 3-*h*.

Besides making it easier to directly assess student achievement of these "soft" outcomes, there are two additional benefits of this approach to grading: First, as this table is given to the students in their syllabus, it contributes to their understanding of what the professor is expecting of them. Secondly, it guides the professor in his grading, making it both easier and less subjective.

Conclusion

Several of the measures described here involve essay-type assignments. Specifically, at least three essays may be required, for Criteria 3-*f* (ethics), 3-*h* (impacts), and 3-*j* (issues). This is also a type of work that instructors in engineering and the natural sciences may not be familiar and comfortable in assigning. Nevertheless, it is imperative that we do so, and that we give those assignments and the corresponding learning outcomes the attention we give to technical work that we require of our students.

References

[1] ABET, Inc., "Criteria for Accrediting Engineering Programs; Effective for Evaluations During the 2009-2010 Accreditation Cycle", http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Process/Accreditation_Documents/Current/eac-criteria-2012-2013.pdf, accessed October 5, 2012
[2] MSCHE, "Characteristics of Excellence in Higher Education; Requirements of Affiliation and Standards for Accreditation", http://www.msche.org/publications/CHX-2011-WEB.pdf, accessed October 5, 2012
[3] National Society of Professional Engineers (NSPE), "Code of Ethics for Engineers", July, 2007, http://www.nspe.org/resources/pdfs/Ethics/CodeofEthics/Code-2007-July.pdf, accessed October 25, 2012.
[4] National Academy of Engineering, Online Ethics Center for Engineering and Research, http://onlineethics.org/, accessed October 25, 2012.
[5] General Dynamics, "Standards of Business Ethics and Practice," Fifth edition (Rev. 3), August, 2011, http://www.nassco.com/pdfs/blue-book.pdf, accessed October 25, 2012.
[6] Carbo, T., "Models for Ethical Decision-Making for Use in Teaching Information Ethics: Challenges for Educating Diverse Information Professionals" http://www.i-r-i-e.net/inhalt/002/ijie_002_08_carbo.pdf, accessed October 25, 2012.
[7] Warner, Keith Douglass OFM, with David DeCosse, "A Short Course in Environmental Ethics, Lesson Twelve, An Environmental Ethics Decision-Making Guide", http://www.scu.edu/ethics/practicing/focusareas/environmental_ethics/lesson12.html, accessed October 25, 2012.
[8] University of Colorado "Steps to Resolving an Ethical Dilemma," http://www.colorado.edu/geography/gfda/resources/professionalethics/Hay_Steps%20to%20Resolving%20an%20Ethical%20Dilemma.pdf, accessed October 25, 2012.
[9] Zachry Dept. of Civil Engineering, Texas A&M Univ., "Introducing Ethics Case Studies into Required Undergraduate Engineering Courses, http://ethics.tamu.edu/, accessed October 25, 2012.
[10] EBI http://www.webebi.com/about, accessed October 25, 2012.

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