Assessing Diverse Student Outcomes More Efficiently:

An Example From Engineering Education

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In recent years, we have seen a growing trend toward outcomes assessment in higher education. The desired set of educational outcomes is sometimes identified by the individual educational institution. In other cases, such as in engineering, a set of desired educational outcomes is specified by an accrediting body. Regardless of their source, desired outcomes are usually represented by a list of seemingly diverse skills.

Those responsible for assessment design and implementation must identify appropriate assessment instruments that provide meaningful data, but we also are under pressure to minimize the cost and effort associated with the assessment process. Of particular concern is a possible trade-off between course content and the use of classroom time for assessment. The prominence of this concern became clear when we were asked to help the U.S. Air Force Academy's engineering accreditation working group design assessment strategies to satisfy new accreditation requirements, known as the ABET Engineering Criteria 2000 Program Outcomes (Accreditation Board of Engineering and Technology, 1997).

This article presents an efficient way to assess a diverse set of educational outcomes. Assessment efficiencies result from minimizing the number of assessment instruments used, generating more useful information, and embedding the assessment tasks as developmentally structured learning opportunities in normal coursework. We describe an assessment planning process that involves organizing a given set of outcomes (ABET, 1997) using a well-founded developmental structure (Fischer & Bidell, 1997;

Hofer & Pintrich, 1997; King & Kitchener, 1994; Kitchener & Fischer, 1990; Lynch, 1996; Pascarella & Terenzini, 1991). To illustrate the recommendations in this article, we use an example assignment adapted from the introductory mechanical engineering course at the U.S. Air Force Academy. Although the example is from engineering, the approach can be used to satisfy outcomes assessment needs in any setting.

A Generic Model for Addressing Open-Ended Problems

Open-ended problems also have been called ill-defined or unstructured problems. Such problems are fraught with significant and enduring uncertainties, and experts often disagree about optimal solutions. Ambiguity and uncertainty are evident in such factors as (a) the scope and definition of the open-ended problem, (b) evaluations of the appropriateness of related assumptions, (c) interpretations of related information, (d) the implications of possible solutions, and (e) the best way to monitor the impact of our choices. Appropriate responses to open-ended problems often require that we draw on a wide range of information and highly structured skills for problems that do have correct answers, or what is sometimes called the "content" of the curriculum. The focus of this article, however, is the problem solving skills necessary to use information appropriately in the face of real uncertainties.

Elsewhere we have described a generic process for addressing open-ended problems (Lynch, 1996; Lynch, Wolcott, & Huber, 1998; Wolcott & Lynch, 1997). It involves a sequence of increasingly complex skills found in many definitions of critical thinking and models of inquiry, decision making, professional judgment, and open-ended problem solving (e.g., Dewey, 1933; Golub, 1997; Polya, 1957; Schoenfeld, 1985; Schon, 1983; Woods, 1994): **identifying** the open-ended or unstructured nature of the problem, **framing** the complexities of the problem, **resolving** the problem, and **re-addressing** the problem as necessary. We elaborate on these terms later in this manuscript.

More than two decades of rigorous reflective judgment research (King & Kitchener, 1994) indicate that the skills necessary for addressing open-ended problems effectively develop and strengthen in that order (identifying, framing, resolving, and re-addressing). Research suggests that strong performance in the preceding, less complex skills increases the likelihood of strong performance in subsequent, more complex skills (Fischer, 1980; Fischer & Bidell, 1997; Kitchener, Lynch, Fischer, & Wood, 1993). For example, a person who does not adequately frame a problem is less likely to arrive at the best solution than a person who does frame the problem by attending to its complexities, exploring the context of the problem, and evaluating evidence from a variety of perspectives.

The overlay of outcomes onto the problem solving proces provides three primary benefits: (1) more efficient assessment plans, (2) more useful information, and (3) meaningful implications for curriculum design.

1. Outcomes such as those specified by ABET can be arrayed from less complex to more complex using the problem solving process. This allows design of a single open-ended exercise to simultaneously gather data regarding a variety of outcomes. By asking students to address an open-ended problem in a written format, it is possible to assess not only higher order thinking skills but also students' written communication skills and their use of highly structured technical skills. For example, an open-ended engineering design problem might present a myriad of complexly intertwined factors that introduce uncertainty and prevent a single "correct" solution, but some aspects of the design do have correct answers that depend on the highly structured laws of physics. Attending to the process sequence in the assessment instrument facilitates more complex student performance because performing less complex tasks lays a foundation for attempting more complex skills.

2. The process can help us interpret assessment findings. For example, the process can help educators and students understand why weaknesses in a less complex skills such as framing are likely to lead to weaknesses in a more complex skill such as resolving. Parallel evaluation forms for use by faculty and by students (for self-evaluation) provide mechanisms for structured feedback and student reflection on their performance and learning. Understanding that typical skill patterns are likely to be associated with different sets of beliefs about knowledge that might hinder student performance helps faculty provide more developmentally appropriate feedback and challenges. (See Lynch, Wolcott, & Huber, 1998, for lists of beliefs about knowledge associated with each skill pattern.)

3. The problem solving process provides a framework not only for assessment, but also for curriculum refinement. The time spent on different aspects of the problem solving process can be varied based on the needs of the majority of students in a particular class. If assessment data indicate that students are failing to adequately recognize the open-ended nature of problems, it would be particularly useful for coursework activities to focus upon this aspect of the problem solving process. If assessment data indicate that students do adequately recognize the open-ended nature of problems, then it would be more appropriate to focus on more complex aspects. If faculty include some attention to all parts of the process, they will provide learning opportunities for the wide range of skill patterns that is usually evident among a group of students (Wolcott & Lynch, 1997).

Using the Problem Solving Process to Organize

ABET Outcomes and Assessment Questions

In the following discussion, we move from less complex to more complex problem solving skills and briefly define the core skills for each phase of the problem solving process. We list the ABET outcomes that can be related to each skill in **bold** print. Of course, outcomes can be interpreted at different levels, and some might argue with my interpretation and subsequent assignment of an outcome to a particular place on the concept map of increasingly complex skills. The best placement of outcomes in the

problem solving concept map will vary depending on your interpretation of the outcomes and the specific nature of the assigned task (Fischer & Bidell, 1997). The point of this article is that a developmental sequence can be used to organize diverse outcomes and show how multiple outcomes can be assessed more efficiently.

The example assessment assignment involves posing an open-ended engineering problem, followed by a carefully sequenced series of questions requiring students to explain how they addressed the problem. These questions provide data about the outcomes associated with that phase of the problem solving process. The assignment is printed in *italics* below, and related questions from the assignment are presented in *italics* along with the skill definitions and related ABET outcomes for each phase of the process. For further information about this type of assignment, see Wolcott and Lynch (1997), Wood and Lynch (1998), and Lynch, Wolcott, and Huber (1998).

EXAMPLE ASSIGNMENT--

Engineering Mechanics 120, Introduction to Mechanics Design Project

Purpose: The purpose of this assignment is to give you an opportunity to apply your problem solving skills to a problem in engineering mechanics.

Assignment: Write a formal report to chronicle your team's efforts in solving the following engineering problem. Air Force Special Operations Command (AFSOC) is currently developing a Special Operations Forces (SOF) Team extraction system. The system must be capable of extracting a team of four from a remote location. The system must interface with a Special Forces C-130 performing a slow overhead pass. Initial prototype tests have resulted in several failures. The most notable was the rupture of the support cable between the team harness assembly and the aircraft. Your task is to evaluate the failure of the current design, and then propose your own design to satisfy the AFSOC requirement. In addition to the technical analysis, your evaluation and design report must address the following questions: [The questions are presented below in italics under the appropriate problem solving skill.]

SKILLS--ARTICULATING FOUNDATION "CONTENT": Uses or recites the well-structured information that has been the traditional focus of most courses, such as definitions, facts, mathematics, and other well-structured problem solving skills. Although people accumulate knowledge and build an array of well-structured problem solving skills throughout their lives, merely reciting information or accomplishing calculations does not require the type of reasoning called for in many outcome statements. Asking students to respond only at this level fails to address many desirable outcomes. Faculty may not realize that their students probably understand course content in less complex ways than they do. For example, a student may be able to use formulas to accomplish complex quantitative calculations and arrive at the correct answer for a well-structured problem. When presented with a professional scenario, however, the same

student may not recognize which formulas apply or fail to interpret the results in a realistic way. Appropriate applications and interpretations require more complex framing skills.

ABET--"**An ability to identify, formulate, and solve** [well-structured] **engineering problems.**" When this outcome is interpreted to mean only well-structured problems that have single correct answers, it fits here on the concept map. When it is interpreted to include open-ended problems, it falls under the resolving category (see below).

ABET--"**An ability to use techniques, skills, and modern engineering tools necessary for engineering practice**." Again, a very simple interpretation of this outcome focuses on well-structured tasks. When this outcome is applied to an open-ended problem, however, knowing which techniques, skills, and tools to use for a given scenario requires more complex skills than recitation or calculations.

ASSIGNMENT EXAMPLE--ARTICULATING FOUNDATION "CONTENT"

"*In addition to the technical analysis, your evaluation and design report must address the following questions."* "Technical analysis" refers to well-structured problem solving and thus fits here in the concept map.

SKILLS--IDENTIFYING THE NATURE OF AN OPEN-ENDED PROBLEM: Distinguishes highly-structured problems that have "correct" answers from open-ended problems. Faculty often assume that students understand the complexities involved in open-ended problems that preclude absolutely correct solutions. However, substantial data indicate that this is not the case for many undergraduates (King & Kitchener, 1994; Kitchener, Lynch, Fischer, & Wood, 1993; Wolcott & Lynch, 1997).

ABET--"**A knowledge of contemporary issues.**" Placing this outcome here implies that students need to do more than recite a list of contemporary issues provided in a textbook or listed in a lecture. When we encourage students to consider factors that preclude certainty about a given problem or scenario, we foster a more realistic and complex awareness of professional, civic, and personal issues.

ASSIGNMENT EXAMPLE--IDENTIFYING

1. Does this problem look like any of the problems you have seen in this or other classes?

a. If so, which ones?

b. If not, what is different about this one?

2. Are viable solutions to the problem already available?

3. Do you think knowledgeable persons can ever be certain about the BEST solution to this problem?

a. If so, how do you know which one is correct?

b. If not, why not? What factors contribute to the uncertainties surrounding the problem?

SKILLS--FRAMING AN OPEN-ENDED PROBLEM: Looks beyond personal perspective and initial assumptions; articulates the larger context of the problem, and makes legitimate, qualitative interpretations of relevant evidence from different perspectives. Strong framing is usually the most time-consuming part of addressing an open-ended problem effectively. It involves understanding your own assumptions and the assumptions that are embedded in other perspectives. For this reason, teamwork and effective communication are related to framing skills.

ABET--"**An ability to apply knowledge of mathematics, science and engineering**." Drawing on one's knowledge and applying well-structured information and techniques appropriately to open-ended problems often requires a complex understanding of the problem at hand and assumptions that are embedded in different parts or approaches to the problem.

ABET--"**An ability to design and conduct experiments, as well as to analyze and interpret data**." The first part of this outcome could be part of re-addressing in an on-going process, but the on-going process aspect is not articulated in the statement. The emphasis on interpreting data (from different perspectives as needed) allows us to consider it part of framing in which one coordinates theory and evidence in the interpretation of data.

ABET--"**The broad education necessary to understand the impact of engineering solutions in a global and societal context.**" This outcome focuses on the "big picture," which is an important part of adequate framing.

ABET--"**An understanding of professional and ethical responsibility.**" If this outcome had been stated differently, as making sound ethical judgments, it would be placed more appropriately under the resolving category.

ABET--"**An ability to function on multi-disciplinary teams.**" Understanding different perspectives is an important part of working with other professionals.

ABET--"**An ability to communicate effectively.**" In framing, the most important communication skills are probably listening and asking appropriate questions about the problem. Communication is also related to resolving (i.e., articulating and defending a solution). We can also use the written products that students produce in response to open-ended problems to evaluate general communication skills when we use guidelines designed specifically for this purpose. This further enhances the efficiency of assessment plans.

ASSIGNMENT EXAMPLE--FRAMING

4. What factors should be considered in addressing this problem?

5. What assumptions and biases are embedded in different perspectives (including your own) on the problem?

6. What are the possible alternate solutions to this problem?

7. Detail the arguments for and against each solution, paying particular attention to interpretations of relevant evidence.

SKILLS--RESOLVING AN OPEN-ENDED PROBLEM: Articulates and uses relevant guidelines or principles for making sound professional judgments across options or perspectives; reaches a conclusion and provides a well-founded justification in light of other options. It is important to note here that when we do employ open-ended problems in coursework, we often ask only for students' resolution and justification. In some respects this is counterproductive because it encourages students simply to stack up evidence in support of what they initially believed rather than to consider a range of options more objectively. This discourages the development of framing and resolving skills that can lead to better judgments about potentially viable solutions. A significant body of data suggests that most undergraduates and many adults in the U.S. do not develop strong framing and resolving skills (King & Kitchener, 1994; Langer, 1989).

ABET--"**An ability to identify, formulate, and solve** [open-ended] **engineering problems.**"

ASSIGNMENT EXAMPLE--RESOLVING

8. Which solution is likely to be most viable?

9. What is your justification for this belief?

SKILLS--RE-ADDRESSING AN OPEN-ENDED PROBLEM: Coordinates identifying, framing, and resolving skills into a viable process that moves toward better solutions or more confidence in a solution as the problem is addressed over time. (Lynch, 1996; Wolcott & Lynch, 1997). The term open-ended implies an iterative process. In some cases, we need to monitor the results of implementing a solution and, if necessary, continue to improve it. Examples include management decisions, design projects, research and development efforts, and the faculty responsibility for continuous curriculum refinement. To meet these challenges, we must integrate open-ended problem solving skills into an iterative process of generating and using meaningful information. This happens only after we have sufficiently developed the underlying skills and practiced them repeatedly in addressing a variety of problems. Professionals need to understand the process of learning in terms of identifying problems and opportunities; searching out, analyzing, and interpreting relevant information; and reaching a well reasoned conclusion that is open to reconsideration.

ABET--"**An ability to design a system, component, or process to meet desired needs**." In practice, re-addressing is required as one confirms or becomes more confident that the product or recommended solution does meet desired needs in the most efficient manner.

ABET--"**A recognition of the need for, and an ability to engage in life-long learning**." Understanding the process of inquiry in an open-ended environment is an important part of learning to learn (Accounting Education Change Commission, 1990).

ASSIGNMENT EXAMPLE--RE-ADDRESSING

10. What steps, if any, would you recommend to further explore the viability of the solution you endorsed? Why do you recommend these steps?

Conclusion

As demonstrated in this article and summarized in Table 1, overlaying or conceptually mapping a list of desired educational outcomes onto the problem solving process allows us to (a) construct assessment plans that simultaneously address a range of outcomes, (b) better understand the results of assessment information from a student development perspective, and (c) more effectively design educational efforts. These benefits can improve the usefulness and efficiency of our assessment and curricular efforts as we prepare students for the wide variety of professional challenges they will meet in a

complex and ever-changing world. For more information about designing and evaluating assignments based on the problem solving process described here, including examples from a variety of disciplines, visit this web site: http://www.du.edu/~swolcott.

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Table 1: Overview of Problem Solving Process Concept Map for ABET Outcomes and Example Assignment Questions

Phase of the Process	Related ABET Outcomes	Related Assignment Questions
Articulating foundation content	"**An ability to identify, formulate, and solve** [well-structured] **engineering problems.**"	*"In addition to the technical analysis, evaluation and design report must add following questions."* "Technical analy refers to well-structured problem solvi

	"**An ability to use techniques, skills, and modern engineering tools necessary for engineering practice**."	thus fits here in the concept map.
Identifying the nature of an open-ended problem	"**A knowledge of contemporary issues.**"	*1. Does this problem look like any of problems you have seen in this or oth classes? If so, which ones? If not, wha different about this one?* *2. Are viable solutions to the problem available?* *3. Do you think knowledgeable perso ever be certain about the BEST solutio problem? If so, how do you know whic correct? If not, why not? What factors contribute to the uncertainties surroun problem?*
Framing an open-ended problem	**"An ability to apply knowledge of mathematics, science and engineering**." "**An ability to design and conduct experiments, as well as to analyze and interpret data**." "**The broad education necessary to understand the impact of engineering solutions in a global and societal context.**" "**An understanding of professional and ethical responsibility.**" "**An ability to function on multi-disciplinary teams.**" "**An ability to communicate effectively.**"	*4. What factors should be considered addressing this problem?* *5. What assumptions and biases are em in different perspectives (including yo on the problem?* *6. What are the possible alternate solu this problem?* *7. Detail the arguments for and again solution, paying particular attention interpretations of relevant evidence.*
Resolving an open-ended problem	"**An ability to identify, formulate, and solve** [open-ended] **engineering problems.**"	*8. Which solution is likely to be most* *9. What is your justification for this b*
Re-addressing an open-ended problem	**"An ability to design a system, component, or process to meet desired needs**." "**A recognition of the need for, and an ability to engage in life-long learning**."	*10. What, if any, steps would you reco to further explore the viability of the you endorsed? Why do you recommer steps?*

Note. Outcomes from ABET, 1997. See Lynch, Wolcott, & Huber, 1998 for more information about problem solving assignments.