Testing in the Engineering Curriculum without Numbers

F.G. Edwards, E.W. LeFevre, W.M. Hale

4190 Bell Engineering Center, Department of Civil Engineering, University of Arkansas, Fayetteville, AR, (479) 575-4456, edwards@engr.uark.edu

Abstract
Since putting numbers, even of mixed units, into a formula to determine the answer is a "no-brainer" with today's calculators, constructing a test similar to the type given even ten years ago does little to evaluate a student's understanding of the subject matter and definitely does not evaluate the levels of knowledge as described by Bloom. The National Society of Examination of Engineers and Surveyors is in the process of evaluating a test that does not require any calculations for the Professional Engineering exam. Examinations using questions that test conceptual understanding, the ability to apply knowledge to a new area, and ability to evaluate alternatives can be constructed using short answer questions and multiple choice questions. Example questions from various civil engineering sub-disciplines are presented as well as guidelines for writing these types of questions.

Introduction
The calculators that are available today are more powerful and easier to use than the computers used 15 years ago. The software standard on programmable calculators allows the user to solve equations for an unknown variable without separating out the unknown variable and variables can be input in mixed units.

Due to concerns about exam security, the National Council of Examiners of Engineers and Surveyors (NCEES) has recently setup a committee to evaluate the advantages and disadvantages of constructing the Professional Engineering (PE) tests as "no calculation" examinations. In part, the security issues revolve around the ability of using today's calculators to transmit exam questions within the evaluation room and even outside the evaluation room using wireless FM radio transmitters. In addition, questions could be typed into the memory of a calculator and removed from the secure evaluation site when the examinee leaves the site. The NCEES psychometricians have indicated that evaluation of knowledge does not require that the examinee calculate an answer using a formula; but, it is possible to evaluate understanding using other types of questions.

Learning
Levels of learning have been categorized by numerous researchers (Bloom, 1956; Biggs & Collis, 1982; Pask, 1975; Säljö, 1979; Anderson & Krathwohl, 2001) giving the engineering instructor some guidance as to the types of questions to ask to determine the level of learning that the students have obtained. Bloom identified three domains of learning: 1) Cognitive, 2) Affective, and 3) Pshyco-Motor. Cognitive learning refers to knowledge skills, which is the area of learning we are interested in for teaching engineering (except possibly for ethics). Cognitive learning was further subdivided into levels of understanding, which from lowest to highest are:

Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. Bloom's Taxonomy of cognitive understanding is presented in Table 1.

Designing Test Questions

There are numerous learning evaluation methods which fall into one of the following categories:

1) selected response,
2) constructed response,
3) product assessment,
4) performance assessment, and
5) process-focused assessment.

Selected Response includes: mulitple choice, true-false, and matching. Constructed Response includes: completion (fill-in-the-blank), short answer, essay, label-a-diagram, concept map, figural representation, and open-ended questions. Product Assessment includes: reports, research papers, and projects, in the engineering curriculum; but, also includes: diary/journals, portfolios, exhibits, and videos. Performance Assessment in engineering curriculum typically includes: 1) oral presentation or lab demonstration. And lastly, Process-Focused Assessment includes: oral questioning and self-assessment checklist.

Constructing a good examination takes time, lots of time, and although universities often place publishing and research dollars above teaching, if instructors take the time to construct good examinations their student evaluations should improve (Felder, 1992). Some aspects of a good examination are given by Felder (2002) but, other factors to consider are the type of questions to ask; for instance:

1) Which of the five evaluation method categories (see above) should be used?
2) How much of the test should be "100% or 0%" versus allowing partial credit?
3) Does working through a calculation demonstrate that the student understands the problem to the cognitive level of understanding to which you want to test?

In lieu of constructing an examination from calculations, Selected Response and Constructed Response questions can test the students understanding and not allow their calculators to derive the answer for them. Both the Selected Response and Constructed Response questions have the following advantages: understanding cannot be easily bluffed, the questions can focus on details, a broad range of topics can be covered on an exam, ESL (English Second Language) students are not required to write answers (can be viewed as a disadvantage also), and the test is easy to grade. Some of the disadvantages are: writing questions that are well thought out and provide a fair evaluation are difficult and time consuming and may require pre-testing, the correct answer is typically given amongst the possible answers and this can jog the examinees memory or they may get lucky by guessing the correct answer, sometimes it is difficult to construct good distractors (incorrect answers), and more questions are required to make up an exam since the individual value of each question is low versus most other types of questions.

If the instructor is testing at the Knowledge, Comprehension, and even the Application level, exam questions should: be relevant to the material being tested, be unambiguous, and have one correct answer which is not based on the examinee getting a correct answer to a previous question. In addition, the question should: be simple and only involve one concept, not be

Table 1. Bloom's Taxonomy

Educational Objective	Description	Learning Performance Objective Terms	Assessment Strategies*
Knowledge	Remembering of previously learned material, often seen as reflecting rote learning. Includes specific knowledge and ways and means of dealing with specifics.	Describe, List, Name, Examine, Who, Identify, Show, Label, Name, When, Tabulate, Define	Objective tests - all formats
Comprehension	Reflects the first level of understanding, in which the meaning of material is grasped, and skills such as translation, interpretation, and extrapolation can now be applied. Verbatim repetition not desired.	Explain, Estimate, Restate in your own words, Summarize, Describe, Interpret, Contrast, Estimate, Differentiate	Objective tests - MC most desirable. Many basic EQ.
Application	Previously learned material can now be used in new contexts, although applications are typically to very concrete situations. Abstract applied to concrete.	Solve, Compute, Apply, Use, Apply, Solve, Examine, Modify, Change, Relate, Classify, Calculate, Complete	Objective tests - MC, EQ, OB, CS, THE
Analysis	Material can now be broken down into component elements so that relationships and organizational principles can be identified and applied.	Analyze, Order, Explain, Classify, Select, Explain, Compare, Contrast, Analyze, Identify, Separate, Discriminate	Objective - EQ, THE, OB, CS, Journal/Portfolio, Performance testing
Synthesis	Information about analyzed parts can now be put together to create new wholes, unique plans or patterns, new perceptions or abstract relationships.	Compose, Design, Rearrange, Plan, Combine, Rearrange, Substitute, What if	All formats, Any type of critique
Evaluation	Judgement or evaluation of information and ideas, based on all previous levels of cognitive aplication. Value determinations.	Judge, Evaluate, Support, Test, Measure, Explain, Recommend	All formats depending on wording

* MC - Mulitiple Choice; EQ - Essay Question; OB - Open Book; CS - Case Studies; THE - Take Home Exam

a negative (e.g. “Which of the following is NOT --- “).

Multiple Choice questions should have several (3 to 5) distractors which are plausible without giving away the correct answer, have answers with similar length (or significant digits), have distractors that can be derived by common student errors, have numeric answers in increasing or decreasing order, and have the correct answers located randomly and not predictably (i.e. the correct answers should be somewhat evenly distributed between A, B, C, D & E). In addition, terms such as “never” and “always” in should be avoided in the question and answers; instead, terms such as “usually,” “most likely,” and “rarely” should be used. Questions with “none of the above” does not indicate that the examinee knows the correct answer; and, questions with “all of the above” are too easily ruled out if only one of the above does not fit.

True-false questions have the added disadvantage of giving a 50-50 chance of getting the correct answer to the student. To decrease the ability of the examinee of guessing the correct answer, both answers should be plausible.

Because of the way they are constructed, a matching question tests more than one concept at a time (i.e. if the student misses one part of the question they will often miss another part since they have misused one of the answers). To lessen the examinee determining that the last remaining answer does not match the last question, so they must have made a mistake in a previous matching, the answer column should have two or more answers than the number of questions.

Completion (fill-in-the-blank) and Short Answer questions require the examinee to come up with an answer on their own. A given answer may be correct, incorrect, or have part of the correct answer. Fairness in grading requires that the question writer determine before hand what value will be given for various partially correct answers (0 to 100%). It is important to understand that if examinees are required to recite an answer word-for-word, the level of examination is lowered to the Knowledge level, since they will simply memorize the notes or text and may not understand the meaning of what they have written.

One type of question that is unique to engineering is the Computation Flowpath question. In this type of question the examinee is asked to list the steps required to determine an answer; but, they are not given any numbers to use in calculations. For an answer to this type of question the examinee would state: 1) C would be calculated given variables A, B, and m and the formula $C = mA + B$, 2) F would be determined from C and the formula: $F = A - C$, and 3) the answer is determined by adding F and B. Because this is not a common type of examination question, the examinees should be familiar with this type of questioning from lectures, quizzes, or homework.

Example Questions

Given below are a number of example questions (with answers) for each cognitive educational objective category in the areas of environmental engineering, geotechnical engineering, and concrete design.

Environmental Engineering Questions
Knowledge level

Q. What is the primary function of an activated sludge basin?
A. The biological conversion of organic compounds (BOD) in a wastewater to biosolids and CO_2.

Comprehension level

Q. Control of the activated sludge process is typically accomplished by monitoring what operational paramenters?
A. mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), sludge blanket depth in the secondary clarifier, or sludge volume index (SVI).

Q. The advantages of using membranes as a solids separator in the activated sludge process include which of the following:
A. optimization of the biological reactor design without considering settlability of the MLSS

Application level

Q. The solids loading rate (SLR) for a secondary clarifier is calculated according to what formula?
A. $[(Q_i + Q_{RAS})(MLSS)] \div$ (surface area of the clarifier)

Analysis level

Q. If an activated sludge system has an effluent that meets the permit with regard to BOD; but, has too high of a suspended solids concentration, which of the following are most likely
A. check EPA.

Soils Engineering Questions
Knowledge level

Q. Define Porosity.
A. Porosity is the volume of the voids divided by the total volume in a given sample.

Q. Define coarse-grained soils.
A. Soil with more than half of material larger than the #200 sieve.

Comprehension level

Q. What is the relationship between plasticity as measured by the Atterberg Limits and swelling potential of a clay soil?
A. The higher the plasticity index, the greater the swelling potential.

Q. What soil property influences the load capacity of a friction pile?

A. The load capacity of a friction pile is the contact area of the pile multiplied by the soil cohesion. The soil property is the soil cohesion.

Application level

Q. Given the unconfined compression strength of a clay soil, what is the cohesion?
A. The cohesion is one-half the unconfined compression strength.

Q. If in an unconfined compression test, a 500 pound vertical load is applied to a cylindrical sample with a cross-sectional area of 5 sq-in and a height of 10 inches, what are the principal stresses on this soil cylinder?
A. The horizontal principal stress is zero. The vertical principal stress is 500/5 = 100 psi.

Analysis level

Q. In order to select a foundation type, what information would you need?
A. In selecting a foundation type, the applied loads and their location plus soil strength properties would need to be known.

Q. You are designing a retaining wall. You must choose between backfill material (A) with a friction angle of 30 deg. and one (B) with an angle of 40 deg. Which would create the greater active earth pressure?
A. The greater the phi angle, the less the active earth pressure. The greater active force would be created by using Material A. This is a function of tan^2(45 deg - phi/2).

Synthesis level

Q. What property of a clay soil is affected by addition of stabilizing agents?
A. By combining clay platelets into larger groups, the swelling/shrinkage of a clay soil is reduced.

Q. What factors are relevant in a design of an exploration plan for a building site.
A. The relevant factors are the geologic history of the region, structural behavior of other structures in the region as well as the magnitude and location of proposed loads.

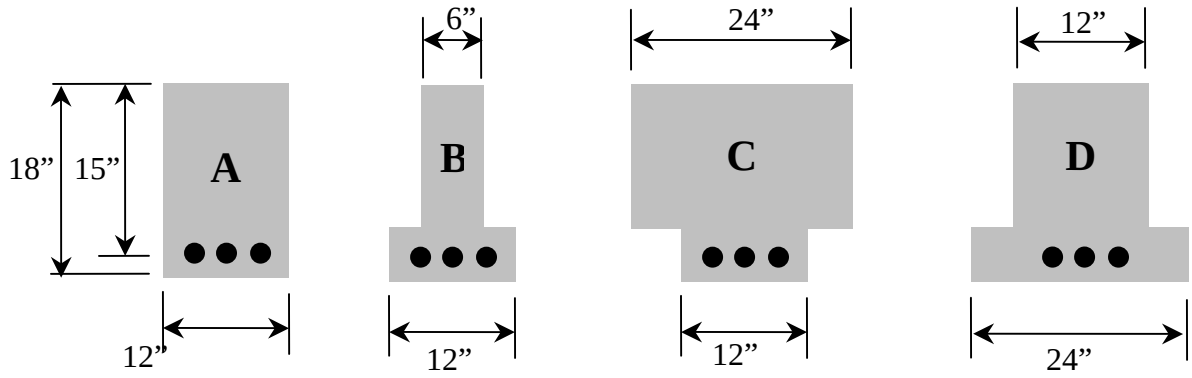
Evaluation level

This educational objective is beyond the undergraduate level or more complex than can be answered by short responses.

Concrete Design Questions
Comprehension level

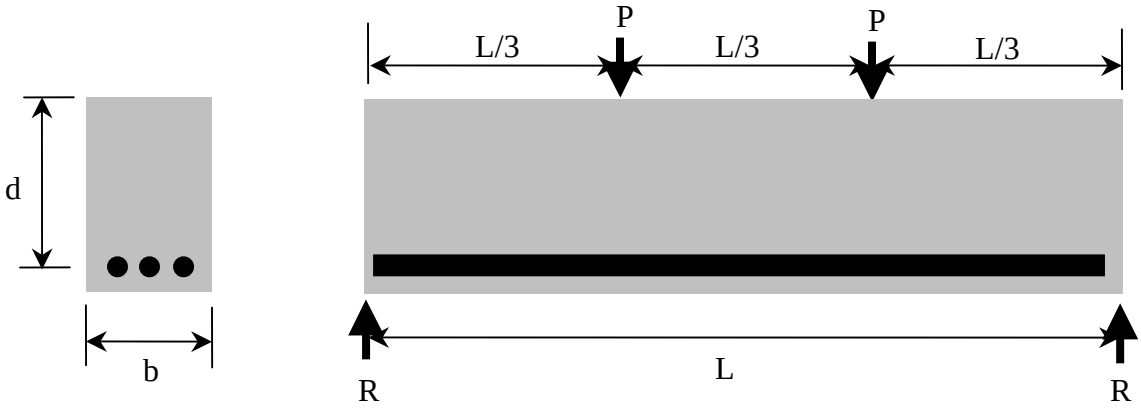
Q. Using greater-than (>) and if needed equal to (=) symbols, rank the cross-sections in order, from highest to lowest, according to the nominal moment capacity. For all cross-sections, the

compressive strength of the concrete, f'_c, and the yield strength of the reinforcement, f_y, is the same, and the cross-sectional area of the steel reinforcing, A_s, is the same.



A. C>D=A>B

Given the beam and loading show below



Knowledge level

Q. Why is the longitudinal reinforcement placed in the bottom of the beam?
A. To resist the tension force in the bottom of the beam.

Application level

Q. If the compressive strength of the concrete (f'_c) is doubled what happens to the nominal moment capacity?
A. the nominal moment capacity only slightly increase.

Analysis level

Q. If a load greater than P is applied to the beam and some crushing of the concrete takes place between the point loads; then, the load is decreased to P, will the beam be able to resist the load of P again? Explain your answer.
A. No, the crushed concrete on the top of the beam will decrease the effective depth, d, (the moment arm), which will decrease the nominal moment capacity.

Conclusions

Use of well thought out questions that do not require calculations (or only minor calculations that do not require a calculator) can be used in engineering to test various levels of knowledge, to increase understanding of engineering principles and decrease reliance on calculators, and to decrease the potential for cheating.

References

Anderson, L.W., & Krathwohl, D.R. (eds.). (2001). *A Taxonomy for Learning,Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, Longman, New York.

Biggs, J., Collis, K. (1982) *Evaluating the Quality of Learning: the SOLO taxonomy*, Academic Press, New York, NY.

Bloom, B.S. (ed.) (1956) *Taxonomy of Educational Objectives, the classification of educational goals – Handbook I: Cognitive Domain*, McKay, New York, NY.

Felder, R.M. (1992). "What do they know, anyway?" *Chemical Engineering Education, 26*(3), 134–135.

Felder, R.M. (2002). “Designing tests to maximize learning”, *J. Prof. Issues in Engr. Education & Practice, 128* (1), 1–3

Pask, G. (1975) *Conversation, Cognition, and Learning*, Elsevier, New York, NY.

Säljö, R (1979) "Learning in the Learner's Perspective: 1: some commonplace misconceptions" *Reports from the Institute of Education*, University of Gothenburg, 76.