CONCEPT QUESTIONS IN ENGINEERING: THE BEGINNINGS OF A SHARED COLLECTION

Peter Goodhew

University of Liverpool

ABSTRACT

Concept questions (CQs) have been pioneered by Eric Mazur and others, and popularised by the Force Concept Inventory (FCI). CQs require that the student thinks about and applies engineering principles and ideally require the recall of few, if any, facts or data. At present they are available (or at least published) in just a few areas of engineering. A review of the available literature reveals only a dozen or so examples of the systematic use of concept questions. This session will be dedicated to sharing what is currently available and stimulating the writing of further CQs in currently under-populated areas of engineering.

KEYWORDS

Concept questions; assessment; engineering principles

INTRODUCTION TO CONCEPT QUESTIONS

Concept questions are questions for students which seek to explore their understanding rather than their recall or knowledge. In higher education they have been developed by teachers in various fields, but principally in physical sciences, over the twenty years since about 1991. Concept questions could be used for either formative or summative assessment, but one of the huge advantages they offer is the potential for the teacher to discover the misconceptions held by his or her students in time to do something about this deficit. Consequently there are more reports of concept questions being used in class, or in pre-course surveys, than in summative examinations. [e.g. 1, 2].

It is probably helpful to illustrate the power of concept questions by using an example from the engineering education domain, rather than from a technical domain such as mechanics or thermodynamics. Let us consider possible questions about assessment:

1. List ten ways in which a taught course might be assessed;
2. Describe, giving advantages and disadvantages for each, three ways in which a course might be assessed;
3. Would you devise the summative assessment for a course before or after assembling the content to be taught? Explain your answer.

Question 1 simply tests recall of facts (whether these were included in a lecture or in a source found by the student). Question 2 tests recall of facts, but also requires a little more detail about each. This detail might arise from understanding but equally might demonstrate better recall. (I have seen a recent example of two complete pages of detail being recalled by a student in a closed examination – demonstrating no understanding whatsoever.) Question 3 is a concept question. In order to answer it the student would need to understand not only the meaning of the phrase “summative assessment” but also its purpose and its relationship to the “taught” material and the intended learning outcomes of the course. Unless the students had previously been presented with the identical question, recall of facts (or a model answer) is of very little use in answering it.

Concept questions were originally used by Mazur as a focus for student engagement in large classes and were associated with responses via a “clicker” (personal response system). However this is merely one way in which such questions can be deployed. Many education researchers have also used sets of concept questions as a research tool with which to investigate the extent of, and reasons for, student misconceptions about key concepts in engineering and physical science.[e.g. 3, 4, 5, 9, 11]

Many good concept questions offer “distractor” answers which reflect common misconceptions, but the questions do not necessarily have to be multiple choice. Some equally good questions ask for open-ended responses in free text. Mazur [I think, but cannot find the reference!] recommends marking these on a very coarse scale, analogous to that used when refereeing a paper (e.g. 3 for “accept unchanged”, 2 for “minor corrections needed”, 1 for “major re-write needed” and 0 for “reject”. The analogous rubric for a concept question is clear.) Such marking does not require a long time per answer.

In this paper I want to outline the small number of published sets of concept questions which are available in the engineering domain, and encourage CDIO members to contribute to extending this resource.

EXISTING SETS OF QUESTIONS

The best known set of concept questions is probably the Force Concept Inventory (FCI) devised by Hestenes [6] and accessible at http://modeling.asu.edu/r%26e/ and in Mazur’s book [1]. Gray and a team of co-workers have assembled a Dynamics Concept Inventory of 29 questions [7], but in order to forestall student discovery and the sharing of answers, the inventory is only accessible to faculty on application to the team. Mazur published several sets of questions with his book “Peer Instruction” in 1997 [1] and these cover a range of topics drawn from undergraduate physics. This is the largest set of questions in a single open source and many of the questions are applicable to engineering students.

Good concept questions are quite time-consuming (and intellectually challenging) to produce, so for obvious reasons it is sensible not to release them to students but to use them only in controlled class situations. Mazur for one, and maybe others, have also regularly used concept questions in formal summative examinations [1].

In order to give a flavour of the questions which have already been written, I have appended a small selection. To reduce the risk of letting good question sets out of the bag, I have not credited each individual question with its provenance, except to say that the source of every question has been cited in this paper [8, 10, 12, 13 and other references] .

A CDIO CONCEPT QUESTION RESOURCE

I propose that we establish a shared CDIO bank of concept questions. This would include (with permission from the authors) existing sets of questions but would be considerably enhanced by the addition of questions written by faculty members of CDIO member institutions. As a start I propose that everyone at this conference should devise a single question in their own domain of specialisation.

As a second step I am willing to collect and coordinate this question bank, either or both via Mendeley [www.mendeley.com] and/or Dropbox [www.dropbox.com]. In both cases I am happy to give access to any CDIO Faculty member or other bona fide engineering academic who wishes to contact me. Mendeley is an excellent package for sharing pdf resources but has a number of sharers limited by the rate of subscription so cannot be completely open to all those who request access. I will give first preference to CDIO faculty.

At the conference in Copenhagen I will be asking all delegates to submit concept questions for inclusion in this resource. It would be useful to look through Mazur's book first, because this is the largest single pre-existing resource. I have also compared the available concept questions with the set of concepts which the lecturers of first year classes claim to teach at the University of Liverpool. Topics which appear to be currently under-supplied with concept questions include the following (in no particular order):

- Vectors
- Bending moment diagrams
- Tracking a load through a structure
- Non-dimensional groups
- Bernoulli equation
- Thermodynamic reversibility/irreversibility
- The logical ideas behind a computer program
- Systems thinking
- The link between properties and microstructure
- Interaction between basic deformation modes (e.g. bending and torsion)
- Crystallinity and its implications

These topics require a conceptual grasp, but there are many other first-year topics which require knowledge and – especially – a clear understanding of vocabulary. A common set of questions in these domains would also be useful but is not the subject of this paper.

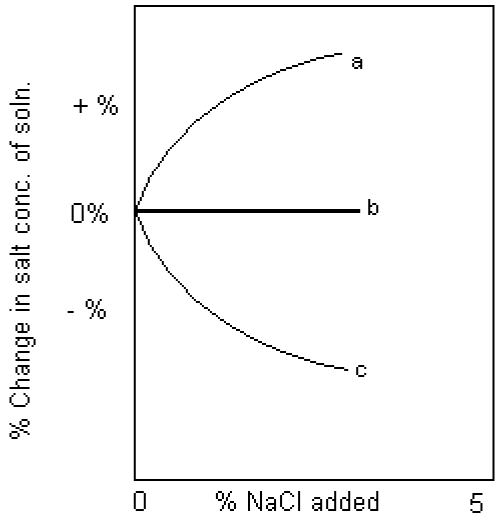
SOME EXAMPLES OF CONCEPT QUESTIONS

1. Draw the free body diagram for a coin just after it has been tossed. [Alternatively: What is the force on a coin just after it has been tossed?] Are the forces on the coin greater on the way up or the way down? Ignore air friction.

2. H_2O is heated in a frictionless piston-and cylinder arrangement, where the piston mass and the atmospheric pressure above it are constant. The pressure of the H_2O will: (a) increase (b) remain constant (c) decrease (d) need more information.

3. About a teaspoon of water-saturated salt sits on the bottom of a beaker. If the solution is allowed to sit for 24 hours and have some of the water evaporate, which curve represents the change in concentration of the salt in the solution from time t1 to t2?

(Circle a or b or c) PLEASE EXPLAIN. [Diagrams in concept questions rarely need to be more sophisticated than this.]



4. A large truck collides head-on with a small car. During the collision:
   a) The truck exerts a greater amount of force on the car than the car exerts on the truck;
   b) The car exerts a greater amount of force on the truck than the truck exerts on the car;
   c) Neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck;
   d) The truck exerts a force on the car but the car does not exert a force on the truck;
   e) The truck exerts the same amount of force on the car as the car exerts on the truck.

5. A system consisting of a quantity of ideal gas is in equilibrium state “A”. It is slowly heated and as it expands its pressure varies. It ends up in equilibrium state “B”. Now suppose that the same quantity of ideal gas again starts in state “A” but undergoes a different thermodynamic process (i.e. follows a different path on a P-V diagram) only to end up again in the same state “B” as before. Consider the net work done by the system and the net heat absorbed by the system during these two different processes. Which of these statements is true?
   a) The work done may be different in the two processes but the heat absorbed must be the same;
   b) The work done must be the same in the two processes, but the heat absorbed may be different;
   c) The work done may be different in the two processes, and the heat absorbed may be different in the two processes;
   d) Both the work done and the heat absorbed must be the same in the two processes, but are not equal to zero;
   e) Both the work done and the heat absorbed by the system must be equal to zero in both processes.
   [Each of the five answers was selected by some students.]

6. If atomic bonding in metal A is weaker than metal B, then metal A has:
   a) lower melting point

b) lower brittleness
c) lower electrical conductivity
d) lower thermal expansion coefficient
e) lower density

7. If you unwrap a new piece of modeling clay that is a rectangular solid 4cm x 4cm x 16cm, which one of the following would most increase its surface area?
   a) Press down on a long side (making it, e.g. about 16 x 8 x 2 cm3)
   b) Form it into a cube, about 6.5 cm per side.
   c) Form it into a cylinder, keeping the length about 16cm.
   d) Make a sphere.

8. What do these three processes have in common?
   Rust forming on iron nail
   Water evaporating from a dish
   A piece of candy dissolving in your mouth
   a) The rate of change depends on the mass of the substance.
   b) All three processes involve a change in phase.
   c) All three processes are chemical reactions.
   d) All three processes occur at the surface of the substance.
   e) All three processes depend on the solubility of the substance.

9. You are in an elevator travelling upwards at constant velocity. Suddenly you drop your keys: It so happens that when they strike the floor they are at the same height above ground level as when they left your hand. The keys fall dead on the floor without bouncing. Make a single graph showing qualitatively the height above ground of both the keys and the elevator as a function of time, starting before the keys are released until after they strike the floor.

REFERENCES

[1] Mazur, Eric; “Peer Instruction: A User’s Manual”, Prentice Hall, 1997, ISBN 013565441-6

[2] Krause, S, Kelly, J, Triplett, J, Eller, A and Baker, D, “Uncovering and addressing some common types of misconceptions in introductory materials science and engineering” J Materials Education, Vol 32, 2010, 255-272

[3] Krause, S, “Assessing conceptual transfer of phase behaviour from the domain of chemistry to the domain of materials engineering, 1st Int Conf Engineering Education, Honolulu, ASEE, 2007

[4] Light G, Swarat S, Park, E J, Drane, D, Tevaarwerk, E and Mason, T “Understanding undergraduate students’ conceptions of a core nanoscience concept: size and scale”, 1st Int Conf Engineering Education, Honolulu, ASEE, 2007

[5] Meltzer, David E “Investigation of students’ reasoning regarding heat, work, and the first law of thermodynamics in an introductory calculus-based general physics course”, Am J Phys 72 (11) 2004, 1432-1446

[6] Hestenes, David, Wells, M and Swackhamer, G, “Force Concept Inventory,” The Physics Teacher, Vol. 30, No. 3, 1992, pp. 141-151.

[7] Gray, Gary L, Evans, D, Cornwell, P J , Self, B and Costanzo, F "The dynamics concept inventory assessment test: A progress report", Proc 2005 American Society for Engineering Education Annual Conference, Portland and "Dynamics Concept Inventory Web Site" www.esm.psu.edu/dci/

[8] McCarthy, T J and Goldfinch, T, "Teaching the concept of free body diagrams" Proc AaeE Conf, Sydney, 2010 pp 454-460

[9] Krause, S, Decker, J C & Griffin, R; "Using a materials concept inventory to assess conceptual gain in introductory materials engineering courses", Proc 33rd ASEE/IEEE Frontiers in Education Conference, 2003, T3D-7

[10] Midkiff, K C, Litzinger, T A, and Evans, D L, "Development of engineering thermodynamics concept inventory instruments" Proc 31st ASEE/IEEE Frontiers in Education Conference, 2001, F2A-3

[11] Newcomer, J L and Steif, P S "Gaining insight into student thinking from their explanations of concept questions" 1st ASEE Int Conf Research in Engineering Education, Honolulu, 2007

[12] Steif, P S and Dantzler, J A "A statics concept inventory: Development and psychometric analysis", ASEE, 2005, pp 1-9

[13] Streveler, R A, Miller, R L, Nelson, M A, Geist, M R and Olds B M, "Development and psychometric analysis of the thermal and transport concept inventory" 1st ASEE Int Conf Research in Engineering Education, Honolulu, 2007

BIOGRAPHICAL INFORMATION

Peter Goodhew is Emeritus Professor in the School of Engineering, University of Liverpool, UK. He is one of the Directors of CDIO and the joint Leader of the UK & Ireland region. He is interested in many aspects of engineering education and has recently published a short book on the subject: "Teaching Engineering", downloadable from http://www.materials.ac.uk/resources/Teaching-Engineering.pdf

CORRESPONDING AUTHOR

Professor Peter Goodhew
School of Engineering
University of Liverpool
Liverpool L69 3GH
goodhew@liv.ac.uk