THE GENERIC QUIZ

A Device to Stimulate Creativity and Higher-Level Thinking Skills

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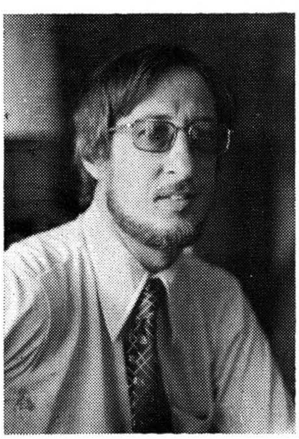
Several troubling questions occasionally intrude on the thoughts of some engineering professors.

1. **The standard format for all classes from first grade through graduate school is lectures (teacher presents information to students), homework (students demonstrate that they can repeat and perhaps apply this information), and quizzes (students demonstrate again that they can repeat and perhaps apply the same information).**
   Question: What do students learn from this approach? More to the point, what don't *they learn from it?*
   Question: Are the skills required to succeed in the lecture-homework-quiz routine the same as the skills required to be an excellent engineer, or even a good one?
   Question: Are less rigid alternative teaching approaches feasible, given the amount of material that must be covered in the engineering curriculum?
2. **Most engineering course time is spent teaching students to solve well-defined problems that have (so we believe) one correct answer. However, most real nontrivial problems don't fit this description: the questions are vaguely defined, and the "correct" answer usually begins with "It depends."**
   Moreover, all of our courses are based on well-defined compartmentalized bodies of knowledge: we teach thermodynamics in the thermodynamics course, fluid mechanics in the fluid mechanics course, and rarely do the twain meet in the minds of the students who take these courses. Show me a professor who has not been greeted by blank looks and mumbled denials when he has asked about material from other courses, and I will show you a professor in his first week of teaching.
   Question: If open-ended and poorly defined problems are the norm in the world, why don't they show up in our courses? Is it possible to introduce such problems and give students training in the thinking skills needed to solve them, given the number and variety of well-defined convergent problems we must teach them to solve?
   Question: Since most serious problems facing technology and society require for their solution techniques from several disciplines, shouldn't we regularly expose our students to interdisciplinary material in our courses? Can we do so, given the amount of straight disciplinary material we have to cover?



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It was time for me to make up the third quiz in a recent graduate course on chemical reaction engineering. Wishing to do something different from the usual "Given this and this, calculate that," I decided to give a take-home quiz in which the students would make up a final examination for the course. It was not an original idea, and in fact I had done several things like it in previous courses; however, as I thought about how to structure the quiz it occurred to me that I could use it to deal with all of the questions raised above—questions that have concerned me to an increasing extent since I first got into the teaching business [1].

I announced the quiz in the eighth week of the course, and set a due date five weeks later, a week before the last day of class. The quiz (see Table 1) turned out to be an extremely interesting experiment—both for me and, as it turned out, for the students. In this paper I discuss what I did, what the students did, what we all learned from the

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experience, and how the technique might be profitably adapted to any course on any subject.

PRE-QUIZ PREPARATION

Shortly after I announced the quiz, I decided that the students would benefit—and would make up much better tests—if they knew a little about the thinking skills I was trying to exercise in them and which I wanted them to exercise in the hypothetical takers of their examinations. I therefore devoted about 20 minutes of a lecture to Bloom's *Taxonomy of Educational Objectives* [2]:

1. Knowledge (memorization)
2. Comprehension (understanding)
3. Application (using)
4. Analysis (taking apart)
5. Synthesis (putting together)
6. Evaluation (making value judgments)

I noted that the last three of these categories are collectively referred to as the higher-level thinking skills, and told the class that one of their objectives was to have all three of these skills represented on their examinations, although not to equal extents. I gave several illustrative problems of different types, got the students to speculate on which skills would be required to solve them, and then gave my own opinions.

I next gave the students a warm-up exercise for the quiz, both to let them do some of their initial floundering in a relatively safe (non-graded) setting and to help solidify their understanding of the thinking skills. I told them that as part of their next homework assignment, they were each to make up a single problem related to the assignment topic (diffusion of gases in porous catalysts) that involved higher-level thinking skills. They were not required to provide solutions to these problems.

As would be expected, the problems they created were very uneven in quality, although on the whole not bad for a first effort. Most emphasized primarily the lower-level skill of application and quite a few incorporated analysis, but there was little synthesis and almost no evaluation. I compiled the problems, made up one of my own to

TABLE 1
The Quiz

Make up an open-book final examination for this course. Submit the examination, including a statement of the testing conditions for which it is designed (3-hour in-class, or take-home due after a specified period between one day and one week), and a fully worked-out solution, on April 19. The ground rules are as follows:

1. The test must have something to do with chemical reactor design and analysis. You don't have to hit every topic we've covered this semester, but try for a reasonable balance.
2. The questions must be original. You can look at any references you want and talk to anyone you want, including one another, in search of ideas, but your final result should be entirely the product of your own creative efforts.
3. A straight plug-in test (A→B, given a rate law, calculate the reactor volume) which is internally consistent and error-free will receive a minimal passing grade. Extra points will be given for questions that do some of the following things:
   - Require analytical skills. For example, ask the students to derive formulas used in class for which derivations are not presented in the notes or textbook, or ask them to provide theoretical and/or physical explanations of observed phenomena.
   - Require synthetic (creative) skills. For example, give problems with solutions that require putting outside material (e.g. from chemistry, mathematics, or other engineering courses) together with material from this course. Or, give problems that require using methods presented in the course in new ways. Or, give problems that seem to have nothing to do with chemical reaction engineering, but whose solutions require techniques used to analyze reactors. You may use humor, but not too much, and only if you feel comfortable doing so.
   - Require evaluative skills—call for value judgments. Ask the students how they would judge the "goodness" of, say, a reactor design. (It may work, but is it a good design?) Call on them to speculate about possible environmental or social or ethical consequences of something. Test the breadth and depth of their thinking. In short, do unto them what I'm trying to do unto you in this test.

That's all there is to it. Be aware, however, that you're likely to find this a tough assignment. My advice is to get started right away, so that you can see early what kind of problems you're going to run into and get help with them. Trust me—this is not something you're going to be able to do if you start on April 18. Have fun. You may use humor, but not much, and only if you feel comfortable doing so.

better illustrate evaluation, ran off copies, and handed them out in the next class period. Several of the problems are given in Table 2, along with my opinions of the thinking skills likely to be exercised in solving them.

The class and I reviewed all the problems, and for each one collectively formulated answers to two questions: (1) What thinking skills does the problem require for its solution? (2) How could the problem be improved? Several students who had written relatively weak problems came up with good ideas for their improvement as the discussion proceeded, which led me to infer that something useful was being accomplished.

At this point, I felt reasonably confident that I had done all that needed to be done by way of preparation, and that to do much more would be counterproductive. The only other thing I did to help the class was to give relatively light homework assignments in the two weeks before the quiz was due. I had warned them to begin early, but I have been teaching long enough to know when the work would really get done.

THE EXAMINATIONS

Fifteen examinations were submitted, which ranged in quality from acceptable to spectacular, surpassing anything I had expected to see in a trial run of an experiment. Most were reasonably balanced and would have been suitable as one- or two-day take-home exams. (No one succeeded in making up an examination that could be completed in three hours, even though about half the class claimed to have done so.) Most of the tests appropriately involved primarily straightforward application and analysis, and all but two or three of them contained at least some of the desired creativity and evocation of higher-level thinking skills.

Not surprisingly, the scopes and levels of the examinations wandered all over the map. There were easy questions, hard questions, and killer

TABLE 2
Illustrative Problems

1. The pore diffusion model derived in class was for a cylindrical pore. Suppose the pore were approximated by a cone of base radius R, altitude h, and side length s (distance from the outer edge of the base to the peak). ($V_c = \pi R^2 h/3$, lateral surface area $A_1 = \pi R s$.) The catalyst particle volume is V, and the particle surface area is W. Assume that $s \rightharpoondown h$ (i.e., that the cone is long and skinny), and that all diffusion is Fickian.

(a) Derive the differential equation for one-dimensional diffusion in the pore, and solve it to obtain an expression for the concentration of reactant for the reaction A→B. Include all assumptions and discuss them. (*Analysis, possibly synthesis, depending on the level of the mathematics needed to solve the problem.*)

(b) Write the conical equivalent of the Thiele modulus, ϕ, and plot the conical effectiveness factor, ϵ_c as a function of ϕ. (*Analysis*)

2. In an experimental packed-bed reactor (capacity W = 2 kg) using very large recycle of product we obtain the following data:

A→R, C_{AO} = 10 mol/m³

C_A(mol/m³)	1	2	3	6	9
r(mol/m³_s)	5	20	65	133	540

The process is to be scaled up to a larger packed bed reactor, also with a very high recycle ratio. What will be the amount of catalyst needed for 90% conversion for a flow rate of 1000 mol A/h if C_{AO} = 8 mol/m³? (*Comprehension: this is a straight plug-in problem.*)

3. Chain reactions involving free radicals can terminate homogeneously by combining with other free radicals. Frequently, they are also said to terminate homogeneously on surfaces. This is usually written

R– + surface → ?

I find such a step unpalatable. What might be happening and what implications might this have for chain reactions in the presence of a catalyst? (*Synthesis: Much more material from physical chemistry is involved here than we covered in the course.*)

4. You are the process engineer in charge of the design and construction of a large fixed-bed catalytic reactor. The design was performed by a recently graduated chemical engineer with an M.S. degree, using published rate data for the same reaction with the same catalyst. You checked the design, found it sound, and approved it. The reactor construction is currently about 2/3 complete.

Today a project engineer who will be in charge of startup on the project came into your office with a copy of the design, which he had been given to review, and informed you with some concern that nowhere in the design had possible pore diffusion effects been taken into account. You realize immediately that he is right, and proceed to do the necessary calculations.

(a) What questions would you ask, and what calculations would you perform to determine the answers? (*Application, analysis*)

(b) What might you do if you determine that pore diffusion will lower the rate of reaction significantly, so that the reactor will be seriously underdesigned? Consider as many realistic options as you can think of. (*Analysis, evaluation*)

(c) Who should be held principally responsible if the omission turns out to have serious consequences, and what action should be taken? (*Evaluation*) questions. There were problems whose solutions required applications of principles from transport phenomena, thermodynamics, biotechnology, physical chemistry, applied mathematics, and economics. There were applications of reaction engineering principles to biotechnology, process control, environmental science, on-line process optimization, plant safety, male-female relationship formation (there were two of these), the relationship between predators and their prey, and a mathematical model of human accomplishment. There was also humor, some of it quite good.

The students tended to go to their strengths, also appropriately. The food science major in the class managed to find food science contexts for a broad spectrum of the course material and framed his questions in these contexts; the wood and paper science major did the same in his field, and likewise the chemistry major. The mathematically inclined students put together examinations heavily oriented toward analysis, and the experimentalists came up with more phenomenological questions.

Following are outlines of some of the more noteworthy examination problems.

1. **A mechanism is given for a polymerization reaction, and an approximate rate law is also given. In successive parts of the problem, the student is asked to (a) determine whether the mechanism could possibly be compatible with the rate law; (b) choose a reactor type, discussing reasonable alternatives and justifying the final choice; (c) design the reactor; (d) examine heat transfer data for the reactor and comment on possible reactor stability problems; (e) comment on how the use of a chemical initiator might alter the reactor design; (f) propose possible explanations for a dramatic drop in yield two months after the reactor is started up; (g) propose methods to deal with new EPA waste standards that make current levels of unreacted monomer in a waste discharge stream unacceptably high, considering both technical and nontechnical aspects of the problem.**

2. **A brief outline of evolutionary operations (EVOP), a statistically-based on-line process optimization technique, is given, followed by data for an antiquated process used to produce a specialty chemical. The student is asked to select variables which, if adjusted, would be likely to yield significant process changes; to summarize the probable and possible effects of the adjustments; and to describe the probable outcome of an EVOP run performed on the process.**

3. **Joe Dolt has purchased a B.S. degree in chemical engineering for $2500 from an obscure university in the Bahamas, and has gone into business for himself since no company would hire him. He finds data for a reaction that yields a valuable product, designs and sets up a pipe reactor, runs the reaction at the conditions he finds in a published paper, and gets a product yield 10% higher than the paper indicates he should have gotten. The student is asked to (a) suggest possible reasons for the discrepancy; (b) critique the reactor design; (c) outline possible hazards associated with the operation; (d) use Dolt's experience as a basis for discussing the notion that "the piece of paper is all that matters because you never use what you learn in school anyway."** *(The student's problem solution contains a pretty good refutation of this philosophy.)*

4. **A quote from an F. Scott Fitzgerald story is given in which it is suggested that a woman who succeeds in making herself attractive to any one man becomes more attractive to all others, including the one she wants, and so is more likely to form a relationship than is her less attractive counterpart. The student is then asked to (a) translate this observation into a mechanistic model for the pairing of couples at a social gathering with equal numbers of males and females; (b) solve the model equations to determine the pairing rate; (c) discuss the defects in the model, and indicate the difficulties one might run into verifying it experimentally.**

   In another problem, the same student came up with two creations I am particularly fond of: "Von Uberheit's Auto Radiator Boutique," and an artist who bills herself "Butterfly Troppe-Roth: Creations in Welded Boiler Plate."

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5. **A solid catalyst particle in the shape of a cylindrical shell is proposed, and the student is asked to derive expressions for the effects of diffusion in the catalyst pores on the performance of the catalyst.**

   Solving this problem involves deriving a differential equation, obtaining the solution in terms of Bessel functions, and then performing several mathematical operations on the solution to achieve the desired result—an excellent problem in applied mathematical analysis. Its only flaw is that it was only worth 20 out of 100 points on an in-class examination designed to be completed in three hours! I mentioned this and several similar problems to the class, and let them deduce the moral regarding the difficulty of making up tests to fit within tight time limits. (As their subsequent evaluations disclosed, many of them got the point.)

6. **A sheep rancher has been troubled by marauding coyotes, and is trying to decide whether or not to undertake an expensive trapping operation. The student is given an outline of the Lotke-Volterra model of predator-prey interactions (which has important applications to the analysis of biochemical reactors), and is asked to (a) use the model (with specified values of the model parameters) to determine whether the**

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trapping operation can be justified; (b) comment on the assumptions integral to the analysis that might affect the validity of the model, and (c) to propose modifications that might make the model more applicable to the given situation.

The student's solution, which involves the computer generation of phase-plane plots that asymptotically approach stable limit cycles, is a beautiful illustration of an important phenomenon in chemical reactor dynamics. I hope to persuade him to publish it.

7. **A model of human accomplishment is proposed, wherein something called "motivation" is converted to something called "achievement" by a first-order rate process occurring in the brain. The proportionality constant, I, is called "intelligence." Motivation is said to originate in infinite supply at a concentration M_s in a small region centrally located in the brain, and diffuses to all regions of the brain at a rate proportional to the negative of its concentration gradient. The diffusion coefficient is inversely proportional to D, the brain density, and S, the "sloth factor." The parameters I and D are immutable (hereditary traits), while M_s and S can be influenced by human will (environmental traits). The student is asked to (a) derive an expression for the concentration of motivation at any point in brain space; (b) determine how the value of the sloth factor determines the extent to which individuals reach their personal potential for achievement; (c) comment on the weaknesses of the model and suggest improvements.** *(In the course of the solution, the student makes some nice points regarding the nature versus nurture dichotomy, and suggests that Bloom's taxonomy might well be augmented by an additional category to cover creative leaps in knowledge.)*

8. *The last examination to be considered here was a total pleasure to read. The introduction follows in its entirety.*

   "Graduating with a strong background in chemical reaction engineering and kinetics, you have taken a job with an established paper company and will be working at a pulp mill. Your mind is frothing with fantasies about working with high-performance PFR's, packed-bed catalysis, and reactor optimization studies. However, nothing is as expected in the pulp and paper industry. Much to your chagrin, you have been assigned to a position as an engineer in the mill's waste treatment plant. How pagan! There's not even much to call a proper reactor—just a bunch of ditches and ponds.

   "You have a lot to learn, buddy. The problems you are going to encounter in waste treatment, while not standard, require a great deal of knowledge in the area of kinetics and reactor design. In addition, you will need far more common sense and consideration of the issues than in a lot of 'standard' reactor design domains.

   "It's a great job. Good luck."

   The examination goes on to pose an outstanding series of problems involving biological waste treatment kinetics, treatment system evaluation, environmental impact evaluation, and deduction of the mechanism of a reaction when faced with incomplete data and a management unwilling to release needed information. Along the way we meet such characters as "Phyllis Smugley, Yuppie-in-Charge of environmental operations," and "Marvin Spite, your assistant and the man passed over in order to hire you straight from school." (You are horrified to discover that the dissolved oxygen levels in the river are drastically lower than normal, whereupon Marvin giggles impishly. "Nothing is wrong," he sneers. "Trust me.")

EVALUATION

It was apparent to me as I reviewed the examinations that the students had put in an extraordinary amount of time and energy in constructing and solving them. In a sense, each examination represented a personal statement: the students were playing their own game rather than the teacher's (they couldn't play the teacher's game, since they weren't sure what it was), and most of them put everything they had into it. It was also clear that in taking the quiz they had learned a great deal about many things, including but not limited to chemical reaction engineering. What I think they learned and what they think they learned are summarized in the next section.

Grading the examinations was an interesting exercise. First, it was the one and only time in my 16 years of teaching that I ever enjoyed reading test papers; this alone was almost enough to make the exercise worthwhile from my point of view. I also found that it was impossible to define an objective grading scale since there were no precisely defined requirements, and even the students who made up relatively pedestrian examinations put a great deal of effort into them and demonstrated a good grasp of a broad spectrum of material. I ended up giving nine grades between 90 and 100, four between 80 and 89, and a 75 to a student who had constructed a reasonable test but whose solutions contained a number of rather serious errors.

While I was delighted with what the students did and felt that the quiz had done everything I wanted it to do (and then some), I was aware that some of the students were uncomfortable about the fuzziness of the requirements and the time it took them to make up their examinations. To assess how they regarded the experience after the fact, I prepared and distributed an evaluation form and asked them to fill it out after the quizzes were handed in but before they were graded and returned. On the form I asked them to rate their agreement or disagreement with seven statements regarding the difficulty, instructiveness, and enjoyability of the quiz, and the level of effort required to take it. I then asked them to furnish comments regarding what they liked and disliked about the quiz.

I got responses from 14 of the 15 who took the quiz. The unabridged and unedited responses are as follows.

Attitudes toward the test

The choices were agree strongly (AS), agree (A), neutral (N), disagree (D), disagree strongly (DS).

1. The test was easy.
   AS-0%; A-0%; N-7%; D-21%; DS-71%
2. The test was more difficult than the usual type of quiz.
   AS-29%; A-64%; N-7%; D-0%; DS-0%
3. The test was enjoyable.
   AS-29%; A-50%; N-21%; D-0%; DS-0%
4. The test was instructive.
   AS-71%; A-29%; N-0%; D-0%; DS-0%
5. The test was more trouble than it was worth.
   AS-0%; A-7%; N-21%; D-57%; DS-14%
6. I think I am good at this sort of thing.
   AS-0%; A-14%; N-57%; D-29%; DS-0%
7. I hope I never have to do anything like this again.
   AS-0%; A-0%; N-21%; D-29%; DS-50%

Things liked about the test

- Allowed exercise of creativity and allowed us to learn more in the specific areas which interested us the most.
- The option of thinking about all or many problems that you can solve and to find out about what you can do, or what you know.
- To do the test, you had to have a very good grasp of the material in the course. It was a very good way to tie the material together and excellent preparation for the final.
- 1. Allowed one enough time to do a thorough job, unlike class period quizzes. 2. Caused one to really explore the subject material.
- That's a new experience I've never had before. But it supports a new way to organize all the stuff you learn from the book and lectures, and most important, it can give you ideas how to use those practically.
- Challenge of evaluating one's own efforts, which is a necessary step in making a good test.
- Forces one to think deeper than just memorization, helps one be able to see interconnections between this course and others.
- I liked it! I've always felt like the weakling or underdog when it comes to battles with exams or tests, but this exercise made me feel strong. I feel that this type of test is one of the few that allows both the pragmatist and theoretician to show their stuff.
- The most important thing for this test was it made me do outside research, in my case in my own work at food science.
- For once, I was able to use my strength—my ability to apply what I know to realistic situations—rather than have my weaknesses—time-limited proofs, unrealistic (to me) problem-solving—played upon.

I distributed an evaluation form and asked them to fill it out after the quizzes were handed in but before they were graded and returned.

- I liked having to encompass everything on the test. It made me study over everything, and end up with a better feel for the whole class as well as an in depth look at different aspects about it.
- Two things: 1. Forced a review of the course material (and beyond) in an integrated fashion. 2. Gave insight into what professors have been up against when making out all those tests that I've taken over the years.
- I liked the freedom to look at the material without having to worry about missing some detail that would hurt me on a more conventional test.
- It gave me a chance to take a chemical engineering situation and explore everything I could think of concerning this situation.

Things not liked about the test

- Trying to turn ideas into questions which were neither impossible nor trivial.
- Precisely that I could ask many questions and it was so difficult to answer them that some times it is frustrating, but actually it was constructive.
- It took a lot of time.
- Criterion for writing questions was too general, too much time was spent deciding what questions which I wrote were appropriate.
- Since it is the first time, a little bit of confusion and difficulties with it. But I believe the more difficult you find a test, the more you learn from it.
- I wasn't sure, despite all the class time spent on it, exactly what was expected.
- It took too long for me to do it.
- The fact that I've never done this sort of test, and also not being too sure of what problems are the most suitable.
- It was difficult to come up with a good image or theme—perhaps some mild limitations on subject or style would force us to go down one vein or another. I'm not advocating the suppressing of creativity—merely suggesting narrowing down the wide range of possibilities.

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adequately illustrated through examples. The number, and more importantly the variety, of exercise problems in many chapters should have been increased. Use of experimental data as the basis for problem formulation is rarely attempted in the book. A refreshing exception is provided by the example problem under dimensional analysis dealing with the formation of bubbles of one phase in another. I also wish that the problem statements were more interesting than they presently are throughout the book in order to capture the students' interest. One would have expected to see in the Third Edition examples and problems illustrating the application of transport theory to modern chemical engineering problems —those that have become important in the years since the Second Edition of the book.

Overall, *Momentum, Heat, and Mass Transfer* by Bennett and Myers has firmly established itself as a textbook for those choosing to study unit operations guided by transport theory. While one or another feature of the book may be found less than satisfactory by different instructors, they could easily be improved by the use of supplementary material prepared by instructors. Until a more appealing approach to teaching transfer operations emerges, the book by Bennett and Myers will remain prominently in many students' bookshelves. □

CORROSION ENGINEERING

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- **I think the only thing about it that makes me feel uncomfortable is the grading. While in some cases it may be pretty obvious the person didn't work hard it seems to me that in others a person might come up with a good comprehensive test, but just not be in the type of format the grader may be looking for. This feeling would be hard to verify, though.**
- **If it had a drawback it was in the time required to do a decent job. Clearly, this was an assignment which could absorb as much time as one was willing to give to it.**
- **I think it is very difficult to be creative and yet produce reasonable questions. This made the exercise somewhat frustrating and time consuming.**
- **Nothing. I couldn't wait to work on it.**

Things gained from the experience

Students also volunteered comments on what they had gained from the experience. Many repeated points they made in the "Things liked" category regarding the depth of study required to make up a good examination. One comment I particularly appreciated was: "I know what *you* go through now. I also understand some of the puzzling questions put on tests in my undergrad classes in ChE—when you're preparing the test yourself, even unfair questions seem reasonable." If a few students who go on to join faculties get this message, the exercise will have served a useful purpose indeed!

CONCLUSIONS

I was planning to summarize here what I think the students got out of the experience, but in reading over their comments I realize that they've said it all.

I will conclude, then, by restating the challenges with which I began this paper. First, in the straight lecture-homework-test format, the instructor can cover a much larger body of material than can be covered in any other manner, but there is a real question of how much of the material is actually learned this way (as opposed to being temporarily stuffed into short-term memory and then forgotten). Second, instructors can make life relatively easy for themselves by sticking to convergent (single-answer) questions, but then they are not preparing students to deal with the really important problems they will be called upon to solve in their careers—problems usually open-ended and poorly defined. Third, it's difficult to find the time for interdisciplinary material in content-heavy engineering courses, but interdisciplinary thinking is necessary to solve the toughest of society's problems—and if we don't train our students in it when they're with us, they're not likely to be able to use it when they leave us.

I suggest that the do-it-yourself examination represents an easily implemented step toward meeting each of these challenges within the framework of the standard engineering course. The quiz took very little time to construct and administer, and if you look over the version given in this paper, you will see that with only minor changes it fits every course in every engineering curriculum (hence its label in the title of this paper). It forces the students to assimilate course material on their own, to a much greater extent (I believe) than is required by the usual lecture-quiz format. It requires them to deal with open-ended questions; to engage in divergent thinking; to exercise their own creativity in seeking ways to exercise the creativities of those who would take their examinations. It encourages them to seek out and synthesize material from several disciplines, and so prepares them to deal with the most serious and difficult problems they are likely to encounter in their professional careers. And, *it does all this without taking much from the in-class time the instructor needs to cover his or her syllabus.*

Clearly, one wouldn't want to make every test in a course like this. Also, the approach and expectations might have to be scaled down for most undergraduate classes. Instead of requiring a complete final examination, for example, you might get the students to make up and solve individual problems, homework assignments, or quizzes. Alternatively, you might assign "creativity exercises," in which they are given open-ended problems and asked to brainstorm as many possible solutions as they can, without regard (at least on the first round) to technical feasibility or practicality [3]. In any case, I am convinced that introducing variations of this device into engineering courses could lead to substantial positive changes in the way students view both the courses and themselves. After all, if you can do something in a class that the students almost unanimously agree is challenging, instructive, AND enjoyable, something good is bound to result.

POSTSCRIPT

For the final examination in the course, I gave a straight-down-the-middle, comprehensive, and (in my opinion) quite difficult test, covering almost every topic treated in the course. For whatever reason, the students ate it up—the average was 80, fifteen or more points higher than the averages on previous tests other than the infamous third quiz. I don't know how much, if anything, the quiz had to do with the students' apparent mastery of the course material. Obviously, though, it didn't hurt.

REFERENCES

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2. B. S. Bloom, Ed., *Taxonomy of Educational Objectives.* Handbook I: Cognitive Domain. New York, David McKay (1967).
3. R. M. Felder and R. W. Rousseau, *Elementary Principles of Chemical Processes,* 2nd Edition, New York, John Wiley & Sons. □