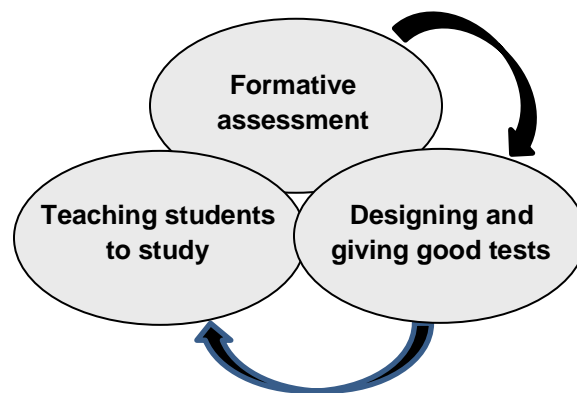


# Assessing students' learning rigorously and fairly

Rebecca Brent  
President, Education Designs, Inc.  
Chapel Hill, NC

Richard Felder  
Hoechst Celanese Professor Emeritus of Chemical Engineering  
North Carolina State University



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**Rebecca Brent, Ed.D.**

President, Education Designs, Inc.  
Chapel Hill, North Carolina

Email: [rbrent@mindspring.com](mailto:rbrent@mindspring.com)

Twitter: @RebeccaBrent

Dr. Brent is President of Education Designs, Inc., a consulting firm in Chapel Hill, North Carolina. She has more than 40 years of experience in education and specializes in staff development in engineering and the sciences, teacher preparation, and evaluation of educational programs at both precollege and college levels, and she has authored or coauthored roughly 120 papers on those topics. She holds an Ed.D. from Auburn University and a Certificate in Evaluation Practice from the Evaluators' Institute at George Washington University. Prior to entering private consulting, she was an Associate Professor of Education at East Carolina University where she won an outstanding teacher award. In 2014, Dr. Brent was named a Fellow of the American Society for Engineering Education.

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**Richard M. Felder, Ph.D.**

Hoechst Celanese Professor Emeritus of Chemical Engineering  
North Carolina State University

Email: [rmfelder@mindspring.com](mailto:rmfelder@mindspring.com)

Website: [https://www.ncsu.edu/effective\\_teaching](https://www.ncsu.edu/effective_teaching)

Dr. Felder joined the N.C. State University faculty in 1969. He is a co-author of the book *Elementary Principles of Chemical Processes*, which has been used as the introductory chemical engineering text by roughly 90% of all chemical engineering departments in the United States and many abroad, and he has authored or co-authored over 300 papers on chemical process engineering and engineering education. He has won numerous awards for his teaching, research, and publications, including the International Federation of Engineering Education Societies Global Award for Excellence in Engineering Education (first recipient) and the American Society for Engineering Education Lifetime Achievement Award in Engineering Education (first recipient).

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Drs. Brent and Felder are coauthors of *Teaching and Learning STEM: A Practical Guide* (Jossey-Bass, 2016, [educationdesignsinc.com/book/](http://educationdesignsinc.com/book/)). Separately and together, they have presented over 500 workshops on effective teaching, course design, mentoring and supporting new faculty members, and faculty development, on campuses and at conferences around the world. They co-directed the American Society for Engineering Education National Effective Teaching Institute from 1991 to 2015. Visit their company website—including a blog with their ideas on teaching and learning—at [www.educationdesignsinc.com](http://www.educationdesignsinc.com), and their Facebook page at [www.facebook.com/felderandbrent](http://www.facebook.com/felderandbrent).

## Assessment and Evaluation of Learning

**Assessment:** Gathering information that will be used to improve students' learning and instructor's teaching (*formative assessment*) or to inform decisions about students' learning and instructor's teaching (*summative assessment*).

**Evaluation:** Interpreting assessment data and applying the results to making the decisions (assign students a pass/fail or a letter grade or credit for auditing a course, give instructors merit raises, tenure, promotion, awards,....)

**Formative assessment** (Felder & Brent, 2016a, pp. 61–63, 94–95). Examples:

- *Monitor students' questions in class and office hours and their responses to instructors' questions in class.*
- *Monitor students' facial expressions and body language during class.*
- *Monitor students' contributions in face-to-face and synchronous online class group activities ("active learning").*
- *Give ConcepTests—multiple-choice questions that address students' understanding of and misconceptions about course-related concepts (Mazur, 1997). ConcepTests are increasingly found in STEM textbooks and online compilations and by entering "ConcepTest \_\_\_\_" into a search engine, where \_\_\_\_ is any general or specific topic.*
- *Give online quizzes—short low-stakes tests that follow assigned readings and viewings identify areas of weakness that should be addressed in the next class session. Monitor distribution of correct and incorrect responses. The instructional power of online readings, videos, and multimedia tutorials may be significantly increased by accompanying them with automatically graded online quizzes on their content (Adesope et al., 2017; Cassady & Gridley, 2005; Spajners et al., 2015).*
- *Create and manage online discussion boards. Monitor students' responses to instructors' prompts and other students' comments on the responses.*
- *Minute paper. Stop the lecture with two minutes to go and ask students to anonymously write the main point(s), (2) the muddiest (least clear) point(s). Collect the papers and look through the responses to check for the students' (1) recognition of the main points, and (2) common points of confusion. Begin the next lecture by addressing the latter. Provide students the option of including their names so that you can address individual questions via email (Angelo & Cross, 1993).*
- *Midterm evaluation. A few weeks into the course, ask students to respond anonymously to at least three prompts: "What features of this course and its instruction are helping you learn?" "What features of the course and instruction are hindering your learning" "What other comments do you have?" You might also include a request for comments on a specific feature of the course, such as "Are in-class group activities (a) helping your learning? (b) hindering your learning? (c) having little effect on your learning?" and "What will you do differently in the future to improve your performance?"*

The day the evaluations are collected, skim through them and note the two or three most common responses to each prompt. In the next session, share your summary with the students, say what you plan to do in response to their requests for change that you plan to address, and explain why you are not willing to meet other requests (Felder & Brent, 2016a, pp. 102–103).

Student responses to minute papers and midterm evaluations identify features of the class that are and are not working well and ways to improve the latter. Positive responses from you in the next class give the students the powerful message that you're concerned about their learning and willing to listen to them. Administering and responding to midterm evaluations raises end-of-course ratings (McGowen & Osgathorpe, 2011).

In an analysis of thousands of published studies of factors that promote student achievement, Hattie (2009) found that formative assessment ranked #1 among 34 teaching practices examined and #3 among 138 factors of all types.

**Summative assessment** (Felder & Brent, 2016a, Ch. 8).

Summative assessment tools include exams, quizzes, assignments, lab reports, and written and oral project reports. All summative assessments can have a formative component, depending on what instructors and students do with the results. When instructors find out what their students missed, they can modify their teaching to address the deficiencies, and when students find out what they missed, they can go back and study those things before the next assessment.

**Activity #2.** Shown is the first test in an introductory mechanics course followed by the instructor's worked-out solution. The students have been exposed to the concepts of unit conversions, density and specific gravity, and Archimedes' Principle. Individually read the test (below this box) and skim the solution key (following two pages), spending no more than two minutes. In your group, critique the test. When the 1-minute warning is given, choose a spokesperson for the group to report if called on by breakout room number.

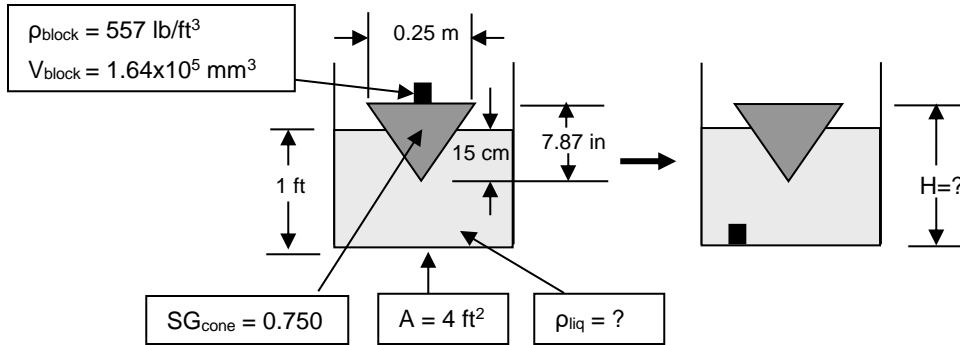
**CHE 203–Exam #1.** 50 minutes—Closed Book. (Refer to handout with conversion factors.)

A copper block with a volume of  $1.64 \times 10^5 \text{ mm}^3$  and a density of  $557 \text{ lb/ft}^3$  rests on the base of a solid cone of base diameter 0.25 m and height 7.87 in, which floats in a liquid the determination of whose density is part of this problem and is immersed to a depth of 15.0 cm in a cubical tank 2.00 ft on each side. At a certain time the copper block is picked up and immersed in the tank. The liquid level before the immersion of the block is half the height of the tank. The specific gravity of the cone is 0.750.

- (a) Calculate the density of the liquid ( $\text{g/cm}^3$ ).
- (b) Calculate the vertical distance (cm) from the bottom of the tank to the base of the cone after the block is immersed in the liquid. If you have no time to work out the numbers, outline a solution procedure.

**Exam 1: Solution** (Numbers in circles are point values)

(a)



Volume of liquid:  $V_{liq} = (30.48 \text{ cm})(3716 \text{ cm}^2) - V_{immersed} = 113,263 - 1381 = 1.119 \times 10^5 \text{ cm}^3$  (5)

volume of cone

$\frac{D_i}{h_i} = \frac{25}{20} \Rightarrow D_i = \frac{5h_i}{4} \Rightarrow V_{DL} = \frac{\pi}{3} \left( \frac{5h_i}{8} \right)^2 h_i = (0.4091 h_i^3) \text{ cm}^3$  (5)

Mass of liquid displaced by cone & depth of immersion

$M_{DL} = [0.4091 h_i^3 (\text{cm}^3)] \left( 2.836 \frac{\text{g}}{\text{cm}^3} \right) = 1.390 h_i^3 (\text{g})$  (5)

Archimedes  $\Rightarrow M_C = M_{DL} \Rightarrow 2454 = 1.390 h_i^3 \Rightarrow h_i = 12.09 \text{ cm}$

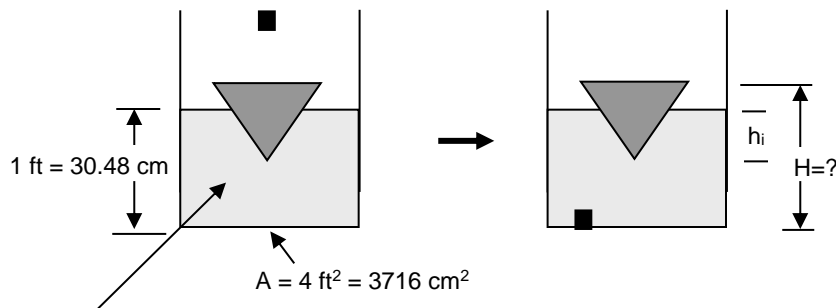
$\Rightarrow$  Base of cone is  $(20.0 - 12.09) = 7.91 \text{ cm}$  above liquid surface (15)

Mass of displaced liquid and liquid density

(10) (10) (5)

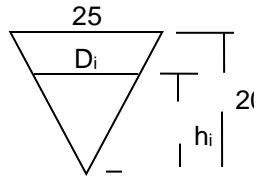
$M_D = V_D \rho_{liq} = 1381 \rho_{liq} \xrightarrow{\text{Archimedes}} (M_C + M_B) = 1381 \rho_{liq} \Rightarrow \rho_{liq} = \frac{(2454 + 1463) \text{g}}{1381 \text{ cm}^3} = 2.84 \text{ g/cm}^3$

(b)



Volume of liquid:  $V_{liq} = (30.48 \text{ cm})(3716 \text{ cm}^2) - V_{immersed} = 113,263 - 1381 = 1.119 \times 10^5 \text{ cm}^3$  (5)

Immersed  
volume  
of cone



$$\frac{D_i}{h_i} = \frac{25}{20} \Rightarrow D_i = \frac{5h_i}{4} \Rightarrow V_{DL} = \frac{\pi}{3} \left( \frac{5h_i}{8} \right)^2 h_i = (0.4091 h_i^3) \text{ cm}^3 \quad (5)$$

Mass of liquid  
displaced by cone

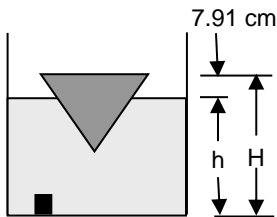
$$M_{DL} = [0.4091 h_i^3 \text{ (cm}^3)] \left( 2.836 \frac{\text{g}}{\text{cm}^3} \right) = 1.390 h_i^3 \text{ (g)} \quad (5)$$

& depth of  
immersion

$$\text{Archimedes} \Rightarrow M_C = M_{DL} \Rightarrow 2454 = 1.390 h_i^3 \Rightarrow h_i = 12.09 \text{ cm}$$

$$\Rightarrow \text{Base of cone is } (20.0 - 12.09) = 7.91 \text{ cm above liquid surface} \quad (15)$$

Final solution:



$$V_{liq} = 1.119 \times 10^5 = 3716h - V_{(cone)immersed} - V_{block} \quad (10)$$

$$= 3716h - (0.4091)(12.09^3) - 164$$

$$\Rightarrow h = 30.35 \text{ cm} \Rightarrow \boxed{H = (30.35 + 7.91) \text{ cm} = 38.3 \text{ cm}} \quad (10)$$

Solution time = 35 minutes

## Tips on Problem-Solving Tests (Felder & Brent, 2016a, pp. 166–174)

- ***Give students guidance in how to prepare for tests, take them, and learn from them.*** Before your first test, tell them how—and how not—to study. Details are given below this list.
- ***To avoid having to create multiple make-up tests, announce that there will be one comprehensive make-up test near the end of the semester.*** The test will serve to make up for any test missed during the semester for any reason.
- ***Let your learning objectives guide your design of lessons, assignments, and tests, and test only at the levels you teach.***
- ***Consider handing out a study guide containing your learning objectives 1–2 weeks before each test. There should be no surprises on tests.***

Don't replace a study guide with something like "This test will consist of four of the following 10 problems." Students will get together beforehand, work out solutions to all 10 problems, and memorize them.

- ***Give point values for each part of a multiple-part problem on the test page.*** Consider setting up multiple-part problems so that if students miss Part (a) they can still solve the subsequent parts. For example, tell them to begin with a specified answer to (a), regardless of what they actually got. (Give practice on this type of problem before putting it on a test.)
- ***Always work out a test from scratch when you have the "final version."*** Time yourself when you do it. Then revise and do it again. If possible, have a colleague or graduate student read (or work through) the test for clarity. Revise again if necessary.
- ***Design tests that most students can finish and check in the allotted time.*** No one has ever shown that someone who takes 20 minutes to solve a problem will make a better professional than someone who needs 35. In fact, people who are careful but slow often do better work than people who are quick but sloppy. Here is a common guideline:  
*The test period should be at least three times longer than the time it takes you to work out the solution (or four or five times longer if the test is very difficult or requires a lot of calculations).*  
If it isn't, cut down the test length.
- ***Include some questions and problems on the test to discriminate between A-level and B-level performance, but not too much.*** If you don't include any high-level material, students won't bother studying it. If you put too much (e.g., 50%), the A students will do well and the B, C, D, and F students will all fail. For undergraduate courses, we recommend that 10–15% of the test content should be at this level.
- ***Closed-book exams test primarily memory; open-book exams test primarily understanding and simulate the professional environment.*** If you have material you really want the students to memorize, give a closed-book test. If you don't care, give an open-book test. If there's some of both types of material, give a closed book portion and have students turn it in and then take the open book portion. Allowing instructor-prepared or student-prepared summary sheets in place of the text is a reasonable compromise.
- ***Beware of take-home exams, especially in undergraduate classes.*** It is too easy for students to cheat on them.
- ***Return graded tests promptly to maximize learning.***



- ***If test grades are much lower than you anticipated and you take some responsibility for it (either you didn't cover the course material effectively or the test was unfair), consider adjusting the grades.*** You may (1) scale the grades by adding enough points to them to bring the top grade up to 100 or the average to a desired level; (2) give a retest, and if the second grade is better than the first one, replace the first grade with the average of the two grades; (3) if the grades are low because most students missed one problem, give a short quiz consisting of a similar problem and add the points to the original test grades.
- ***Prepare a detailed solution key before giving the test.*** (This is often the only way to discover flaws in the test.) Give the key to whoever proctors the exam and whoever grades it. Consider posting it after the test is collected (but only if you don't plan to reuse it). Having a solution key also makes it easier to respond to students who want to argue for more points by helping you be more consistent.
- ***Be generous with partial credit on time-limited tests.***
- ***Give the lowest test grade less weight than the others.***
  - Advantages: Avoids make-up tests, keeps students from getting destroyed by one bad day.  
Disadvantage: Works against students who do much better than average on a particularly hard test. (Remedy: Scale all grades to a common high score or a common average.)
  - *Unless you give a lot of tests in a course, don't drop the lowest grade.* Some students who are doing well before the last test won't bother to study for it.
- ***Consider a time limit for requesting re-grading (e.g., one week). Have students make all requests in writing explaining their case.*** Doing these two things will cut down substantially on requests for regrading, especially at the end of the semester when students are desperately seeking more points to raise their course grades.

### **Helping your students learn how to study effectively**

Every semester after teachers have given their first test, a wave of dismay comes over them. They lament to each other about how poorly many of their students did on material they covered explicitly in class sessions and assignments. Their pain can be particularly acute in first-year and departmental gateway courses, and they wonder if their students have a clue about how to study.

The sad fact is many of the students don't! They got A's in high school just by looking over their class notes and graded homework before the test and repeating it all on the test. As we know and they learn the hard way, rote memorization falls woefully short in college courses—at least in the good ones, which hopefully include yours.

So if students don't know how to study, how can you help them without regressing to pure memorization tests? Here are a few strategies you might consider.

1. ***Use study guides to make your expectations clear.*** It's hard for students to prepare effectively for tests when they aren't sure what kinds of thinking they'll be expected to do. Clear learning objectives can help a lot. If you give objectives to students in the form of a study guide a week or so before an exam (To do well on this test, you should be able to define..., explain..., calculate..., derive..., critique..., formulate..., design...), students can make sure they're studying the right things.

You may worry that giving students study guides is spoon-feeding them. It isn't—not if it's done right. Study guides just clarify instructors' expectations, including expectations of high-level thinking and problem-solving, and make it clear that rote memorization won't be enough. You can make your expectations as high as you want (within reason); when you make them clear to the students, you'll maximize the chances that the students capable of meeting them will do it (Felder & Brent, 2016a, Ch. 2).

2. **Tell students explicitly about study strategies supported by cognitive science** (Felder & Brent, 2016b). Warn them about the uselessness of just re-reading lecture notes and old problem solutions, which can lead to “illusions of competence” and disappointing exam grades. Tell them instead to give themselves *spaced retrieval practice*—self-tests on material they may need to recall, setting up problem solutions from memory to be sure they really understand how to solve the kinds of problems you may ask on the test, and spacing out their study sessions instead of cramming at the last minute.
3. **Give spaced retrieval practice in class.** All the strategies listed in the previous suggestion can and should be modeled in class. Give students periodic short quizzes so they can test their understanding of the material before a higher-stakes mid-term exam. Use individual and small-group active learning exercises in class so they can practice the skills you're teaching and get immediate feedback on their attempts. A step-by-step process for using partially worked-out problem solutions effectively to promote learning can be found at <https://tinyurl.com/SolvingSolvedProblems>. For a brief tutorial on active learning exercises, go to <https://tinyurl.com/ActiveLearningIntro>, and to see narrated videos that illustrate active learning in STEM classes, go to <http://www.youtube.com/watch?v=1J1URbdisYE> (12 minutes) or <https://www.youtube.com/watch?v=0p7gNXGvcww> (35 minutes—you may first get a brief ad).
4. Before at least your first midterm exam, **hand out an exam preparation guide**, such as “Tips on Test Taking” (<https://tinyurl.com/Tips-on-Test-Taking>). Alternatively, when you return at least your first graded exam, attach an *exam wrapper* (e.g., <https://tinyurl.com/Exam-Wrapper>) a short questionnaire in which the students reflect on how they prepared for the exam and how they might improve on future exams. To see a sample physics exam wrapper, go to <https://www.cmu.edu/teaching/designteach/teach/examwrappers/examwrappers-docs/PhysicsExamWrapper.pdf>. To see a physics homework wrapper, go to <https://www.cmu.edu/teaching/designteach/teach/examwrappers/examwrappers-docs/PhysicsHwkWrapper.pdf>.
5. **Promote a growth mindset.** When students have a growth mindset, they believe that they can improve their performance with hard work. This attitude contrasts with a fixed mindset, a belief that performance is based on a talent you either have or you don't, as in “I'm just bad at math.” Research has shown that compared to a fixed mindset, a growth mindset generally leads to a better academic performance. You can have a profound influence on your students by regularly suggesting that even if the material you're teaching seems difficult, they can master it by working hard and using the strategies you've taught them. You might also note that some of the same material was also hard for you when you first encountered it.

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- Update: In p. 1, Column 2, replace  
Creating rubrics is made easy...*4teachers.org*  
with  
Rubrics for almost every conceivable student product and skill can be found by entering  
"Rubric for \_\_\_\_" (e.g., "Rubric for lab report" or "Rubric for oral presentation" or "Rubric for critical thinking") in a search engine.
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