LEARNING OBJECTIVES*

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Student A: "*Buffo's first test is next Monday. I haven't had him before—can you just plug into formulas on his exams or does he make you do derivations and stuff?"*

Student B: "*There's no telling—last fall most of his questions were straight substitution but a couple of times he threw in things I never saw in the lectures."*

Student C: *"Yeah, and if you ask him what you're responsible for on the test he just gets mad and gives you a sermon on how bad your attitude is…we had a 600-page textbook and according to Buffo we were supposed to know everything in it."*

Student A: "*Forget that—no time. I'll just go through the homework problems and hope it's enough*."

You can often hear conversations like that in the student lounge, and if you step across the hall to the faculty lounge you'll hear their counterparts.

Professor X: "*All these students can do is memorize—give them a problem that makes them think a little and they're helpless*."

Professor Y: "*I don't know how most of them got to be sophomores. After my last exam some of them went to the department head to complain that I was testing them on things I never taught, even though the chapter we just covered had everything they needed to know.*"

Professor Z: "*It's this whole spoiled generation—they want the grades but don't want to work for them!"*

Things are clearly not going quite the way either group would like. Many students believe that their primary task in a course is to guess what their professors want them to know, and if they guess wrong they resent the professors for being unreasonably demanding, tricky, or obscure. Professors then conclude that the students are unmotivated, lazy, or just plain dumb.

There is another way things can go. Suppose you hand your students a preview of the kinds of problems they will be expected to solve, including some that require real understanding, and then include such problems on homework assignments and tests. Since they will know up front the things you want them to do and will have had practice in doing them, most of them will be able to do them on the tests—which means they will have learned what you wanted them to know. Some professors might regard this process as "spoon-feeding" or "coddling." As long as you maintain high expectations, it is neither. It is simply good teaching.

Making education a guessing game has never been shown to promote knowledge acquisition or skill development. Common sense says and many references [e.g., Ambrose *et al.*, 2010; Felder & Brent, 2005, 2016; Weimer, 2013] affirm that the clearer instructors are about their expectations, the more likely their students will be to meet those expectations. If you write clear statements of your expectations in the manner described in the preceding paragraph and use

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* Adapted from *Chem. Engr. Education, 31*(3), 178-179 (1997), and *Teaching and Learning STEM: A Practical Guide,* (Jossey-Bass, 2016), Ch. 2.

them appropriately, your course will be in *constructive alignment* [Biggs, 1999] with lessons, class activities, assignments, and tests all pointing toward the same knowledge and skills, and you will get few complaints about the tests being unfair, even from students who did poorly. Most importantly, many more students who are capable of succeeding as STEM professionals will be able to meet your expectations, especially those that require high-level thinking and problem-solving skills.

Learning objectives

An effective way to communicate your expectations is by giving your students *learning objectives.* A learning objective is a statement of an action (task) students should be able to perform if they have learned something the instructor wanted them to learn. An objective must meet two criteria to be acceptable: the action it specifies should be *observable* (the instructor should be able to observe either the students doing it or the results of their having done it), and *clear* (the students should understand it well enough to judge whether or not they can do it).

A learning objective has one of the following stems:

- *At the end of this [course, chapter, week, lecture], you* (or "the student") *should be able to ****
- *To do well on the next exam, you should be able to ****

where *** is a phrase that begins with an action verb (e.g., *list, calculate*, *solve*, *estimate*, *describe*, *explain*, *predict*, *model*, *design*, *optimize*,…). Here are some examples of phrases that might follow the stem of a learning objective, grouped in six categories according to the levels of thinking they require[*]:

1. **Remembering** (repeating verbatim): *list* [the first ten alkanes]; *state* [the steps in the procedure for calibrating a gas chromatograph].
2. **Understanding** (demonstrating understanding of terms and concepts): *explain* [in your own words the concept of vapor pressure]; *interpret* [the output from an ASPEN simulation].
3. **Applying** (applying learned information to solve a problem): *calculate* [the probability that two sample means will differ by more than 5%]; *solve* [the compressibility factor equation of state for P, T, or $\hat{V}$ from given values of the other two].
4. **Analyzing** (breaking things down into their elements, formulating theoretical explanations of observed phenomena): *derive* [Poiseuille's law for laminar Newtonian flow from a force balance]; *explain* [why we feel warm in 70°F air and cold in 70°F water].
5. **Evaluating** (choosing from among alternatives and justifying the choice using specified criteria): *determine* [which of the given heat exchanger configurations is better, and explain your reasoning]; *select* [from among available options for expanding production capacity, and justify your choice].
6. **Creating** (creating or designing something new to the creator, combining elements in novel ways)**:** *formulate* [a model-based alternative to a specified PID controller design]; *make up* [a homework problem involving material covered in class this week].

[*] The six given categories are the levels of the cognitive domain of *Bloom's Taxonomy of Educational Objectives* [Bloom & Krathwohl, 1956; Anderson & Krathwohl, 2001], which we will shortly describe. The last three categories—analyzing, evaluating, and creating—are often referred to as the *higher level thinking skills.*

The forbidden four verbs

There are an uncountable number of acceptable action verbs that may begin learning objectives, but some verbs violate the rule that the action specified in an objective must be observable. Here are four such verbs, which we refer to as the *forbidden four:*

> **The forbidden four verbs in learning objectives**
>
> …the student will
>
> **know…**
> **learn…**
> **understand…**
> **appreciate…**

Those actions are important learning goals for instructors to have, but they are not observable and so should never be used in learning objectives. You can't directly see a student understanding a concept or method, for example; to determine whether or not she does, you would have to ask her to carry out an observable task that reflects her understanding and evaluate how well she did it. That task would be a learning objective that addresses your goal of understanding.

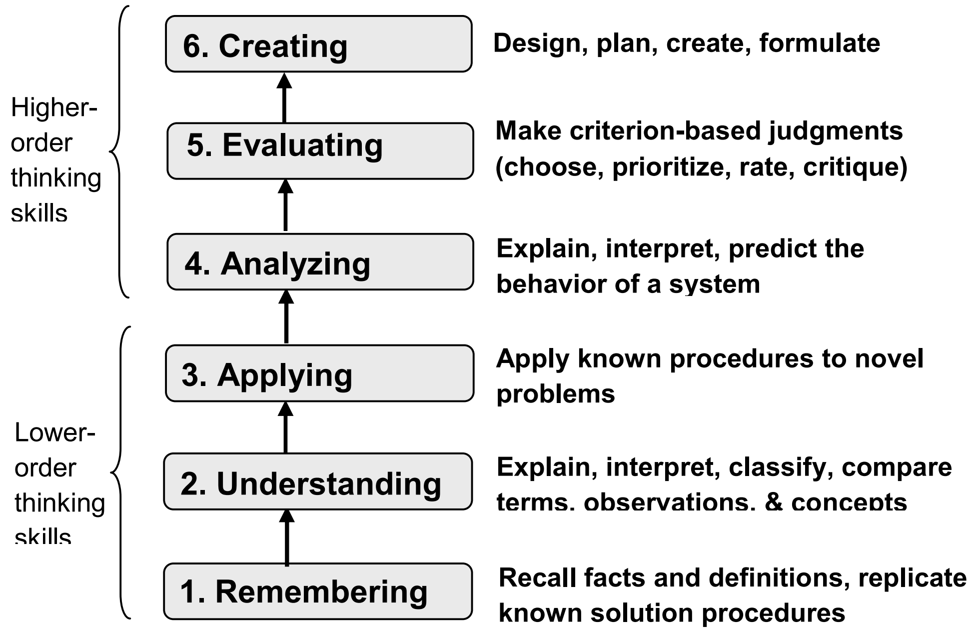
When is an objective clear?

We said that to be useful, an objective should be observable (to the instructor) and clear (to most students in the class). Observable is easy—you can look at a verb and tell immediately whether an instructor could see a student doing it or see the results of the students having done it. Clear is another story—whether an objective is clear to students depends on how well the instructor taught them how to do the specified task and how well the students understood what they were taught. We're going to suppose that the students are going to look at the objective after the instructor has covered the type of task specified and has given the students illustrative examples of how to do it and a reasonable amount of practice in doing it in class activities and/or assignments, and the students did a reasonable amount of studying. We'll declare that if all of those conditions are satisfied, the objective is *probably* clear, and that's as far as we can go.

Bloom's Taxonomy

In the 1950s, Benjamin Bloom of the University of Chicago and colleagues of his formulated categories of learning objectives that varied in the difficulty and complexity of the demands they placed on students [Bloom & Krathwohl, 1956]. The categories fell into three different *domains*: *cognitive* (thinking-related tasks involving knowledge, conceptual understanding, and thinking skills), *affective* (emotion-related tasks involving interests, attitudes, and levels of appreciation), and *psychomotor* (tasks involving physical activity such as clinical procedures and operation of equipment). The six categories in the cognitive domain were reordered and relabeled in 2001 [Anderson & Krathwohl, 2001]. Figure 1 shows the result.

Figure 1. Bloom's Taxonomy of Educational Objectives: Cognitive Domain*



- Each skill involves the skills below it.
- Usually, undergraduate education deals almost exclusively with remembering, understanding and applying.
- Ideally, all Bloom levels should be addressed in every course. (They don't have to be addressed sequentially—1, then 2, then 3, etc.).

Why write objectives? Well-formulated learning objectives provide a basis for:

- *Planning content*. Identify and delete obsolete or extraneous course material (doesn't match any of instructor's learning objectives). Make sure all Bloom levels are being addressed (especially higher ones). Minimize time spent in class on low-level material.
- *Getting constructive alignment* (Biggs, 1999) *among lectures, activities, assignments, and exams*. Avoid teaching one thing and testing on something else. Help assure that adequate practice and feedback is provided on high-level skills before the skills are assessed.
- *Constituting study guides for exams*. If you don't give objectives to the students, they have to guess what you think is important for them to know, a skill that has never been shown to correlate with learning. If you give all of your objectives to the students on Day 1, they will never look at them again. ***Giving objectives as study guides maximizes the chances that students capable of meeting the objectives will do so***. A sample study guide for a midterm exam in an introductory chemical engineering course is shown in Table 1.
- *Telling faculty colleagues what they can expect students who pass this course to be able to do*. Provide invaluable information about course content to instructors preparing to teach the course for the first time, teachers of follow-on courses, curriculum planning committees, and accreditation coordinators.

Table 1. Illustrative Study Guide*

In order to do well on the next test, you should be able to do the following:

1. Explain in your own words the terms *separation process, distillation, absorption, scrubbing, extraction, crystallization, adsorption*, and *leaching*. (What are they and how do they work?)
2. Sketch a phase diagram (P vs. T) for a single species and label the regions (solid, liquid, vapor, gas). Explain the difference between a vapor and a gas. Use the phase diagram to define (a) the vapor pressure at a specified temperature, (b) the boiling point at a specified pressure, (c) the normal boiling point, (d) the melting point at a specified pressure, (e) the sublimation point at a specified pressure, (f) the triple point, (h) the critical temperature and pressure. Explain how the melting and boiling point temperatures vary with pressure and how P and T vary with time (increase, decrease, or remain constant) as a specified path on the diagram is followed.
3. Estimate the vapor pressure of a pure substance at a specified temperature or the boiling point at a specified pressure using (a) the Antoine equation, (b) the Cox chart, (c) the Clausius-Clapeyron equation and vapor pressures at two specified temperatures, (d) Table B.3 for water.
4. Use data in the text to speculate on whether distillation and/or crystallization might be a reasonable separation process for a mixture of two given species. **List the additional information you would need to confirm your speculation.**
5. Distinguish between intensive and extensive variables, giving examples of each. Use the Gibbs phase rule to determine the number of degrees of freedom for a multicomponent multiphase system at equilibrium, and state the meaning of the value you calculate in terms of the system's intensive variables. Identify a feasible set of intensive variables to specify that will enable the remaining intensive variables to be calculated.
6. In the context of a system containing a single condensable species and other noncondensable gases, explain in your own words the terms *saturated vapor, superheated vapor, dew point, degrees of superheat*, and *relative saturation*. Explain the following statement (or a similar one) from a weather report in terms a first-year engineering student could understand: "*The temperature is 75^{o}F, barometric pressure is 29.87 inches of mercury and falling, the relative humidity is 50%, and the dew point is 54^{o}F.*"
7. Given an equilibrium gas-liquid system with a single condensable component (A) and liquid A present, a correlation for p_A*(T), and any two of the variables y_A (mole fraction of A(v) in the gas phase), temperature, and total pressure, calculate the third variable using Raoult's law.
8. Given a mixture of a single condensable vapor, A, and one or more noncondensable gases, a correlation for $p_A^*(T)$, and any two of the variables y_A (mole fraction of A), temperature, total pressure, dew point, degrees of superheat, and relative, molal, absolute, and percentage saturation (or humidity), use Raoult's law for a single condensable species to calculate the remaining variables.
9. For a process system that involves a gas phase containing a single condensable component and specified or requested values of feed or product stream saturation parameters (temperature, pressure, dew point, relative saturation or humidity, degrees of superheat, etc.), draw and label the flowchart, carry out the degree-of-freedom analysis, and perform the required calculations. **After completing your analysis, identify as many possible reasons as you can for discrepancies between what you calculated and what would be measured in a real process. Include any assumptions made in the calculation.**

* Higher-level objectives in boldface.

Table 1 (cont'd)

10. Explain the meaning of the term "ideal solution behavior" in the context of a liquid mixture of several volatile species. Write and clearly explain the formulas for Raoult's law and Henry's law, state the conditions for which each correlation is most likely to be accurate, and apply each one to determine any of the variables T, P, x_A, or y_A (temperature, pressure, and mole fractions of A in the liquid and gas phases) from given values of the other three.
11. Explain in your own words the terms *bubble point, boiling point*, and *dew point* of a mixture of condensable species, and the difference between vaporization and boiling. Use Raoult's law to determine (a) the bubble point temperature (or pressure) of a liquid mixture of known composition at a specified pressure (or temperature), and the composition of the first bubble that forms, (b) the dew point temperature (or pressure) of a vapor mixture of known composition at a specified pressure (or temperature), and the composition of the first liquid drop that forms, (c) whether a mixture of known amount (moles) and composition (component mole fractions) at a given temperature and pressure is a liquid, a gas, or a gas-liquid mixture, and if the latter, the amounts and compositions of each phase, (d) the boiling point temperature of liquid mixture of known composition at a specified total pressure.
12. Use a *Txy* or *Pxy* diagram to determine bubble and dew point temperatures and pressures, compositions and relative amounts of each phase in a two-phase mixture, and the effects of varying temperature and pressure on bubble points, dew points, and phase amounts and compositions. Outline how the diagrams are constructed for mixtures of components that obey Raoult's law. Construct a diagram using a spreadsheet.
13. For a process system that involves liquid and gas streams in equilibrium and vapor-liquid equilibrium relations for distributed components, draw and label the flowchart, carry out the degree-of-freedom analysis, and perform the required calculations.
14. Explain in your own words the terms *solubility of a solid in a liquid*, *saturated solution*, and *hydrated salt*. Given solubility data, determine the saturation temperature of a feed solution of given composition and the quantity of solid crystals that precipitate if the solution is cooled to a specified temperature below the saturation point. Perform material and energy balance calculations on a crystallizer, and identify sources of error in your calculation.
15. Given a liquid solution of a nonvolatile solute, estimate the solvent vapor pressure lowering, the boiling point elevation, and the freezing point depression, and list the assumptions required for your estimate to be accurate. Give several practical applications of these phenomena. Identify sources of error in your calculation.
16. **Given the description of a familiar phenomenon involving more than one phase, explain it in terms of concepts discussed in this chapter. Given an explanation of such a phenomenon, evaluate its scientific soundness.**

Tips on writing objectives

- *Try to write learning objectives for every topic in every course you teach*. Take a gradual approach, however—you don't have to write them all in a single course offering.
- *Go for clarity and observability in your objectives.* The actions they specify must be *clear* to the students and *observable* by the instructor. For an objective to be considered clear, students should be able to read it and say with confidence, "Yes, I know what that means and I can do it" or "No, I can't do that—and I'd better learn how before the exam." Avoid the forbidden four verbs.
- *Include some objectives at the levels of analyzing, evaluating and creating.* They are not that hard to write, even in undergraduate courses, but if you don't consciously set out to write them you probably won't, and if you don't, you'll lower the chances of your students developing skills at those levels. You don't have to address all three levels in every course you teach, but it's a good idea to make sure all three are addressed in several courses distributed throughout the curriculum (not just concentrated in the last year).
- *Strive for constructive alignment by using your objectives to guide your construction of lectures, in-class activities, assignments, and exams.*
- *Share your objectives with students as study guides for exams.* We said it before, but it bears repeating: giving study guides is one of the most powerful techniques you can use to facilitate your students' mastery of targeted skills, especially high-level skills.

To take a multiple-choice quiz on the content of this tutorial with immediate feedback on correct and incorrect responses, go back to the page from which you linked to the tutorial (under the "Introduction to Learning Objectives" tab on your browser) and click on the link to "Learning Objectives Quiz."

References

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