A Model for Instructional Design

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Introduction

For the past five issues of the *Journal of Professional Issues in Engineering Education and Practice*, we have examined a variety of teaching tools and techniques: the chalkboard, questioning, drama, physical models, and demonstrations. All of these tools are focused on the delivery of classroom instruction. All are valuable, and mastering them will undoubtedly improve your teaching. However, effective teaching entails more than just the application of effective classroom techniques. Exemplary teachers must also master the broader endeavor of *instructional design*—the process of crafting coherent learning activities and experiences that ultimately result in students' achievement of desired instructional objectives.

When designing instruction, professors must invariably answer a wide range of questions, such as

- What are the learning outcomes I expect my students to achieve?
- To what extent should I expect my students to read and understand the course textbook?
- Should I devote our limited classroom time to discussing theory, working problems, or both?
- Should I work an example problem at the chalkboard, or is it better to have the students work problems at their seats?
- What kind of homework problems should I assign?
- How should the homework be graded?

There are no universal right or wrong answers to these questions. Rather, the answers depend on the subject being taught, the students' capabilities, the amount of time available, and many other factors. The challenge of instruction design is taking these factors into account in a logical and coherent way.

Student Learning as the Basis for Instructional Design

In this paper, we present a general model for instructional design, developed as an integral component of the ASCE ExCEEd Teaching Workshop. This Model Instructional Strategy is both simple and flexible. More importantly, it derives directly from a well-established model of the human learning process. As such, the strategy provides a decision-making framework that will help you answer questions like the ones posed above—in a manner that ultimately will facilitate effective student learning.

Let's begin with a design project:

Suppose that you are an undergraduate student who is required to learn a complex engineering concept, one with a variety of important problem-solving applications. You currently know nothing about this concept. The resources available to you include a textbook that covers the topic, a subject-matter expert, and 6 h. The subject-matter expert is only available to you for 2 of the 6 h; for the remaining 4 h, you're on your own. Your challenge is to design a sequence of activities that will help you learn the concept and its applications most effectively.

For the past 5 years, we have posed this same problem to ExCEEd Teaching Workshop participants, as an introduction to instructional design. In response to the challenge, teams of participants develop integrated sequences of learning activities and then present their solutions to the workshop faculty and other participants. And while the teams' solutions differ considerably in detail, they are invariably consistent in terms of overall concept and structure. A typical team's solution to the instructional design project follows:

First, we would ask the subject-matter expert to provide us with a broad overview of the concept. We would want to know why the topic is important and what kind of practical problems we'll be able to solve once we've mastered it. Next, on our own, we would read about the concept in the textbook. We would return to the expert to ask questions about aspects of the text material that we didn't understand. The expert should then work an example problem, to demonstrate a typical practical application. The expert should give us several homework problems to solve on our own. The initial problems should be relatively simple, to confirm that we understand the basics; others should be more challenging, to expand our understanding. If we have difficulty solving these problems, we would consult with each other and perhaps with the expert. Finally, the expert should give us feedback on our work. If we make errors, the expert should coach us toward correct solutions. Ideally, we would then get an opportunity to solve an even wider variety of problems and again receive feedback—to ensure that we really do understand the concept and its applications.

This typical solution to our introductory instructional design project is significant for two reasons. First, it very closely reflects the Model Instructional Strategy that is presented in the ExCEEd Workshop—but which the participants have not yet seen at the time they do the design project. Second, this solution is typically proposed by faculty members who have never employed this sort of instructional strategy in their own teaching.

How do workshop participants intuit our Model Instructional Strategy, even though they are largely unfamiliar with this form

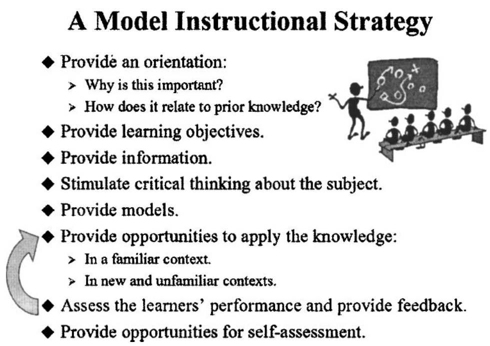

Fig. 1. Model instructional strategy

of instructional design? The answer lies in how the question is asked. The design problem statement asks participants to assume the role of an undergraduate student. Their responses, then, do not reflect "how I would teach this subject," but rather, "how I would prefer to learn this subject." It seems that, when placed in the role of the *learner* rather than the *teacher*, they are much better equipped to design learning experiences that will produce effective learning outcomes. This observation suggests the obvious but often ignored notion that student learning should be the foundation upon which instructional design is based.

Model Instructional Strategy

The ExCEEd Model Instructional Strategy derives directly from the "Learning Process Methodology" developed by Apple et al. to enhance students' skills as self-learners (Apple et al. 1995). Thus the Model Instructional Strategy reflects the premise that instructional design should build upon an underlying model of the human learning process. The Model Instructional Strategy describes an eight-step process for facilitating student learning of a major concept or topic. The eight steps are summarized in Fig. 1 and explained in the following paragraphs.

Provide an Orientation

The instructor should communicate why the topic is important and how it relates to other topics that students already understand. Educational research demonstrates unequivocally that students learn more effectively when they clearly perceive the value in what is to be learned, when they are able to meaningfully connect new learning to prior knowledge, and when they are able to attach personal meaning to new learning (Angelo 1993).

Provide Learning Objectives

The instructor should define what students will be able to do upon successful completion of the learning process. Research suggests that students learn more effectively when they are aware of the desired learning outcomes (Stice 1976), as well as the standards by which their achievement of these outcomes will be evaluated (Angelo 1993).

Learning objectives should be expressed in terms of measurable action verbs, defined in accordance with Bloom's taxonomy (Bloom 1956). Ideally the upper two levels of Bloom's taxonomy—synthesis and evaluation—should be addressed in every course, in order to develop students' higher-order thinking skills. It is important to recognize, however, that Bloom's six levels of cognitive development are generally achieved cumulatively. True synthesis-level thinking cannot occur without first developing students' capacity for analysis-level thought. Analysis must be preceded by application, and so on. Students cannot reasonably be expected to exhibit evaluation-level cognitive development without having first developed the previous five levels.

In any event, using Bloom's taxonomy as the basis for defining lesson objectives is a valuable enhancement to the instructional design process, because the act of choosing the appropriate cognitive level prompts the teacher to add clarity and specificity to the desired learning outcomes.

Provide Information

Effective teaching entails much more than simply providing information; and effective learning entails much more than receiving information. Nonetheless, it is often necessary for the learner to acquire basic-level information—theories, concepts, terminology, methodologies, techniques—before higher-order learning can occur. Depending on the instructional design, information might be provided by the teacher (e.g., in a lecture), by the learner (e.g., by reading an assignment in the course textbook), or by a combination of the two. Regardless of the means, if the acquisition of basic-level information is a prerequisite for higher-order learning, then the teacher should take some positive action to ascertain whether students have, in fact, acquired the necessary information before the learning process is continued. This might be accomplished through quizzes, questioning, or informal classroom assessment techniques (Angelo and Cross 1993).

Stimulate Critical Thinking

For deep learning to occur, the learner must construct understanding in his or her own mind. This process of constructing personally meaningful understanding requires that the learner think critically about the concept being learned. The teacher can stimulate critical thinking by asking conceptually challenging questions (Apple et al. 1995). Here the phrase "asking questions" is used in the most general sense; in addition to posing a question verbally, the teacher might ask questions through collaborative learning exercises in class or even through homework problems. Whatever the technique, the reason for asking challenging questions is to cause students to think deeply about a concept, such that they begin to make the connections that constitute *bona fide* understanding.

Provide Models

Models are examples, usually provided by the instructor, for the purpose of advancing students' understanding in some way. Models can be physical (e.g., a rubber model of a beam, used to illustrate bending) or conceptual (e.g., a problem-solving strategy). In engineering, instructors often model the problem-solving process by working representative example problems in class. The objective of this activity should be more than just showing students how to solve a particular example. By "thinking out loud" as he or she works through the problem, the instructor can help students understand a more generalized problem-solving approach, with emphasis on the key decisions and assumptions that are made en route to a correct solution. By asking questions during the solution of an example problem, the instructor can also stimulate critical thinking, thus effectively merging this step with the previous one.

Provide Opportunities to Apply Knowledge

Educational research emphasizes the importance of students' active engagement in the learning process (Chickering and Gamson 1991). Students may *think* they understand a concept after hearing the instructor explain it; however, they don't truly *know* the concept until they can apply it successfully themselves. Research also suggests that one of the strongest contributors to student learning is *high-quality time on task* (Angelo 1993). Practice makes perfect. More specifically, practice provides learners with opportunities to reinforce what they know and reveal what they do not yet know. In engineering, practice typically takes the form of problem-solving homework assignments and projects; however, opportunities to apply knowledge can just as easily be provided through in-class exercises, performed by individual students or by teams of students. The advantage of in-class problem solving is that the instructor can monitor students' work, assess their progress, and answer their questions immediately. The disadvantage is that, as teachers, there is never as much in-class time as desired to devote to a given subject. Because of the inevitable constraints on in-class time, homework problems can generally be more complex and more comprehensive than in-class exercises.

Regardless of the format, students should always be provided with opportunities to apply knowledge at two distinctly different levels. First, they should be asked to solve relatively simple problems *in a familiar context*—for example, a homework problem that is similar to the instructor's in-class example problem. This initial application reinforces students' nascent understanding of the topic, identifies misconceptions or gaps in their understanding, and builds confidence.

Having successfully solved a familiar problem, students should then be presented with a problem (or problems) of greater complexity in *a new and unfamiliar context*. This component of the Model Instructional Strategy is critical, because it promotes *transfer of learning*, the ability to apply concepts and problem-solving strategies to wholly new types of problems in entirely new settings. As a National Research Council report notes, "A major goal of schooling is to prepare students for flexible adaptation to new problems and settings" (Bransford et al. 2001). This is particularly true for engineering graduates, who are likely to encounter many real-world situations that are vastly different from the types of problems they learned to solve as students.

Engineering educators generally recognize, at least implicitly, that transfer of learning is important. All too often, however, they ignore this in instructional design and then evaluate it on exams—for example, by using conceptually challenging exam questions that are substantially different from problems that students have worked in class and on homework assignments. However, for many students, particularly immature learners, the ability to transfer learning does not come naturally or easily. (Witness students' common complaint that "the exam questions were nothing like our homework problems.") Like most skills, this one must itself be learned—preferably before it is evaluated. And as with most skills, an effective way to *learn how to transfer learning* is through practice and feedback.

Assess Performance and Provide Feedback

As noted above, problem-solving practice reinforces students' learning of a subject while providing the teacher with opportunities to identify students' misconceptions or incomplete understanding. Clearly, however, shortcomings in students' learning can only be identified if the instructor rigorously assesses the students' performance, with respect to the established learning objectives. And performance assessment can result in improved learning only if it is accompanied by constructive feedback oriented toward improving those shortcomings.

For the purpose of this discussion, it is useful to differentiate between *assessment* and *evaluation*. Assessment is *the process of measuring performance, for the purpose of improving future performance* (Apple et al. 1995). Evaluation, on the other hand, is *the process of measuring performance against a defined standard, usually for the purpose of reward or punishment*.

The distinction is important, because many professors choose to assess students' performance with examinations, even though exams are far better suited for evaluation than for assessment. Exams inevitably occur at the end of the learning process, when there are few (if any) remaining opportunities for students to apply feedback to improve future performance. Effective assessment should be primarily *formative*, rather than *summative*. It should provide students with formal and informal performance feedback throughout the learning process, rather than solely at the end of that process. Note the feedback loop on Fig. 1, an indication that several iterations of performance and feedback are often necessary to achieve high-quality learning outcomes.

Formative assessment can be performed in many ways. Traditional problem-solving homework assignments can be used as assessment tools, provided (1) that they are assigned at interim points within a block of instruction, rather than only at the end, (2) that they are graded and returned to students very soon after they are handed in, and (3) that the grading includes specific feedback about the students' errors, rather than generic point deductions. The key is that homework can only be effective as an assessment tool if students receive substantive performance feedback with sufficient time to integrate that feedback into their future performance.

But to rely solely on homework for performance assessment is to ignore a rich array of other assessment tools that are effective, economical, and easy to use. Simple classroom assessment techniques, such as the minute paper, muddy point paper, preconception check, and approximate analogy, can be administered in the final 1 or 2 min of any class and can provide the instructor with immediate feedback on the extent to which student learning outcomes coincide with the instructor's expectations (Angelo and Cross 1993). In instances where assessment results are inconsistent with expectations, the instructor should provide specific feedback to students at the start of the following class and should adjust the planned learning activities to address these problem areas.

Provide Opportunities for Self-Assessment

Most engineering students will eventually graduate. Once they have left school, they will no longer have the benefit of their professors' performance assessments. Graduates will need to learn new concepts and skills on their own—and they can only be assured that their self-directed learning is correct if they are able to assess their own learning processes. Thus long-term growth as a self-learner requires strong self-assessment skills. Students can and should be given opportunities to develop such skills before they graduate from college. Instructors can foster the development of assessment skills, for example, by asking students to check each other's homework, just as practicing design engineers conduct design reviews (Hamilton 2005) or by having students critique their own oral presentations before receiving feedback from the instructor.

Application of the Model Instructional Strategy

Although there are no hard-and-fast rules regarding the application of the Model Instructional Strategy, our experience with the model suggests a few guidelines. First, the model works best when it is applied to a *block of instruction*—say, two to five lessons, all of which are associated with a single learning objective or with a single coherent set of learning objectives. Given its emphasis on iterative practice and feedback, the model cannot be effectively applied to a single lesson. (An important corollary is that discrete single-lesson topics are unlikely to produce high-quality learning outcomes.)

Second, while the eight steps in the model are arranged in a logical sequence, many deviations from that sequence are possible. For example, for a given instructional design, it might make sense to establish and communicate learning objectives prior to the orientation. For the benefit of inductive learners, it might be desirable for the instructor to present a specific practical application at the very beginning of the learning process—even prior to students' acquisition of basic-level information about the subject. Deciding when such deviations from the model are warranted is an integral part of the instructional design process. The Model Instructional Strategy enhances this process by prompting the instructor to make conscious decisions about the sequencing of learning activities—and to justify these decisions on the basis of enhanced student learning.

Finally, the Model Instructional Strategy helps to guide the instructors' decisions about allocating responsibility for student learning. Some of the steps in the Strategy must necessarily be performed primarily by the instructor. Providing an orientation, setting objectives, modeling the problem-solving process, and assessing student performance generally require a professor's disciplinary expertise and breadth of perspective. Application of knowledge and self-assessment, on the other hand, must be performed primarily by the students. Responsibility for providing or acquiring information and for stimulating critical thinking may be assigned to the instructor or to the student, or the responsibility may be shared. Again, the Model Instructional Strategy prompts the instructor to make conscious decisions about the allocation of responsibilities in a coherent, learning-centered manner.

Let's conclude this discussion with a specific example. Below, the Model Instructional Strategy is applied to the design of a three-lesson block of instruction on truss analysis, as might be found in a typical statics course. In this example, "Lesson 0" is the lesson immediately prior to the three-lesson truss analysis block.

- ***Lesson 0***: During the final 10 min of class, the instructor provides an **orientation** to the topic of trusses. She shows digital images of real-world trusses—a local truss bridge, the roof structure of the university's basketball arena, a construction crane, and a power transmission tower—all of which are familiar to her students. She explains that, through their prior study of two-dimensional static equilibrium, the students already possess all of the theoretical knowledge required to perform truss analysis. She concludes class by outlining the **learning objectives** of the upcoming truss analysis block and pointing out portions of next lesson's reading assignment that deserve special attention.
- ***Lesson 1***: The instructor begins class by reviewing today's **learning objective**: *Solve for internal forces in truss members using the Method of Joints*. She asks a series of questions to ensure that students understand the **information** they were required to read in the course textbook before class. She uses a wooden model of a truss to illustrate the assumptions used in truss analysis—that joints are represented as frictionless pins and that loads are applied only at the joints. She then works a simple truss analysis problem at the chalkboard, **models** the problem-solving process, and asks lots of questions that emphasize the application of equilibrium concepts that the students had been studying in previous lessons. For homework, she assigns students a truss problem that is very similar to the one she has just worked at the chalkboard—a **familiar context**. She also gives a textbook reading assignment covering the Method of Sections. She concludes the class by asking students to write down the one concept or technique from today's class that most requires further explanation. She uses this "muddy point paper" to **assess** the students' level of understanding of the Method of Joints.
- ***Lesson 2***: The results of the Lesson 1 "muddy point papers" indicate that, while most students feel comfortable with applying the Method of Joints, many are puzzled about which joints to select for a given analysis problem. The instructor begins today's class with a minilecture on this topic. She then presents the solution to the homework problem (on a transparency), asking the students to **assess their own work** (using a colored pen provided by the instructor). After responding to the students' questions, the instructor collects the students' homework. She reviews today's **learning objective** and then presents an example problem illustrating the Method of Sections. She works only a portion of the problem at the chalkboard. Once she has modeled the process of isolating a section of the truss, she asks the students to complete the solution, working individually at their seats. As the students work, she circulates around the room monitoring the students' progress and answering their questions. At the conclusion of class, she assigns another homework problem involving a relatively advanced application of the Method of Sections.
- ***Lesson 3***: The instructor begins class by returning the Lesson 1 homework, which she has graded and annotated with detailed performance feedback. She reviews the students' most common mistakes and suggests that those who are still struggling with the Method of Joints schedule some time for tutoring after class. She then collects the Lesson 2 homework and responds to students' questions about the Method of Sections. She reviews today's **learning objective**: *Model a truss structure*. She organizes the students into teams of three and presents them with a highly unorthodox truss problem involving a component of the International Space Station—**a highly unfamiliar context**. The students are asked to formulate a solution to the problem, and with about 20 min remaining in the class, one team is asked to present its solution to the class. The other teams are asked to **assess** the first team's solution, and a general discussion follows. In the final few minutes of class, the instructor wraps up the topic of truss analysis. She notes that truss problems, in some form, will appear again on a future homework assignment, on a midterm exam, and on the final

exam. Future courses will address advanced applications of truss analysis in the context of axial member design, indeterminate structural analysis, virtual work, and steel design. The instructor concludes the class by outlining the learning objectives for the next block of instruction.

This example illustrates how the Model Instructional Strategy can be used as the basis for designing a coherent series of learning experiences spanning a block of lessons associated with a particular engineering topic or concept. The Strategy provides for continuity from lesson to lesson; it ensures consistency between in-class and out-of-class learning activities; and it provides a basis for allocating the instructor's and students' individual and shared responsibilities to the learning process.

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