Instructional Design 101

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This paper outlines a useful way of categorizing content. Just as different kinds of data are best presented with different types of graphs, different content types are best taught with different educational approaches.

A useful way to think about the categories that follow is to apply an object-oriented model. Think of a *concept* as an object, say, a ball. The object has certain *characteristics*, such as size, color, surface texture, etc. The values of those characteristics (small, red, smooth, etc.) are *facts*. The rules that relate how the ball interacts with other objects (when dropped on a hard surface it bounces) are *principles*. Finally, we can apply our knowledge of facts, concepts, and principles to solve *problems*. The sum total of the facts, concepts, and principles that describe a system or body of knowledge form the learner's *mental model* of the system.

Note that there is often overlap between the categories. For example, a chunk of content might be taught either as a concept or as a principle, depending on the outcome desired.

Facts

A fact is an item of information that can be memorized or looked up. Instructional objectives that deal with facts contain verbs such as *recall, state,* and *know*.

It is important to distinguish between facts that must be committed to memory and those that can be looked up. Learners by nature tend to resist memorization even when it is needed, and instructors tend to insist on it even when it is unnecessary.

Many facts do not have to be memorized - the learner needs only to know where and how to look them up. Examples include definitions, chemical and mathematical formulas, and physical constants.

How to teach facts

Facts that are part of a rote procedure (e.g. multiplication, aircraft engine-fire emergency procedures) typically must be instantly available for recall. Repetition, drill, and practice are the most common approaches to this.

If the fact is to be memorized, it is often useful to present it as part of a *fact structure* (see below) if appropriate. Analogies and mnemonic devices can often be used to great effect.

Fact Structures

Most facts do not exist in isolation - they are usually part of a fact structure. Teaching the structure usually makes it easier to acquire the individual facts. For example, the

colors of the rainbow, red, orange, yellow, green, blue, indigo, and violet, have a definite ordinal relationship. That relationship itself is a useful tool in remembering the colors. Instructional objectives that deal with fact structures contain verbs such as *order*, *sequence,* and *arrange.*

How to teach fact structures
Mnemonic devices such as acronyms (e.g. Roy G. Biv) can be very useful in memorizing fact structures. (Not all learners are equally enthusiastic about mnemonics. Isaac Asimov told the story of how he was required to memorize Roy G. Biv in grade-school science. He did it by associating the "meaningless acronym" with the order of the spectrum, which he knew by heart.)

Bringing to mind related facts (*fact networks*) can greatly assist the learner. For example, I recall the fact that red and yellow combine to make orange, so that helps me place the colors in the correct order. When teaching fact networks, make the relationships explicit so that the learner makes the desired associations.

Fact structures may be hierarchical (as in a *parts-of* or *kinds-of* concept structure, described below) or sequential *fact chains* (as in the alphabet or a phone number).

When having the learner recall facts encoded in fact structures, especially fact chains, keep in mind that usually the whole structure must be recalled in order to access even a single fact. (Quick - what is the fifth digit of your social security number? You had to mentally recite the whole chain of digits from the beginning, right?)

Concepts

In the vernacular, the word *concept* has a plethora of meanings. In instructional analysis, however, the meaning is more precise. A concept is a thing that can be associated with and distinguished from other, similar things by examining certain *key characteristics*. Instructional objectives that deal with fact structures contain verbs such as *classify*, *differentiate, sort, discriminate,* and *identify*.

Truck is an example of a concept. A truck has many characteristics - size, color, number of wheels, manufacturer, etc. These can vary widely. What all trucks have in common, however, is that they all have a cab (where the driver sits) and a separate cargo area (usually called the bed), and they all are designed to travel primarily on the road (rather than over the water, through the air, or on rails.)

The cab and separate cargo area are the *key characteristics* (also called *defining characteristics,* or *critical attributes*). All the other characteristics are *non-critical*. So no matter what the color, size, manufacturer, or number of wheels, if a wheeled land vehicle has a cab and a separate cargo area you can safely call it a *truck*. (Note that some non-critical characteristics can become critical if they have certain values. For example, if the manufacturer is Mack or Peterbilt, look no further - it's a truck. Conversely, if the nameplate says Geo or Harley-Davidson, it's not a truck.)

Research shows that people never learn a concept in the abstract, they learn it through examples. The first example they see identified as an example of the concept becomes in their mind the *prototype example*. Every subsequent example presented gets compared and contrasted to the prototype. For me, the concept *station wagon* will forever be represented by the sky-blue '63 Mercury wagon my family had when I was young. Every other station wagon is merely a variation of that prototype.

Research also shows clearly that unless the critical and non-critical attributes are specified, learners will reliably confuse them. For example, toddlers routinely call any mammal a "doggie" until they learn to discriminate more finely.

How to teach concepts

The way to teach a concept is to find or create a prototype example that very clearly exemplifies all of the key characteristics of the concept. The key characteristics should be so clear as to border on stereotyped exaggeration. Present the prototype to the learner and say, "This is a Q." Then give the learner a prototype *non-example*. The non-example should ideally share as many of the non-critical characteristics of the prototype as possible - same size, color, manufacturer, etc. If possible, it should differ *only* in the critical attributes. Tell the learner, "This is not a Q."

These first two presentations are called a *far example* and a *far non-example*. The next step is to present a *near example* and a *near non-example*. They still differ on the critical attributes, but have many non-critical attributes in common. You can label them "Q" and "not-Q" for the learner, but it is usually more effective to pose the question to the learner, "Which of these is a Q?" If they get it wrong, provide feedback that points out the similarity between the prototype example and the near example, and how the near non-example differs from the near example in just the same way as the far non-example differs from the prototype. Don't give them the critical attributes just yet, though. You want them to come up with that on their own.

Provide a few more practice items, varying the non-critical attributes. Finally, ask the learner, "What makes a Q a Q?" Let them look at more examples and non-examples, ask questions, discuss with other learners, etc., and work their way toward a definition of the critical attributes.

Or, you can shortcut the whole process and just teach the key attributes as facts. But beware - you'll get what you ask for. An anecdote illustrates the point: Near the turn of the century, Thomas Dewey visited the classroom of a science teacher. The great educator asked the teacher's permission to question the class. "Of course!" replied the science teacher with pride. Dewey turned to the class. "Class, can you tell me what it's like at the center of the Earth?" No one responded. "They have studied this, have they not?" Dewey asked the teacher.

"Of course they have!" he scoffed. "You're merely asking the question the wrong way! Observe. Students," he prompted, "WHAT IS THE STATE OF THE EARTH'S CORE?"

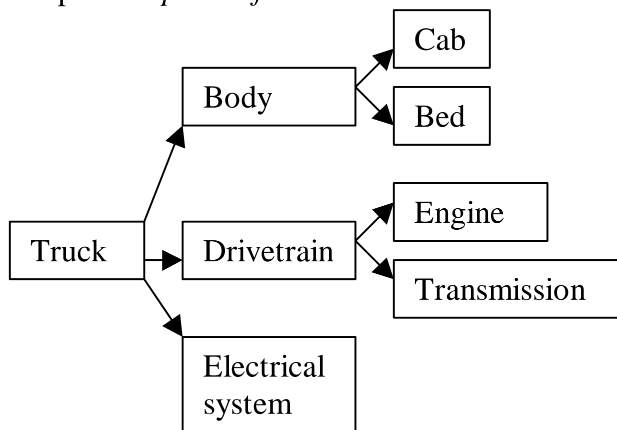
In mindless unison they replied, "IGNEOUS FUSION." That's what happens when you teach concepts as facts - the learner is *reliably* unable to generalize.

Concept structures

Like facts, concepts often exist in relationship to other concepts. When teaching concepts, it is critical to also teach the concept structure if it exists. There are two kinds of concept structures: *parts-of* and *kinds-of*.

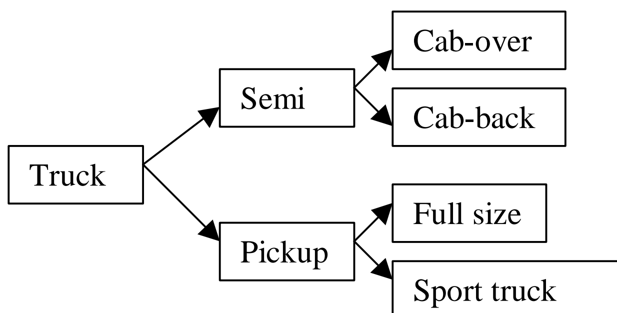
How to teach concept structures
In order to effectively teach a concept structure, you need to show it visually.

An example of a *parts-of* structure is:



Note that you can take the structure to as fine a level of detail as needed: you can break *cab* into *seats, doors, hood*, etc. (Note also that *fuel system* is missing from the structure. Am I considering it part of the engine system? Hard to tell at this level of detail.)

An example of a *kinds-of* structure is:



Note how even a crude diagram makes the relationships between the concepts clear. You may also perceive that there are critical attribute differences between concepts at the same level of the tree. For example, Semis and Pickups are both kinds of trucks, but Semis are different then Pickups because…I'll leave that as an exercise for the learner.

Coordinate Concepts

A coordinate concept is a special kind of concept structure (either parts-of or kinds-of) that compare and contrast two related - and often easily confused - concepts. The key characteristic of a coordinate concept is that an example of one of the concepts is a non-example of the others.

Car and truck is a coordinate concept. Pick any car and any truck. A car is not a truck, and a truck is not a car. (Now, let's leave SUV's and the El Camino out of it.) What's the difference? A truck's cargo area is separate from the cab, whereas a car's trunk is integral with the passenger compartment. You can remove the bed of a pickup without touching the cab. You can't take the trunk off a Buick.

How to teach coordinate concepts
Use the same techniques as for concepts and concept structures, i.e., prototype examples, use near and far examples and non-examples, show the concept structure visually, etc. But when the concept structure is a coordinate concept, it is critical to point out (or guide the learner to discover) the relationship between the concepts.

Principles

Like concept, *principle* has a large number of vernacular meanings. In instructional design, however, it refers specifically to the rules that relate concepts to each other, or that describe the workings of a system. Instructional objectives that deal with principles contain verbs such as *apply, prescribe, explain,* or *predict.*

How to teach principles
Before a learner can apply the principles that describe a system's operation, he or she must know the components of that system - the concepts, facts, and structures that make up the system. Some writers refer to this as the *underlying declarative knowledge*.

Simulations and experiments are often used to teach principles. The learner is presented with a working model of the system, and is guided to manipulate it in ways that reveal the rules that govern its operation. A well-designed simulation can also be used to teach the underlying declarative knowledge, but this must be done explicitly. It is a serious mistake to assume that simply providing a working simulation will automatically give the learner a correct understanding of the concepts that underlie the system.

Procedures

A procedure is a series of steps that accomplish a goal. Procedures are usually taught by simulation. Instructional objectives that deal with procedures contain verbs such as *do*, *start, operate,* and *calculate.*

How to teach procedures
The steps in a procedure can often be treated as a fact chain. If the procedure is time-critical (as in the emergency procedure for dealing with an engine fire in an aircraft) it should be memorized. Mnemonics and drill-and-practice can ease this task.

For non-time-critical procedures, it is often better to give the learner a checklist to use as a reference. Note that a procedure can be critical but not time-critical, e.g. the pre-takeoff checklist for an airliner. For critical procedures, it is wise to provide a checklist or other job aid, even when the procedure is used so often it becomes memorized.

Rote procedures

A rote procedure is done the same way every time, with little or no variation. (e.g., starting the car) There may be branch points to allow for different conditions (e.g., on a bitter cold day, pump and hold the gas pedal while turning the key), but in general the procedure is performed pretty much the same way every time.

The steps in a rote procedure can usually be treated as a fact chain.

Meta procedures

A meta-procedure is really a set of principles that enable the learner to construct a rote procedure on the fly. An example of a meta-procedure is "Take the kids to visit the grandparents." There are a lot of variables that could impact such a trip, such as weather, traffic, the crankiness of the kids, etc., so you cannot come up with a specific list of steps until the actual event. You can however, lay out a general plan.

Problem Solving

There are any number of ways to describe problem solving. The model here is simple, but it works pretty well.

Well structured problems

A well-structured problem is pretty much a rote procedure. There is one correct answer, and one way to get it. You do it the same way every time. The most common examples are arithmetic calculations.

How to teach well-structured problems

Use the same techniques as for fact chains. Be sure to determine if the steps must be memorized or if they can be looked up.

Moderately structured problems

A moderately structured problem has one or a very few defined correct answers, but there are several ways to get at that correct answer. Learners will reliably come up with ways to solve the problem that the instructor did not consider. (A high-school physics class was given the task of using a barometer to find the height of a building. The solution the teacher was looking for, of course, was to use the difference in air pressure between the sidewalk and roof. But one student said he would drop the instrument from the roof and time the fall. Another wanted to set it in the sun, measure the shadow of both the barometer and the building, and use the law of similar triangles. A third student said he would give the barometer to the building superintendent in exchange for the information.)

How to teach moderately-structured problems

Moderately structured problems can be very difficult to teach although they make up most of the problems typically faced in the real world. It is best to set up clear expectations for outcomes and solutions to avoid the kind of problem faced by the physics teacher above, e.g., "Given a barometer, use the difference in air pressure between the roof and street to calculate the height of the building." Rubrics (described below) are likewise very useful.

Poorly structured problems

Poorly structured problems typically have many "correct" solutions, though some may be more optimal than others. Likewise, there are many ways to reach an answer, and while some may be more or less optimal, efficient, or elegant, it is difficult to say categorically that a particular solution is "right" or "wrong."

Most design tasks fall into this category. Examples include tasks such as designing a website or a marketing campaign, producing a work of art, or writing an article.

How to teach poorly-structured problems

It is best to set clear goals and requirements for poorly structured problems, e.g., the marketing campaign must cost no more than $X, the website must include these features, and so on. It is very helpful to provide rubrics, or examples of "poor work," "good work," "better work" and "best work." Treat these as coordinate concepts, and point out what about the project makes the difference between "good" and "better."