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Tutorial: Understanding Concepts: Implications for Behavior Analysts and Educators

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Abstract
How we make sense of the world is founded on our understanding of simple and complex concepts, which form the basis for our vocabulary (Layng, 2016a). We often gain this understanding through life experience, but conceptual learning can be explicitly taught. This tutorial provides a brief introduction to concept learning and teaching that has its roots in behavior analysis and related disciplines (Bruner, Goodnow, & Austin, 1956; Englemann & Carnine, 1982; Markle & Tiemann, 1969; Mechner, 1962; Tiemann & Markle, 1990). Presented here are examples drawn from a sequence designed to teach physical science to elementary school learners to illustrate how concept teaching can be used to improve instruction. These examples include both intradimensional concept teaching, where features of a physical stimulus guide behavior, and interdimensional concept teaching, where relations among different stimuli guide behavior (Bruner, Goodnow, & Austin, 1956; Layng, 2014; Tiemann & Markle, 1990). Efficiencies in teaching using conceptual inheritance designs is briefly described, as well as the implications of what are referred to as conceptual hierarchies, where instances of one concept may share features inherited from a superordinate concepts. The purpose here is not to perform a literature review, but to provide an overview of how concept analysis and teaching may improve instruction.

Keywords Concept · Abstract tact · Intradimensional · Interdimensional

> A person who understands physics behaves like a physicist under the same conditions as a physicist. Given a novel slice of reality, he sees it as a physicist would and takes the same actions as a physicist would. Some part of the action

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> may be verbalizing—naming or giving a formula, or such. But the understanding shown by this verbal repertoire is a strong function of the situation in which it occurs. Rarely in the physicist's world is this situation a verbal stimulus, such as "Define subatomic particle." Given a complex mixture of manipulations, machinery and observations, the key response is deciding whether or not the observed slice of reality is a member of the class which leads him to say "subatomic particle," or to flick a particular switch, or to take any other action relevant to subatomic particles.
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> Each subject matter is a way of looking at reality in terms of certain classes (concepts) and hierarchies of classes (conceptual structures) and stated relations between classes (principles). . . .
>
> Markle and Tiemann (1970)

Few among us would deny the critical role concept learning plays in teaching and learning. We are likely to agree on its importance to learning any subject matter. For example, positive reinforcement, negative reinforcement, punishment, frequency, schedule, discrete trial, free operant, echoic, mand, rate, latency, behavioral contrast are all concepts found on the BCBA task list. If asked, most instructors would say that they teach concepts, whether their learners are children on the autism spectrum or seated in a college classroom. Yet as behavior analysts, scientists, or educators of any kind, do we actually teach concepts? And if we attempt to do so, do we teach them effectively? To answer these questions, first, let's define what is meant by concept.

What is a Concept?

Many years of learning sciences research involving hundreds of studies across several disciplines have come to consensus on what applied learning scientists mean when they use the word "concept," namely, a concept is defined by a set of common attributes[1] found in each example of the concept. That is, each example *must have* certain attributes to be considered an instance or example of the concept. In addition to these *must have* attributes, the examples have other *can have* attributes, which other examples of the concept may or may not have[2] (Bruner, Goodnow, & Austin, 1956; Engelmann & Carnine, 1982, 2016; Layng, Sota, & Leon, 2011; Markle & Tiemann, 1969; Mechner, 1962; Merrill, Tennyson, & Posey, 1992; Sota, Leon, & Layng, 2011; Tiemann & Markle, 1990).

Consider the concept, cup, it has two *must have* attributes, 1) bowl-shaped object, 2) used for drinking. However, cups may differ in size, shape, color, material, weight, and may or may not have a handle. These are the *can have* attributes. Change the shape (a critical attribute) and one has a (drinking) glass. Change the function (drinking) and one has something else, e.g., a pencil holder. Change the color, size, material, etc. while leaving the *must have* attributes unchanged, and one still has a cup. The shared *must have* attributes are what define that object or instance as an example of a concept and do

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[1] What we refer to here as attributes have been referred to by others using the terms features or properties. The term attribute will be used here, but should be considered to be synonymous with the others.

[2] Thanks to Sara Pendergast for suggesting the "must have," "can have" terminology.

not change from example to example. The other nondefining attributes are those features the example *can have*, often changing from example to example, but that don't enter into defining the example as an instance of the concept.[3] This definition corresponds with Skinner's (1957) discussion of the abstract tact. A tact is a verbal response under the control of a nonverbal stimulus where there is no point-to-point correspondence between the stimulus and the response. "Abstract tacts are those tacts that are under the control of properties of a stimulus rather than the entire stimulus itself. . ." (Robbins, Layng, & Karp, 1995). Thus, "abstract tact" (Robbins et al., 1995) could be substituted for "concept," but for clarity of presentation and correspondence to the cited literature, "concept" will be used.

Unfortunately, few, if any, textbooks (including those in the field of behavior analysis), digital interactive texts, online educational movies and activities, interactive whiteboard lessons, or computer programs available today effectively teach concepts (cf. Markle, 1975). Thus, the purpose here is not to perform a review of the literature, but to provide a brief overview of effective methods for analyzing and teaching concepts, and the benefits for applied behavior analysis and teaching in general. Because the author recently helped design a curriculum for teaching science to third to fifth graders, examples of the concept analysis process and program sequencing will be drawn from that effort. This is done for two reasons: the ready availability of examples, and to show that behavior analytic instruction can be applied to any area and any age group.

Teaching science is critically important and can be a challenge. Standards have been developed such as described by the Next Generation Science Standards (NGSS, 2013), but their adoption has been slow. Teachers who teach science in elementary school may not be required to have either majored or minored in a science discipline while in college. It is not surprising then that research into science education by the American Association for the Advancement of Science (2014) has found that learners often emerge from science instruction with troubling misconceptions. How might improved instruction eliminate these misconceptions? What does it really mean to teach a science or any concept? Can behavior analytic approaches to concept teaching help?

What Does It Mean to Understand a Concept?

Understanding a concept means that for each concept learned (or taught), the learner is guided (after Donahoe & Palmer, 2009) by the critical, *must have*, attributes of each instance of the concept and not the variable, *can have*, attributes (as previously noted). Further, examples that do not have all the defining attributes must be rejected as instances of the concept. Thus, concept teaching requires that each concept be thoroughly analyzed and the critical attributes of each instance identified. The set of variable attributes are also described, so that they do not get erroneously paired with the examples used in instruction. Further, these nondefining features need to be systematically varied so that learners will have experience responding to the critical (defining) features across a full range of divergent, different-looking instances. Learners

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[3] Technically, this is a conjunctive concept (after Bruner et al., 1956), a class of stimuli, with class membership defined by a set of common, unvarying attributes while other attributes vary across instances of the class (Tiemann & Markle, 1990).

are often able to respond correctly to the critical and variable attributes or properties without being able to describe them. Being able to state the definition of a concept is not required for its understanding.[4] On the other hand, stating a definition, an intraverbal repertoire (Skinner, 1957), does not necessarily indicate understanding.

To conclude that learners understand a concept, they must be able to do the following:

- Distinguish examples of the concept from close-in (very similar) nonexamples that lack one or more of the defining critical attributes.
- Identify examples of the concept across a wide range of varying, nondefining attributes.
- Demonstrate this with examples and nonexamples not presented during instruction or while learning the concept.

Recent emphasis on multiple exemplar teaching, though a step in the right direction, may fall short of actual concept teaching. For example, at a recent conference on teaching children with autism, a behavior analyst described a procedure using match-to-sample to link the spoken word “fish” to a picture of a fish such that the spoken word “fish” occasioned pointing to a fish, and a picture of a fish occasioned saying “fish.” Once two-way discriminative (stimulus) control was established, another fish was presented and the process repeated. After a few two-way relations were established, teaching the one-way relation, hear “fish,” point to fish, resulted in saying “fish” when that picture of a fish was presented. The behavior analyst expressed confidence that the learner had acquired the meaning of the word fish because the procedure was shown to go two ways, a picture of each fish occasioned saying “fish,” and hearing “fish” occasioned pointing to picture of each fish. However, no novel fish that had not been part of the training and no novel close-in *nonexamplars* were presented. The other nonexamples were animals that were not fish or even aquatic. What would have happened if a dolphin or a flatfish that is nearly flat with two eyes on one side of its head were presented? No evidence was provided that the many match-to-sample trials established more than what Tiemann and Markle (1990) describe as a series of two-way paired associates, hearing “fish” then pointing to a picture of a fish, seeing picture of a fish then saying “fish.” Even if equivalence responding was established where hearing “fish” occasioned pointing to either the picture or the word, concept learning (understanding) would still not be demonstrated. No evidence was presented of concept learning; the three criteria were not met.

This has important implications for teaching. Consider the vocabulary difference for a child with autism, or a neurotypical child, taught fish in the equivalence manner described and one taught fish as a concept. Though both will have saying “fish” in their repertoire, use of the word will occur under different circumstances for each. Reading or hearing “the fish in the sea,” may have entirely different effects for each. In teaching vocabulary to a child, teaching concepts is critically important (see Layng, 2016a, for a more extended discussion of this topic).

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[4] How often has someone asked for the meaning of a word used in a sentence and one struggles to answer although the “meaning” of the sentence is crystal clear?

The Challenge of Concept Teaching

Much of the time we respond to concepts correctly without being able to state the features that are guiding our behavior. Take the concept, chair, for example. If asked to locate a chair and bring it into the room, most people can do this with little trouble. They don't bring in desks or bicycles, or even couches. They can do this even if the type of chair they find is of a kind they have never encountered. Perhaps they locate a chair like the one pictured in Fig. 1. Why can they do it? It is because their behavior is guided by the critical attributes that define the concept, chair. The shared properties define the class—the concept. Something about the object brought into the room is shared with the class of objects we call "chair" and allows us to respond correctly to an instance we have never seen before.

Now ask the same people to define "chair" and one gets a range of definitions. Some definitions will be pretty close, others way off, but few will actually describe the features that result in something being classified as chair. We see two things in this demonstration: 1) our definitions do not necessarily guide our classifications, and 2) we are not necessarily aware of what guides our classifications. These are two important reasons why good teachers can get bad results. We can teach learners definitions or classification rules that are not accurate and that lead to wrong classifications or worse, misconceptions. We may "know" the concept, but do not adequately describe what is guiding our behavior in such a way as to provide that knowledge to our learners. It doesn't matter if the learners are being directly taught, discovering, working on big problems, etc. Unless we fully understand what we are trying to accomplish, creating the right learning environment is difficult and becomes a hit-or-miss affair.

How Can Concepts Be Successfully Taught?

For concept teaching to be successful, we first must identify which critical (*must have*) attributes of each instance or example of the concept are all shared with other instances, and what variable (*can have*) attributes are not shared by each instance. In the case of

Fig. 1 Example of a chair

Fig. 2 Chairs with a range of variable, can have, attributes

our chair, one instance may have four legs, another none (see Fig. 2). Some may be made out of wood, others out of plastic or metal. Some may be black; others may be another color. Some may have arms, others may not, and so on. Yet even though there is all this variation from instance to instance, we still recognize a chair as a chair.

How do we find those features shared by all examples? We can begin by comparing our chair to instances of other concepts that are very close to our example (see Figs. 3 and 4). We can compare a chair to a love seat, for example. What is the difference? The love seat is designed to have room for two, the chair for only one. A chair seats only one person (critical attribute, CA, 1). Are there things that seat one person that are not called chairs? We locate a stool that seats someone at the same height as our chair. What is the difference? A stool has no back. A chair has a back (CA 2). Are there things that have a back and seat only one person that are not called chairs? We find a barstool. What's the difference? When a person is seated on a barstool, the legs

Lacks CA 3
Lacks CA 1
Lacks CA 2
Lacks CA 1
Lacks CA 1 & 2
Lacks CA 3

Fig. 3 Nonexamples of chair, each lacking at least one critical, must have, attribute

Fig. 4 An example juxtaposed with a matched nonexample differing only in one critical attribute

are often left to dangle. When a person is seated on a chair, the legs are supported at about a 90-degree angle (CA 3). This critical attribute (CA 3) is also missing in a chaise lounge.

What we find is that when those three critical attributes occur together in an object, we call that object a chair, and not a stool, a couch, or a bench. And because we have seen these attributes together across a wide range of chairs differing in many other features, we won't be tricked by variations in color or material or number of legs.

Let's consider our chair versus love seat example. We can provide an example of a chair and juxtapose it with a love seat with matched variable attributes. Notice that the two examples in Fig. 4 differ only in the number of people each seats. By matching the variable attributes of the example and nonexample, we can make it much more likely that the critical attributes will guide the learner's behavior. Compare this to what is likely to happen if, instead, we used the example of the love seat depicted in Fig. 5. It is likely that one of the variable attributes would be mistaken for a defining feature.

We can use a concept analysis to design high-quality, guided inquiry-based activities. For example, learners can be asked to form small groups and work together to analyze and identify the differences between examples and nonexamples of a concept. That is, to "think like a scientist" (Global Partnership for Science Education through Engagement, n.d.), even for something as seemingly simple as distinguishing a chair from a love seat. Sometimes, however, we may want to add more variability and have learners test the attributes against one another over a series of examples and nonexamples. Other times we may want to guide the experience a bit more, as learners develop their inquiry skills.[5] With the concepts analyzed and the variable properties identified, we can build highly successful, scaffolded discovery activities that teach content and process at the same time. We can make the example and nonexample very similar, or "close-in." For example, telling the difference between the "high chair" and "stool" (and acting on that difference) shown in Fig. 6 is a challenge, especially when the variable attributes are very similar, and the critical attributes are at the boundaries of the range that guides inclusion in the class.

During assessment or testing, a learner must 1) identify all instances of a concept that include all the critical attributes across a precisely specified set of differing examples that include a full range of variable attributes and must 2) distinguish these from matched nonexamples that do not have the full set of critical attributes. Together the specified examples and nonexamples comprise what Tiemann and Markle (1990) call a *rational set* (see below), of which multiple examples are but

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[5] For an introduction to a behavior analytic approach to providing learners with an effective inquiry repertoire, see Robbins (2011).

Fig. 5 Nonexample varying in both critical and variable attribute when matched with the example of chair in Fig. 4

one component. Thus, the term "multiple exemplars" is not precise enough to capture what is required for teaching and testing concepts.

As a result of this analysis, we can build more effective applications and creative exercises in which learners make full use of the concepts learned. What is more, we can leverage this outcome to quickly extend the concepts and build upon them in such a way as to provide a basis for quickly adding new concepts and principles with little additional teaching, a form of generative learning (Alessi, 1987; Johnson & Layng, 1992, 1994; Johnson & Street, 2018; Leon, Ford, Shimizu, Stretz, Thompson, et al., 2011; Sota et al., 2011; Sota, 2012).

What Does This Mean for Teaching Concepts?

As early as 1971, Clark reviewed 235 studies on the analysis and teaching of concepts and found that the successful teaching of concepts requires a very specific approach. Another early review of the instructional design literature came to a similar conclusion (Tennyson & Park, 1980). Each concept needs to be analyzed and sets of examples and nonexamples produced that allow for the design of sequences that ensure students will learn the concept.[6] The analysis will include a specification of the critical attributes and the full range of variable attributes. From these, nonexamples that lack at least one critical attribute can be specified as well as a set of examples that not only share all critical attributes but expose the learner to a full range of variable attributes. In the chair example, because there are three critical attributes, 1. Has a back; 2. Seats one person; 3. Legs supported bent at an approximately 90° angle, the teaching set will require a minimum of three nonexamples (each nonexample lacking an attribute). There are many configurations of chair, but if we carefully analyze them we see the variable attributes can be categorized as follows

1. Number of legs may be

   a) four b) three c) one d) none

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[6] A similar approach is taken to teaching principles; a principle describes a relation between concepts that can typically be stated, "If . . . , then . . . " (Tiemann & Markle, 1990).

Fig. 6 Very close-in example and nonexample pair

2. Material may be:

   a) wood b) metal c) plastic d) upholstery

3. General shape may be:

   a) flat-planed b) curvaceous

4. Size of back may be:

   a) high b) medium c) low

By carefully selecting examples with specified variable attributes (for example, a four-legged, metal, flat-planed, low-back chair) in this case we can present the entire range of variable attributes in a rational set of four examples. For chair, this leaves us with a minimum set of three nonexamples and four examples. It is called a rational set because each item selected meets a specified rationale for inclusion as determined by the critical and variable attributes. We can then present examples juxtaposed with nonexamples that have matched variable attributes as illustrated above, and at the same time expose learners to the full range of examples. A different, but similar rational set of nonexamples and examples will be required for testing.

There are other benefits to this type of concept analysis. Once the concepts are analyzed, one can more readily specify an optimal learning environment for acquiring the concept. We can target popular misconceptions and prevent them or correct them. Given different classes of student errors, we can precisely diagnose and provide the specific examples or nonexamples required to ensure full understanding (Tiemann & Markle, 1990). For example, if a learner includes items as examples when they are not, we need more practice with close-in nonexamples. We can get more precise. If it is ascertained that only items with particular variable attributes are erroneously included, we know to include those variable attributes in our new nonexamples. Under other conditions, if we discover a learner fails to include an item as an example, we will need more examples. For example, learners who consistently call a nonexample with only two of three required critical attributes of chair—1) furniture that has a back and 2) seats one person, but not attribute 3), one's legs are *not* supported at about 90°—will only need more instruction on nonexamples featuring dangling or reclining legs, e.g., a bar stool or chase lounge, not love seats or benches.

Coordinate Concepts

We may teach more than one concept at a time, such as the science concepts of solid, liquid, and gas, by first presenting the observable differences between these states of matter. States of matter can be distinguished by the attributes of shape and volume. For the concept solid, the critical attributes are: when placed in an unenclosed container there is *no change in shape* and *no change in volume*. For the concept *liquid*, the critical attributes are: when placed in an unenclosed container there is *a change in shape*, but there is *no change in volume*. And for the concept *gas*, the critical attributes are: when placed in an unenclosed container there is *a change in shape* and there is *a change in volume*. Each of these two attributes, shape and volume, is critical to the definition of each state of matter. And because a change in one feature of one concept makes it an example of another concept, we teach these at the same time as coordinate concepts. Coordinate concepts are defined when each concept shares some critical attributes with another concept and an example of one concept is a nonexample of the other. Coordinate concepts are typically taught together. We need to juxtapose the coordinate concepts so as to highlight the critical attribute differences, while holding the variable attributes constant (see Fig. 7). The inquiry about states of matter might begin by asking “What happens to the shape if we put this matter in a container?” or “Does the volume of this matter change or not change in an unenclosed container?,” among others.

The variable attributes are many. For solids, these would include objects that are hard and soft (e.g., an anvil and a pillow), inorganic and organic, alive and dead, on the ground or in the air, etc. The range would be similarly described for liquids and gasses. Learners would be asked to identify examples of each and, in so doing, correctly reject the coordinate nonexample as shown in the practice exercise in Fig. 8.

Sequenced correctly (see Engelmann & Carnine, 2016; Markle, 1991; Tiemann & Markle, 1990), a young learner will come to identify new examples of solids, liquids, and gasses not encountered during instruction, no matter what they are or where they are found. Once these concepts are learned, we can, as shown in Fig. 9, add another defining feature at the molecular level. That is, why do these states of matter have these properties? We can now link the movement of the atoms and molecules to a single example of each (solid: atoms vibrate in place, not much movement; liquid: more movement, atoms slip past each other; gas: rapid movement, with atoms moving away from each other).

Fig. 7 A still from an animated video where variable attributes are held constant, critical attributes are changed. Discrimination can only occur along the dimensions of the critical attributes. From Learning A-Z, Headsprout Science physical science lessons

Fig. 8 Examples of liquids, solids, and gases. Learners match the words sold, liquid, or gas to the pictures representing each. From Learning A-Z, Headsprout Science physical science lessons

As a result of the earlier concept teaching, we need only have the learner match the molecular movement depicted to appropriate state of matter in only one or two examples (see Fig. 10), in order to have them link molecular movement to states of matter. This is accomplished not by pairing the molecular movement with "arbitrary stimuli" (after Sidman, 1994), such as a name to a single stimulus or even a group of stimuli, but by pairing the movement with the already learned critical attributes guiding behavior (and not the variable attributes). We find that the learner can often go on to match those molecular movements to the entire range of solid, liquid, and gas examples, including examples never before presented with no further instruction—an example of simple generative learning (for a more detailed discussion, see Alessi, 1987; Leon, Ford, et al., 2011; also see Johnson & Street, 2018, for other examples of generative relations).

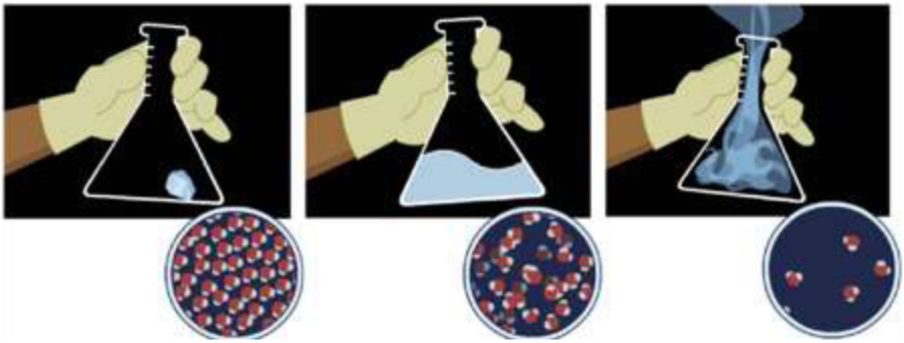

Fig. 9 Animated molecular representations are paired with examples of liquids, solids, and gases. From Learning A-Z, Headsprout Science physical science lessons

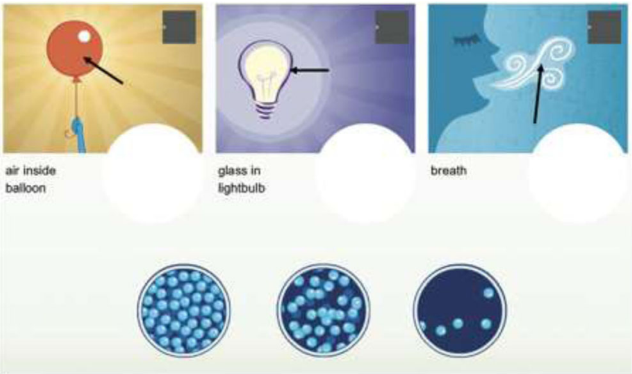

Fig. 10 Learners match animated molecular representations to examples of liquids, solids, and gases containing a range of variable attributes. From Learning A-Z, Headsprout Science physical science lessons

We can next look at what it takes to change the motion of atoms (heat and pressure), and thereby change one state of matter into another. As shown in Fig. 11, we can even provide rather sophisticated simulated experiments that learners can conduct to solve problems involving changing states of matter based on these attributes. And just as before, by linking the changes caused by heat and pressure to molecular movement, we will find that learners will link them to observed states of matter, with little or no direct teaching required—one more example of generative learning.

Learners can now be presented with interesting thought questions about real world events that may occur around the house, such as, "Why can one "pour" a glass of orange juice?" thereby increasing the likelihood of science-oriented discussions around the dinner table or elsewhere (see Fig. 12). In this way, these young learners are encouraged to extend their knowledge in ways in which their families and peers will notice.

Fig. 11 Example of interactive experiments involving the application of concepts taught. From Headsprout Science physical science lessons, used with permission

Fig. 12 Learners are asked, "Why can we pour juice from a cup? They derive the answer from what they learned from the concept teaching sequence. From Learning A-Z, Headsprout Science physical science lessons

Beyond the Single Stimulus

The discussion has focused on concepts where the attributes are part of a single stimulus, such as chair or solid. Layng (2014) used the terms *intradimensional* concept to describe those stimuli where a single stimulus, such as a chair occasions behavior, and *interdimensional* concepts (or tacts), such as distant, believe, or opposite, where specifiable, invariant comparative attributes guide responding.

> An interdimensional tact is one in which a contingency specifies the criterion for responding to one stimulus in comparison with another. An example is "larger than." Bruner et al. (1956) defined this type of responding as a relational concept. Other examples of interdimensional tacts include me, you, they, our, farther, distant, wider, etc. These can be quite "abstract" (as per "believes" vs. "does not believe" vs. "knows"). There is no single (intradimensional) stimulus where the properties can be pointed to, but when a group of stimuli are considered the tact can occur. (Layng, 2016a, p. 343)

A characteristic of interdimensional concepts is that the stimuli being compared themselves typically belong to the class of variable attributes (see Layng's, 2016a discussion of distant and near). Much like the failure of many to define a chair even though they can successfully discriminate chairs from nonchairs, the guiding critical interdimensional attributes often go unstated. Because the physical stimuli may change, it may lead to assumptions that there are no critical attributes guiding a learner's behavior. In fact, most such interdimensional relations can be analyzed, the guiding critical attributes specified, and concept teaching sequences prescribed. An example concept analysis is provided by Leon, Ford, et al. (2011) of the concept, "to believe." Who or what believes varies greatly, and it is not a physical feature of the believer. Let's examine some examples of believe. I open the cupboard door, and the hungry dog runs to the empty food bowl. The dog *believes* it will be fed. The firefighters note everyone who lives in a burning building is not accounted for; they run inside to search. They *believe* someone may still be in the building. I don't quite feel right. I *believe* I may be coming down with a cold. I put the key in the ignition and the car does not immediately start, so I keep turning the key. I *believe* if I turn the key the car will start. What are some similar situations that do not show one believes? The firefighters see a person in the building and run into the building to search for them. They *know* someone is in the building. The cupboard door is opened, and the hungry dog remains where it is (it does not run to the empty bowl). The dog *does not believe* it will be fed. What we see from comparing the use of believe to similar instances involving knowing and not believing, is that a change in single aspect of the event (a critical attribute) changes our response to the event. To say one believes, there must be 1) the absence of an event, and 2) action taken to affirm the likelihood of the event. If an event is present, such as people seen in the building, we *know* there is someone there. If we open the cupboard door and the dog remains, no affirming action is taken: the dog *does not believe* it will be fed.

A rational set of examples and nonexamples can be sequenced to quickly teach what it means to believe.[7] The variable attributes include time frame (past, present, future), type of event, who takes action (the believer or someone else), type of action, or conditions that suggest the event. Who is doing the believing and what is believed are also variable attributes. It is important to note that the same concept analysis and teaching procedures may be used for teaching both the intradimensional concept of chair, and the interdimensional concept of believe. This suggests that what may be considered as too abstract for developmentally delayed children to learn may be systematically analyzed and taught. Other interdimensional concepts that may be similarly analyzed and taught include you, me, them, now, then, same, different, opposite, distant, and near.

These interdimensional concepts often play important roles in extending our repertoires and can allow more advanced forms of understanding. For example, once believe is taught, we can insert it into a sentence to say X believes that Y will. . . . Our reader or listener who may know nothing about X and Y will now understand that X will take affirming action in regard to something Y has yet to do. Likewise, once the concept, opposite, is taught we can say, “X is the opposite of Y.” That one state of the world is at the farthest end of a continuum from another is readily communicated. Skinner (1957) refers to this arrangement as an autoclitic frame. Many such frames are a function of established interdimensional concepts, another form of what Skinner would characterize as abstract tacts. Teaching certain essential interdimensional concepts may result in expanding the autoclitic frames available for a learner and rapidly expanding the linguistic repertoire of the learner creating a form of behavioral cusp (after Rosales-Ruiz & Baer, 1997). In a cusp the acquisition of certain repertoires make possible or more likely the acquisition of others. By learning the concept “opposite,” a young learner can be simply told something is opposite of something else and be able to respond to it accordingly.[8]

Once concepts are analyzed, teaching can be made more efficient through the use of *concept inheritance procedures* (Layng et al., 2011; Tiemann & Markle, n.d.). That is a

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[7] For a complete example of teaching young children an interdimensional concept, see the 14-step procedure for teaching “steeper” provided by Engelmann and Carnine (2016; also see, Layng, 2016a; Layng et al., 2011; Leon, Layng, & Sota, 2011b; Sota et al., 2011; Tiemann & Markle, 1990, for a more detailed discussion).

[8] Further, once the critical and variable properties of various intradimensional and interdimensional concepts are described, and because one instance of a concept may be an example of another concept (e.g., cow and farm animal), instruction can be created that allows for teaching of what Markle (1978) described as *conceptual networks*. We can create exercises where learners come under the guidance of more than one set of features such that features of one are used to describe features of another, Skinner’s (1957) metaphorical tact. We can, for example, bring learners into contact with Rutherford’s atomic model where features of a solar system are used to describe features of the atom (see Bronowski, 1956, and Goldiamond, 1966, for this and other examples) or exquisitely teach children how to write poetry (Koch, 1970).

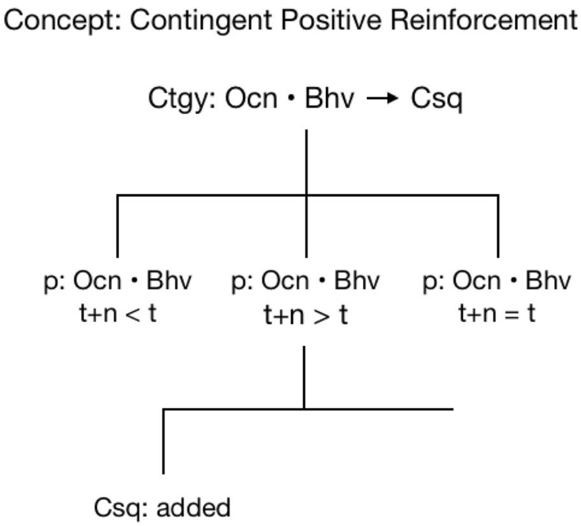


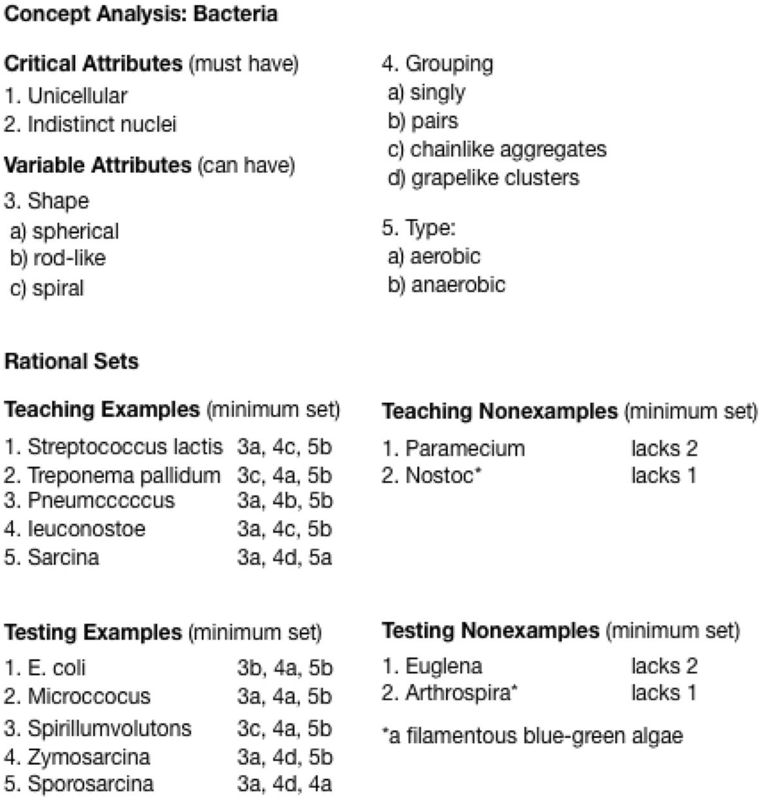
Fig. 13 Critical attribute inheritance hierarchy for Contingent Positive Reinforcement. Concept of contingency (Ctgy) is taught as an environmental arrangement whereby a consequence (Csq) will occur only if an occasion (Ocn) and behavior (Bhv) occur; the occasion and behavior can occur without consequence occurrence. Next, only one new defining attribute is provided to teach reinforcement contingency by adding the attribute that the probability of the occurrence of the occasion and behavior is greater when measured at a later time than when initially measured. And finally, positive reinforcement contingency is taught by adding the single attribute of those conditions under which the consequence is added

hierarchy of concepts can be created where subordinate concepts inherit the critical attributes of its superordinate concept. For example, once the concept, polygon, is taught, (CA 1—straight sides, CA 2—joined end to end [forming a closed figure]) one has simply to say: a polygon with four sides, and one has specified the critical attributes of quadrilateral (Tiemann & Markle, n.d.). Once the concept "polygon," has been learned, one has simply to add the new defining attribute (four sides) to teach the concept "quadrilateral." To teach "triangle" one simply has to say a polygon with three sides. Further, how many learners define a triangle as triangle only when it sits on its base? Because the teaching of polygon required a variation in positioning, that simple variation no longer results in this common "misconception."

The often challenging-to-teach concept of positive reinforcement contingency can be taught using an inheritance procedure. Figure 13 depicts how that concept can be taught using an inheritance procedure. One would first teach the concept of contingency. Next, teach the concept of reinforcement contingency by adding the attribute: those contingencies involving occasions, behavior, and consequences where the probability of the occasion–behavior relation at time t+n is greater than at time t. Notice that the learner only has to learn one new defining attribute, Finally, teach positive reinforcement contingency by adding the attribute: given a reinforcement contingency, those consequences where an event is added.

What We Can Do

The addition of a careful concept analysis may improve everyday teaching and learning. That is, educators who analyze key concepts may find learners less confused



Concept Analysis: Bacteria

Critical Attributes (must have)
1. Unicellular
2. Indistinct nuclei

Variable Attributes (can have)
3. Shape
 a) spherical
 b) rod-like
 c) spiral

4. Grouping
 a) singly
 b) pairs
 c) chainlike aggregates
 d) grapelike clusters

5. Type:
 a) aerobic
 b) anaerobic

Rational Sets

Teaching Examples (minimum set)	
1. Streptococcus lactis	3a, 4c, 5b
2. Treponema pallidum	3c, 4a, 5b
3. Pneumcccccus	3a, 4b, 5b
4. leuconostoe	3a, 4c, 5b
5. Sarcina	3a, 4d, 5a

Teaching Nonexamples (minimum set)	
1. Paramecium	lacks 2
2. Nostoc*	lacks 1

Testing Examples (minimum set)	
1. E. coli	3b, 4a, 5b
2. Micrococcus	3a, 4a, 5b
3. Spirillumvolutons	3c, 4a, 5b
4. Zymosarcina	3a, 4d, 5b
5. Sporosarcina	3a, 4d, 4a

Testing Nonexamples (minimum set)	
1. Euglena	lacks 2
2. Arthrospira*	lacks 1

*a filamentous blue-green algae

Fig. 14 Example concept analysis from Tiemann and Markle (1990) showing a completed concept analysis for the concept, bacteria. Complete teaching and testing rational sets are depicted. Each letter indicates which instance of each variable attribute is included in each example so as to produce the greatest range of examples in the fewest number of examples. Used with permission

and learning progressing more rapidly. Teachers can carefully juxtapose examples and nonexamples and point out how the presence of variable attributes do not influence inclusion into a class. On the other hand, the absence of a single critical attribute eliminates the instance from the class even though the nonexample may have many other features in common with the class. Figure 14 illustrates this using a completed concept analysis of bacteria, along with the rational teaching and testing sets (from Tiemann & Markle, 1990). Notice how the variable attributes are organized so as to present almost the entire range of critical attributes within a relatively small set of bacteria examples. The testing set determines if learners have mastered the concept or if more instruction is required. By carefully analyzing concepts and creating rational sets of examples and nonexamples, instruction that includes exposure to a full range of examples can be efficiently as well as effectively designed (see Tiemann & Markle, 1990, for a comprehensive self-instruction program on how to analyze and teach concepts).[9]

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[9] The program is available through Morningside Press, Seattle, WA.

Interactive lessons that focus on exploration, problem solving, and inquiry can be developed to make it likely that nearly all learners will come to "really understand" the concepts. We want learners to explore, ask questions, change variables, and discover the concepts (and principles) we think are important, so they become thoughtful great thinkers. Problem-based exercises may be developed where examples and nonexamples can be identified by learners in groups or independently, with inquiry exercises, as projects, by using response clickers, etc.

Often, interactive activities are designed that may engage students but produce little real learning or understanding, and little real concept learning. With the concepts fully analyzed we can avoid meaningless engagement, and design more effective, personalized instruction (Layng, 2016b; Layng & Twyman, 2013). Where a full analysis and sequence may not be possible to produce, the inclusion of a broader range of examples and a limited set of nonexamples may improve learning.

For those providing commercial learning activities for the classroom, the instructional design requirements should be met with rigor. Texts, digital exercises, and applications that claim to teach concepts should be required to provide fully analyzed concepts, and a full range of teaching and testing sets of examples and nonexamples. Stated differently, educators who are interested in having their learners "really understand" concepts should insist that those companies and organizations providing interactive learning activities for use in the classroom meet the highest standards of concept analysis and sequencing.

If the time is taken to fully analyze the concepts taught and sequence the learning activities based upon that analysis, those in the business of designing learning activities for the classroom can provide teachers and learners with a broad array of effective and essential science, engineering, technology, art, and literary applications. Behavior scientists, behavior analysts, and educators designing materials or applications can lead in this effort, and by their example help ensure that learners "really understand" the concepts they are taught.

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