Generative Strategies and Teaching for Generalization

Galen Alessi
Western Michigan University

Behavioral approaches to education have been criticized for emphasizing rote learning rather than teaching for generalization. Perhaps a perceived focus on developing long lists of teaching objectives in behavioral programs has set the occasion for this impression. Critics note that children cannot be taught directly each stimulus-response relationship in a curriculum strand. Mathematics provides an object lesson, containing not only an infinite set of stimulus-response relationship possibilities, but also several disjoint groups each containing an infinite number of sets, with each set containing an infinite number of stimulus-response possibilities. Teaching every stimulus-response relationship apparently should take several lifetimes, each of infinite length. Most pupils, however, acquire these repertoires by eighth grade. Clearly there are ways to teach the *general case* (cf. Becker, 1986, pp. 187-197) without teaching each stimulus-response relationship. Pupils are taught general patterns of responding that can in turn be used to produce effective responses in an infinite variety of situations.

Children know much more than they have been taught directly. Behavior analysts need to understand how this occurs in order to increase the effectiveness of teaching programs. Discussions of methods for teaching for generalization (Baer, 1982; Stokes & Baer, 1977) address only part of the problem. This paper will discuss how children learn much more than is taught directly, in terms of behavioral principles and the analysis of verbal behavior presented by Skinner (1957), and of instructional principles and the analysis of teaching behavior presented by Engelmann and Carnine (1982).

The major focus of the paper is on the use of minimal recombinative repertoires, and use of manipulative autoclitic frames to transform minimal recombinative repertoires into other novel repertoires. These approaches can be called *strategic, generative,* or *recombinative,* because they generate a *maximum* novel repertoire after teaching only a *minimum* number of discrete stimulus-response relationships. In this approach, generalization is recast as generality of application of generative skills taught across novel situations. Assessment for mastery involves sampling the generative skills taught, whereas assessment for generalization involves sampling application of generative skills across a wide range of novel situations. The last section of the paper will address issues of verbal behavior practices maintained by verbal communities that make certain subject areas more amenable to generative teaching approaches than others.

Although generative approaches can be described in detail, and research has been designed to validate their effectiveness, it is still not entirely clear how basic behavioral principles, or combinations of principles, account for this effectiveness. Perhaps further basic research will accomplish this.

A brief discussion of current ways of talking about generalized responding will set the occasion for comparing and contrasting these with the generative concepts to be presented. Currently, acquisition of apparently untaught stimulus-response relationships is talked about in terms of stimulus and response generalization, abstract stimulus control and generic extension, and stimulus equivalence. Readers familiar with these may wish to review them briefly here, or skip

I would like to thank Jack Michael for reviewing an earlier draft of this paper, and for his guidance in developing the material presented. All metaphorical and metonymical extensions, however, are the sole responsibility of the author (and his conditioning history).

Reprint requests and comments should be sent to the author, Department of Psychology, Western Michigan University, Kalamazoo, MI 49008

directly to the section on minimal response repertoires.

STIMULUS AND RESPONSE GENERALIZATION

Generalization is perhaps the most common process invoked to account for phenomena involving the acquisition of untaught stimulus-response relationships. This word, however, is used in several different ways, leading to confusion. For some the term seems to denote a kind of magical process, used as an explanatory fiction. Novel responses are said to be products of "generalization" from previous learning, with little regard for the complexity of the responses emitted, and without elaboration of the behavioral principles that might underlay such a process.

Generalization is more properly used to describe situations in which saying "red" has been reinforced in the presence of red objects, and subsequently the child says "red" in the presence of pink objects (*stimulus generalization*) or says "rud" to red objects (*response generalization*). This occurs presumably because response forms and stimulus situations contain many components, all of which are strengthened by contingent reinforcement. When most, but not all, of the response form components are at strength, "rud" may be said rather than "red." When most, but not all, of the stimulus component features are present (e.g., pink), a non-red stimulus may evoke the response "red." The more stringent the criteria applied by the verbal community for differentially reinforcing responses of "red" (i.e., the more proper stimulus and response components required before reinforcement), the less stimulus or response generalization that occurs on future occasions.

Stimulus generalization often is used awkwardly to describe situations in which the response "red" has been differentially reinforced in the presence of red rather than green, blue or yellow objects, and the child subsequently says "red" when presented with novel red objects (e.g., red car, red sky, red juice). In these cases, all responses are made to the identical frequency of light in each example, only the contextual stimuli vary (e.g., size, shape, texture, material). Because all these red stimuli contain all the proper color features of the trained red stimulus, no stimulus generalization has ccurred. Response generalization likewise is awkwardly used to describe situations in which the same child says "vermilion" when presented with novel red objects. Because the response form "vermilion" shares too few component forms with the trained response form "red," little response generalization has occurred.

ABSTRACT STIMULUS CONTROL AND GENERIC EXTENSION

The above type of stimulus control more appropriately can be called *abstract* control (Skinner, 1957, pp. 107-114). The child's response "red" has come under the control of one value, and only that value (i.e., red) along a single stimulus dimension (i.e., color). Concurrently, the response "red" has been weakened in the presence of any other non-red stimulus value within the color dimension (e.g., orange, pink). Furthermore, the response "red" has been freed from control by stimulus dimensions irrelevant to the color dimension (e.g., size, shape, material, texture). The sharpness of the resulting stimulus control is directly related to the precision of the verbal community in applying differential reinforcement contingencies.

Upon observing the correct use of "red" and "not red" to a series of objects varying widely across both color and other stimulus dimensions, traditional educators would say the child "*has* the concept of redness." Behavior analysts might say the child had emitted a series of abstract generic tact extensions.

Emitting the response "dog" in the presence of all the essential canine stimulus features would be called a *generic* tact extension, and a correct response. Were the child to say "dog" in the presence of some, but not all, the essential canine features (e.g., hyena; cat), this would be called a *metaphorical* tact extension, and an error. Were the child to say "dog" in the presence of no essential features, but only irrelevant features which in the past had accompanied essential features (e.g., dog collar), this would be called a *metonymical* tact extension, and an error (Peterson, 1978; cf. Skinner, 1957, pp. 91-102). Errors would be corrected by presenting, and reinforcing differential responses to, new examples and non-examples carefully selected according to any pattern of stimulus control weakness shown.

Skinner uses the term *common abstract tact* to refer to situations in which a response is under control of a single feature (e.g., red, hotter) in a complex stimulus array (Skinner, 1957, p. 113). He uses *concept* (p. 105) to refer to situations in which a response is under control of a specific subset of stimuli in a complex array (e.g., dog, shoe). By comparison, Engelmann and Carnine (1982) use *comparative* (e.g., hotter, bigger) and *non-comparative* (e.g., red, wet) *single feature concept* in the way Skinner uses *common abstract tact* and they use *noun concept* (e.g., dog, shoe) in the way Skinner uses *concept*. As a point of confusion, however, Engelmann and Carnine use *generalization* in the way Skinner uses *abstraction* and *generic tact extension*.

Based on these and related distinctions, Engelmann and Carnine (1982) have developed a taxonomy organized to allow the user to develop efficient teaching routines for establishing elaborate tacting (and other) repertoires. In contrast with other taxonomic systems, which are organized along lines of subject matter content, historical development, or logical themes, Engelmann and Carnine have organized their taxonomy along lines of instructional relevance.

For example, if the instructor's task is to establish a tacting repertoire in the presence of single stimulus features, either a comparative or a non-comparative sequence would be selected, depending on whether the discrimination to be trained involved a relationship between two stimuli (e.g., wider: use comparative sequences, chap. 7) or the presence or absence of one stimulus (e.g., red: use non-comparative sequences, chap. 5). If the task is to establish tacting repertoires involving multiple stimulus features (e.g., shoe, dog), use noun sequences, (chap. 6). If the instructional task is to teach operations incorporating use of tacting repertoires, and/or intraverbal responses, either of which follow a pattern, use single transformation sequences, (chap. 8). If no pattern describes the set of operations or intraverbals, use fact sequences, (chap. 14). If the task is to teach new patterns of operations or intraverbal responses based upon previously established patterns of operations, use double transformation sequences, (chap. 13). The taxonomy continues, building from simpler to more complex forms.

STIMULUS EQUIVALANCE

Stimulus and response generalization, abstract stimulus control, and generic extension, however, account for only part of the stimulus-response repertoire established without direct differential reinforcement. For example, a child may be taught to say "dog" when shown a picture of a dog, and to say "dog" when shown the word *DOG*. If the child then points to the word *DOG* when shown a picture of a dog, she exhibits a stimulus-response relationship that has not been taught directly. This is called *stimulus equivalence* (Sidman, 1971). Behavior analysts use stimulus equivalence to advantage in designing programs that establish much more than directly taught stimulus-response (rote-learning) relationships (cf. Wetherby, 1978; Wetherby & Striefel, 1978).

Wetherby and Striefel (1978) noted that 144 novel stimulus-response relationships were established in the repertoires of retarded children after directly teaching only as few as twelve strategically selected relationships. On the importance of strategic sequencing, they noted that "the manner in which the specific verb-noun instructions are taught is the ultimate determinant of whether generalized responding can be obtained and that training procedures that do not take such factors into account will result in a lack of generalization" (p. 327). They used the term *combinative generalization* to describe the acquisition of these untaught relationships, and contrast this with *primary-stimulus generalization*, which they used to describe generalization as defined above.

MINIMAL RESPONSE REPERTOIRES

With the above brief review of current ways of describing the acquisition of untaught stimulus-response relationships as a backdrop, generative or recombinative approaches can be presented. These ways of acquiring elaborate repertoires without direct teaching involve the concept of *minimal response repertoires* (Skinner, 1957, pp. 55-71). Skinner includes minimal *echoic* repertoires, minimal *textual* repertoires, and minimal *transcription* repertoires (for taking dictation and copying texts). He suggests minimal *imitative* repertoires.

Minimal repertoires require *point-to-point correspondence* between elements of the stimulus array and elements of the *products* of the responses made to those stimulus arrays. Such point-to-point correspondences may be seen in direct similarity of forms (e.g., copying text, echoic responding) or without such formal similarity (e.g., taking dictation, reading text).

An example of *formal* point-to-point correspondence would be a child producing the series of marks on paper "e-l-e-p-h-a-n-t" in response to the series of stimulus elements (letters) seen in the word: *elephant*. This is copying text. The *products* of the child's responses are matched in form point for point with the respective stimulus elements of the word. An example of point-to-point without formal correspondence would be a child emitting the series of sounds "el-ee-f-a-nt" in response to the same stimulus word: *elephant*. This is reading text (i.e., decoding). The forms of the *products* of the child's responses (i.e., sounds) do not match the forms in the stimulus array (i.e., written marks). But there is still point-to-point correspondence between each sound made and each respective letter in the stimulus array.

The important issue for designing efficient instruction programs is that each of these minimal repertoires contains a finite set of stimulus-response elements that can be brought under abstract stimulus control and then combined and recombined to meet response requirements in an indefinitely large target repertoire. Although Skinner's concern in *Verbal Behavior* mainly focused on how such minimal repertoires are brought under abstract stimulus control through the every-day practices of the verbal community, the focus in education would be on *analyzing* targeted subject areas to determine possible recombinative stimulus-response elements that could be brought under abstract control to later enable a child to produce any required response to any complex stimulus array presented within that subject area.

The minimal stimulus-response set is called the *generative* set, and the target or goal repertoire which can be produced by various combinations of stimulus-response elements is called the *universal* set. For example, when establishing minimal *textual* verbal repertoires (reading *decoding* as contrasted with comprehension), the universal set might include a 500,000 word list, and the generative elements might include a set of 40 letter-sound relationships. By blending various letter-sound combinations, the child would be able to emit textual verbal responses (i.e., decode) in the presence of any word in the set of 500,000. This would yield an average *generative* or *multiplicative* power of over 10,000. That is, the child would be able to decode on average 10,000 novel words for every discrete sound-symbol element taught.

In this approach, testing for *mastery* would focus on the recombinative elements and combining operations taught, while testing for *generality* would focus on sampling the application of these skills across the universal set. This contrasts with a rote learning approach in which each word is learned as a separate stimulus-response item, producing little savings for succeeding items, and in which testing for mastery is the same as testing for generality.

One-to-one correspondence. As noted by Skinner (1957), the minimal repertoire strategy requires a one-to-one correspondence between some combination of elements from the generative set and the stimulus-response requirements for any member of the target repertoire. This requirement is often not met in academic subject areas, thus making use of minimal repertoires seem inappropriate.

When there is some, but insufficient, correspondence between elements of a given generative set and requirements of the universal set, two strategies may be employed, depending on the situation. The *first* choice would be to restrict temporarily the universal set only to those items that have regular one-to-one correspondence with members of the generative set. After these basic relationships have been mastered, the omitted irregular members would be introduced gradually as exceptions. The *second* choice would be to expand temporarily the given generative set with novel members contrived to accommodate any irregular patterns in the universal set. After these recombinative relationships are mastered, the contrived members gradually are eliminated until only the natural set remains.

Phonic textual systems are especially suited for use of minimal repertoires when establishing textual verbal behavior. Italian, Spanish and Finnish are almost entirely phonetic, whereas Russian and German are

94% and 90% phonetic, respectively (Mazurkiewicz, 1976, p. 21). Minimal recombinative repertoires can be developed for these systems. Cued speech and finger spelling (for the deaf) fall into this category, as would American Sign Language using "cheremes" (Stokoe, Casterline & Cronberg, 1965). Ideogram based writing systems (e.g., Chinese), not having one-to-one sound-symbol correspondences, are not suited for such minimal repertoire analyses. Languages like English, containing many irregular symbol-sound correspondences, appear to fall between these two extreme positions.

Although there is partial order, English spoken sounds do not correspond one-to-one with textual stimuli. The sound of the letter "a" is different in the words h*a*t, h*a*te and *a*bove. "Th" does not make the same sound in *th*ere as it does in ten*th*. The letter-sounds in *w-a-s*, when read aloud, do not make the sound "wuz." George Bernard Shaw noted that by blending the sounds made by the underlined letters in the words enou*gh*, w*o*men and na*ti*on, *gh-o-ti* would be pronounced "fish." Furthermore, whereas *hop* can be read simply from left to right, *hope* requires the reader to read first from left to right (to note the silent diacritical "e"), and then back to left (to medial vowel "o") to pronounce the "o" long rather than short. Members of the universal set which cannot be produced by simply recombining elements of the generative set are called *irregular.* They are exceptions to the recombination patterns taught. The high frequency of irregular words in English challenges the workability of simple minimal recombinative repertoires in teaching decoding.

Teaching reading of English by sight words (cf. rote-memory) is a non-generative alternative adopted in most basal reading programs. Of course, some recombining power (or teaching savings) would obtain with compound words: After the child had learned "motor" and "boat," she would probably be able to read "motorboat." "Whole-word-approach" advocates claim that, due to the frequency of irregular words, children should use sentence meaning (e.g., *thematic prompts*) rather than sound-symbol relationships to read unknown words. But there are few thematic prompts unless the child can decode a substantial number of words from the start. Furthermore, thematic prompts do not indicate whether a recipe calls for a "dish" or "dash" of salt. Finally, the irregular words actually contain mostly regular symbol-sound correspondences, with only one or two exceptions per word. For these reasons, a feasible strategy for establishing textual verbal behavior would include teaching phonics skills first as a basis from which the reader later could derive thematic prompts (e.g., context and structural analyses cues) necessary to read irregular words, or irregular parts of words.

Due to the number of irregular words in English, either of the two options discussed above could be considered in developing a workable recombinative repertoire. Following the first strategy, one would initially eliminate irregular words, and teach the child a minimal textual repertoire to sound out letters and blend them together using regular words, (cf. Carnine & Silbert, 1979). Letter sounds would be taught rather than letter names. Only the most common sounds for each of the 26 letters would be taught. Lower case letter forms would be taught before upper case forms. The more commonly used letter-sounds would be taught first, (e.g., *a, n, s, t, b, e, m*). *Blending* letter-sound elements together to form vocal words would be taught as a discrete operation. Even though consonants provide stronger stimulus control than vowels for word discrimination, vowels and consonants would be taught in mixed order so that the child more quickly could begin blending minimal textual elements into functional words. After the child had mastered this textual repertoire using regular words in sentences, irregular words would be introduced gradually as exceptions and read either by sight recall, or by thematic prompts provided by the regular words already decoded in the sentence, or by both.

Following the second strategy (cf. Carnine & Silbert, 1979; Engelmann & Bruner, 1974), one would create new letter forms to contrive a one-to-one correspondence between letter symbols and approximately 40 required vocal sounds (roughly, phonemes). The same principles for selecting and sequencing letter-sound combinations would be used as with the first strategy above. After the child had mastered the decoding process, the contrived letter forms would be dropped gradually as sight word recall and thematic prompts supplied sufficient cues to correctly read unknown irregular words.

Each strategy has tradeoffs. In English, irregulars are concentrated in the high frequency words necessary to construct basic sentences (e.g., the verbs "to be" or "to have"). Mazurkiewicz (1976) states: "85 percent of words (or portions of words) in English are regularly spelled and therefore phonetic, while 15 percent are not; but the 15 percent which are not are used 85 percent of the time. . ." (p. 22). Thus, choosing the strategy of restricting irregulars from the universal set is choosing to avoid using the most basic sentences when children practice decoding skills. Expanding the generative set (minimal repertoire) would allow the use of any words deemed appropriate (and any basic sentences) when writing practice stories.

In teaching textual repertoires (i.e., decoding) in English, then, the better option is to expand the generative set. Engelmann adopted this approach in *Reading Mastery* and *DISTAR*, (Engelmann & Bruner, 1974; Engelmann et al., 1975). These programs use a 40 symbol set, expanded from the standard 26 alphabet symbols, (cf. Becker, 1986, p. 243). Pittman also used this strategy in the 44 symbol Initial Teaching Alphabet reading programs (Mazurkiewicz & Tanyzer, 1963; Pittman, Mazurkiewicz & Tanyzer, 1964). After the child learns the 40 basic stimulus-response elements, and practices blending these together reading from left to right, any of a set of 500,000 words can be correctly decoded, including many thousands the child had not been previously exposed to. Testing for mastery would involve assessing the recombinative stimulus-response relationships taught, plus blending skills. Testing for generality of application would involve sampling the use of these recombinative skills across the 500,000 word universal set.

Because eventually the expanded generative set must be reduced to the natural set, careful planning is involved from the start. Engelmann thus modified the traditional orthography of the English alphabet *as little as possible*, until workable one-to-one correspondence capabilities were obtained (cf. Becker, 1986, p. 243). In this way, the program to return to traditional orthography was made a simple as possible. Attempts such as I.T.A. have failed in large part because its 44 symbols, adapted from the 80 character International Phonetic Alphabet, differ too much from traditional Latin orthography, thus presenting difficulties in returning to the natural set, (as well as difficulties in gaining acceptance by teachers and parents).

In most teaching situations, however, temporarily removing irregular stimulus-response members from the universal set is the strategy of choice. Often these irregular members follow a recombining pattern of their own, which could be taught later as a subtype of the more general recombining pattern.

Consider teaching children to read numerals from one to 100, (cf. Silbert, Carnine & Stein, 1981). Recombinative stimulus-response patterns can be developed for more efficient teaching. The only exceptional combining patterns occur in: (A) the teens decade (i.e., read the numerals right to left rather than the reverse; read *1* as "teen" rather than "one"; read *11* and *12* as whole units "eleven" and "twelve"; and read *13* and *15* as "*thir*teen" and "*fif*teen" rather than "*three*teen" and "*five*teen"); and in (B) the initial member of three subsequent decades (i.e., *20, 30,* and *50* are pronounced "*twen*ty," "*thir*ty," and "*fif*ty" rather than "*two*ty," "*three*ty," and "*five*ty"). All numerals are read left to right except the teens. Removing the irregulars will allow the child to master the remaining members by learning a basic set of stimulus-response relationships (*1* = "one"; *2* = "two" etc.), and blending these numeral sounds together from left to right (e.g., "*six*ty*four*," "*eigh*ty*nine*," etc.). Although *20, 30* and *50* are exceptions to the general sound pattern, they form their own pattern subtype. All members within these decade subsets follow the same recombinative left to right pattern. And after these three odd bases are taught, the remaining numerals in the decade can be read using previously taught recombinative patterns (e.g., twenty-*three*, thirty-*six*, fifty-*eight*). Thirteen and fifteen also fall into this pattern. Only eleven and twelve need be taught as final exceptions, along with the change in pattern for reading teen numerals (from right to left rather than left to right).

The entire minimal recombinative repertoire set is mastered by learning some sixteen basic stimulus—response elements, a left to right recombining order, and the exceptional right to left combining order for teens. At this point, expansion to reading numerals from 100-1000 or beyond can be taught easily by teaching the base word for each hundred (i.e., 200 = two hundred, 900 = nine hundred) and then the base word for each thousand (i.e., 1000 = "one thousand," 6000 = "six thousand"). With practice, the child now will be prepared to read any numeral from 1-10,000, whether or not the child had been previously exposed to that particular numeral. Testing for skill mastery would involve assessing the recombinative stimulus-response relationships taught, including reading from left to right (except for teens), whereas testing for generality of skill application would involve sampling use of the recombinative skills across the set of 10,000 numerals in the universal set.

Spelling programs have been developed on minimal recombinative repertoire strategies (Dixon & Engelmann, 1979). The authors selected some 20,000 words considered important in a high school graduate education, removed proper names and foreign words, and then analyzed the remaining set into a minimal recombinative set. The set contains some 640 elements, which basically are morphographs. Using three joining or combining patterns, the 640 elements can be recombined to correctly spell some 12,600 words. This yields a *generative power* of 20:1 over the option of establishing the 12,600 words as separate stimulus-response items, (cf. "rote memorization"). Testing for skill mastery would involve assessing the minimal recombinative stimulus-response set taught, plus three joining operations, whereas testing for generality of skill application would involve sampling use of the recombinative skills across the 12,600 word universal set.

Lloyd Hutchings (1976) developed a recombinative approach for teaching each of the basic four arithmetic operations (add, subtract, multiply, divide). The Hutchings algorithm for addition allows one to add number arrays (e.g., 5 columns by 7 rows) using only the 100 basic math facts. Doing the same problem with our traditional algorithm would require use of some 1,000 basic and complex math facts, or else performing complex addition operations (i.e., carrying) "in our heads." The Hutchings algorithm substantially reduces the number of discrete skills needed over traditional approaches, and requires that no responses be made "in our heads," which teachers cannot see, and therefore correct, when mistakes are made.

A cursive writing program based on generative sets has been developed by Miller and Engelmann (1980). A set of six or so basic writing forms can be combined to produce and connect any of the 26 capitol or lower case cursive letters in English.

Horner, Sprague and Wilcox (1982) identified a recombinative stimulus-response repertoire for operating a variety of vending machines after sampling all vending machines in a defined area of Eugene, Oregon. Once the minimal stimulus-response repertoire, and the patterns of combination, were taught, learners (i.e., retarded citizens) were able to operate any vending machine in the area, including many kinds not encountered in the teaching program.

Becker, Dixon and Anderson-Inman (1980) have completed initial computer analyses to identify minimal recombinative repertoires to teach vocabulary meaning. They identified 3,000 basic elements that can be used (as thematic prompts?) to determine the meaning of 25,000 words. The *generative power* here (8:1) is low by comparison to other work, but still several times more efficient than "rote learning." Vocabulary meaning may remain elusive to recombinative teaching strategies.

MANIPULATIVE AUTOCLITIC FRAMES

Another approach to generating stimulus-response relationships without direct teaching involves use of what Skinner (1957) calls "*manipulative autoclitic frames*" (pp. 340-343). Building on previously acquired recombinative stimulus-response repertoires, manipulative autoclitic frames prompt the learner to transform those repertoires, using verbal behavior *patterns*, into complex new verbal behavior repertoires. After a pupil's verbal behavior comes under the abstract control of various recombining patterns, novel verbal behavior repertoires can be organized along similar patterns without extensive teaching. Some autoclitic frames could be called *logical connectives*, which clarify relationships among various concepts. Examples of such basic frame structures would include: "This is x, and that is not x"; "If x, then y"; "If and only if x, then y"; "X is the same as y"; "X and z are y"; "X but not z is y."

After the child's verbal (or motor) recombining repertoire has come under the control of the abstract features of the basic frame (cf. Skinner, 1957, pp. 107), that frame can then be used to pattern further verbal behavior without direct teaching. To teach equivalent verbal responses for various tacts (e.g., synonyms), the teacher selects the already established abstract frame "X is the same as Y," and then plugs into the "Y" term a series of verbal responses already established in the child's repertoire, and plugs into the "X" term new responses the teacher wishes to become functionally equivalent (but not identical) to the current verbal responses. Verbal relationships strengthened might include new terms (e.g., "*Azure* is blue"; "*der fingerhut* is thimble") or new relationships among terms (e.g., "The *sky* is blue," or "Blue is a *color*, or "Blue is *soothing*). The new verbal relationships may be acquired in a single trial, without the differential reinforcement history needed to establish the original tacts.

At one level this might be considered an example of stimulus equivalence (Sidman, 1971), whereas at another level it might be considered a function of rule-governed behavior (cf. Skinner, 1969, chap. 6). Either way, entire sets of new verbal responses are acquired quickly by building strategically on established verbal behavior, thus short-circuiting direct teaching through contingencies of reinforcement.

The following example (adapted from Engelmann & Carnine, 1982, chap. 7) illustrates how autoclitic frames can be used in instruction. Note the repertoire altering effects as you read this sequence designed to establish a tact response under the abstract control of a single aspect of the stimulus array.

AUTOCLITIC FRAME:	STIMULUS ARRAY:
"Look at this."	_____
"This is it."	______
"This is not it."	_____
"This is it."	____________________
"This is it."	____________________
"This is not it."	_________________
"This is not it."	_______
"This is it."	________

Now answer the following:

	"Look at this."	______
1.	"Is this it?"	__________
2.	"Is this it?"	______________
3.	"Is this it?"	_________
4.	"Is this it?"	____________
5.	"Is this it?"	__________

Your answers in order should be: Yes, Yes, No, Yes, No. If your answers were correct, the brief sequence above brought your "Yes" and "No" verbal responses under control of a single stimulus feature of the line: getting longer. This was done without use of a word for the property ("longer") and without differential reinforcement for your responding. But stimulus control was nevertheless established, based on careful sequencing of the examples and your previous history with the pair of related frames: "This is it" and "This is not it."

Likewise, autoclitic frames can be used to construct new repertoires based on patterns of responding established in previous repertoires. Some academic subjects are more amenable to teaching this way than others. When subject areas can be arranged in roughly parallel strands, so that stimulus-response patterns from one strand can be transformed into another by a relatively simple operation, an autoclitic frame approach is applicable.

Playing a second musical instrument can be taught largely as a transformation of the repertoire established with the first. Reading a second Latin-derived language can be taught largely as a transformation of the repertoire established with the first. Using a second word-processing program or data based management program can be taught largely as a transformation of the repertoire established with the first. Engelmann and Carnine might teach these new repertoires using what they call single and double *transformational* sequences (1982, chaps. 8 and 13).

As a simple example, consider teaching the set of 100 basic addition and multiplication facts. Only 50 stimulus-response relationships need be taught directly if the fact repertoire can be brought under control of the abstract pattern of ignoring the order in which addends are summed (or in which factors are multiplied). Once the child learns the fact $2 + 3 = 5$, or $2 \times 3 = 6$, she will already have learned the fact $3 + 2 = 5$, or $3 \times 2 = 6$, even if never encountered before.

This is a savings of 50% over rote memory of the 100 facts. Testing for mastery would involve assessing the facts directly taught, and the pattern of ignoring the order of combination, whereas testing for generality of application would involve sampling use of the basic skills across untaught (reversed order) facts in the goal set. Similar savings are not available with subtraction and division facts, since the commutative property does not hold for these operations.

Other simple examples include syntax. Once the child learns the singular form of nouns, she can be easily taught to transform these into plurals by the operation of adding an "-s." Once present tense verbs are learned, these can be transformed into past tense by the operation of adding "-ed." Unlike the commutative property, however, the transformations in English grammar have many exceptions. But these exceptions do not justify foregoing the savings in learning of having one's verbal behavior under the abstract control of transformation patterns. Indeed, most verbal behavior comes under the abstract control of these transformation patterns very early in life, without direct teaching. Likewise, mathematical repertoires of children come under the abstract control of the transformation patterns implied by the commutative property, without direct teaching. When a repertoire is not under the abstract control of these stimulus-response patterns, great economies in teaching can be obtained by directly bringing it under such control.

As a more complex example, consider teaching measurement by either the English or metric system. The English system cannot be organized into parallel patterns and thus is not a good candidate for efficient transformational teaching. Mastering the basic distance units "inches," "feet" and "miles" does not provide a minimal repertoire of stimulus-response elements that can be recombined to save learning when teaching the basic units for volume or weight. Learning how many inches are in a foot does not provide recombinative savings when learning how many feet are in a yard or mile. Learning how to transform inches into feet, and feet into miles, does not provide savings when learning how to transform ounces into quarts or pounds.

The metric system, by contrast, is designed as a transformational system. Once the basic prefixes are learned for naming units (e.g., deci-, centi-, milli-, micro-, kilo-, mega-, giga-) and the operations are learned for transforming one unit into another (e.g., either multiply or divide by 10, 100, 1000, etc.), only the new base word (e.g., meter, gram, liter, second) need be taught for the student to become verbally proficient in that dimension. The major effort is invested in teaching the recombinative elements and their patterning in the first strand, and the other response patterns then are taught as recombinative transformations of the first strand.

The child who can define a centimeter, and transform that into a millimeter, has most of the recombinative repertoire needed to define a centigram, and transform that into a milligram. A simple autoclitic frame can be used to establish the transformation pattern for each subsequent strand (i.e., "X is the same as y, except the base word is z"). The child under the control of this rule (cf. Skinner, 1969, chap. 6) can generate effective responses to a wide array of measurement situations never before encountered. Testing for mastery would involve assessing the basic units and recombining patterns taught, whereas testing for generality of application would involve assessing the use of these skills across untaught strands in the system.

The role of autoclitic frames in acquiring novel verbal repertoires might explain why one identical 18-month old twin acquires a larger verbal repertoire than the other. Although a hypothetical situation that would probably not occur, the example is used only to illustrate a point. If one parent (or grandparent) by chance were to teach one twin at 12 months (but not the second twin) the frame "This is x" (while pointing to objects), the first twin would acquire a tacting repertoire substantially larger than the other in a very brief time. Whenever someone pointed to an object and named it, the first twin would attend to the object being pointed to, whereas the second twin would not, perhaps looking only at the pointing finger. The difference in tacting repertoire could become so large at 18 months that the parents might invoke concepts like "brain damage" to explain the discrepancy. However, big deficits in behavioral repertoires do not always call for big explanations. Sometimes a relatively minor, but strategically important, behavioral deficit leads to major problems if given enough time, (cf. Bereiter & Engelmann, 1966, chap. 6; Staats, 1971, chaps. 14 & 15).

Pertinent to the present discussion, this can occur especially when basic manipulative autoclitic frames have not been established. Children said to "have *transformational grammar*" probably have minimal recombinative verbal repertoires, and transformation patterns, under the control of abstract features of many manipulative autoclitic frames, allowing them to recombine numerous verbal patterns and elements to meet various novel situations.

One could argue that preschool curricula should focus on establishing abstract control by such frames in addition to basic tacts, mands and intraverbals. Many preschool curricula in fact do so under the scope of teaching "syntax," (cf. Bartlett, 1972, p. 44). With the exception of *The DISTAR Language Program* (Engelmann & Osborn, 1977), however, they do not use these frames strategically to efficiently generate new verbal behavior.

GENERALITY OF CONSEQUENCES

Regardless of how stimulus-response systems become elaborated, always there is a matter of consequences. And some consequences have greater generality of application than others. *Generalized conditioned reinforcers* (e.g., praise, money, tokens) have broad generality of application because they work without current association with any specific person, situation, setting, reinforcer, or establishing operation. And *conventional* generalized conditioned reinforcers (e.g., praise, money) enjoy wider currency of use in the larger verbal community than do *contrived* ones (e.g., tokens). Although use of contrived reinforcers is reasonable when conventional reinforcers are unavailable or have not yet been established, a major goal of programs should include establishing conventional generalized conditioned reinforcers to ensure that repertoires taught in analog settings will be strengthened naturally in other community settings.

Conventional conditioned generalized reinforcers, furthermore, have additional repertoire generating advantages not shared by contrived ones. Repertoires that can be strengthened (or weakened) only by contrived consequences will be preempted from many learning opportunities provided by the larger verbal community. Repertoires that are strengthened (or weakened) by conventional consequences will benefit from the enormous increase in opportunities to learn provided incidentally by everyday interactions in the verbal community.

Sometimes the *products* of responses may become conditioned reinforcers. A parent might talk to an infant while feeding and caring for it, pairing the sounds with those primary reinforcers. The sounds thus become conditioned reinforcers. To the extent that the infant later produces similar sounds through babbling, those sounds will strengthen not only the vocalization responses that produced them, but also other collateral behaviors which may have occurred at the time. This is called *automatic reinforcement*, (Skinner 1957, p. 58), because the direct product of a response (sound) acts to strengthen that response (vocalizing). Features that may become conditioned reinforcers include task completion itself, or the accuracy, quality, and aesthetic value of the resulting product. Automatic reinforcement may account for many stimulus-response relationships acquired without direct teaching. It may be especially useful in explaining the development of such apparently untaught behaviors as imitating another person's mannerisms, accent, dialect, or idiomatic word usage.

Consequences thus also play a crucial role in generative strategies of instruction. Generalized conditioned reinforcers allow behavior taught in analog settings to be strengthened in natural settings; enable behaviors to acquire wide generality across a variety of natural settings; and increase enormously the number of learning opportunities by allowing incidental learning to occur outside teaching settings. Automatic reinforcement allows elaboration of repertoires to occur without further direct instruction from the verbal community.

GENERATIVE STRUCTURE OF KNOWLEDGE

The ease with which generality of responding can be established is often a function of how the subject matter has been organized. Organization of subject matter evolves as a function of cultural practices, which are a product of what Skinner calls the third level of selection by consequences: Cultural selection (Skinner, 1981).

The metric system by design is more amenable to minimal recombinative repertoire teaching strategies than the English system. Reading by decoding is more amenable to such strategies in Italian, Spanish and Russian than in English or Chinese. As cultures evolve, important changes are made which determine the ease with which recombinative repertoires can be established for future generations. These changes place limitations on instructional design. Discussing examples of these limitations may clarify the importance of recombinative strategies and the role of the instructional designer in analyzing subject areas.

For example, shortly after the metric system was developed in 1792, Thomas Jefferson introduced a bill in Congress to have the U.S. adopt it in place of the English system. The bill was defeated, although Congress did adopt part of the proposal: our metric currency system. Instead of becoming one of the first nations to adopt the metric system, we are now one of the last three nations (and only industrialized nation) not to have adopted it. Our current effort to change to the metric system is failing.

Had Congress adopted the system then (going against the pressure of short-term contingencies), the long term gains for the nation would have been great both economically and educationally. Today's children would not need to learn two systems to operate in an international world. They would not need to spend great effort rote-learning a measurement system that does not lend itself to generalized patterns of responding. Also saved would be the additional academic year invested in mastering fractions as well as decimal operations, because fractions are needed to make unit conversions within the English system. The metric system requires only decimal operations for unit conversions.

As another example, Russian sounds, as with English, do not closely correspond with the Latin or Greek alphabets. However, such one-to-one sound-symbol correspondence was provided by development of the 43 symbol Cyrillic alphabet (initiated by St. Cyril in the Ninth Century). But this was done before a large body of Russian (or other Slavic language) textual material had been established. Had a British monk adopted such a strategy ten centuries ago, English speaking children now would not be limited to the 26 symbol Latin alphabet, and would not have to face so many irregular sound-symbol relationships when learning to decode. Decoding could be taught more easily as a minimal recombinative repertoire. Attempts to modify our alphabet with such systems as the 40 sound-symbols of Unifon (Cokin, 1986) or the 44 sound-symbols of the Initial Teaching Alphabet (cf. Pittman, 1968) have met with even less success than adoption of the metric system.

On the positive side, Western culture selected the Arabic number system over the Roman system. Imagine trying to multiply "CMLXXXVII" by "LXXVIII," (i.e., 987 x 78). The Roman system did not lend itself well to the application of recombinative calculation patterns called algorithms. Multiplication and division were accomplished by long, tedious processes of repeated additions or subtractions. The work was so onerous that tables were kept of the products and quotients, and one merely looked in the table to find the correct answer (much as we do today with various statistical tables). Cultural selection of the Arabic number system has made it possible to teach almost everyone stimulus-response patterns that have great generality for reckoning with quantities.

That we use a decimal number system is an artifact of phylogenic evolution: humans have ten fingers. The decimal system convention does not provide generality of application when the task is computer programming. Computers use octal and hexadecimal number systems. Had humans evolved with eight fingers on each hand, we would probably not have to learn a new number system to program computers.

As another positive example, Western culture (i.e., the ancient Greeks) selected from the Phoenicians writing systems based on phonemes (i.e., phonetic) rather than pictures (e.g., hieroglyphics, kanji, ideograms). Whereas phonetic writing systems yield minimal textual repertoires, picture writing approaches do not. Each word may not have an ideogram in such languages. In China, criteria for reading proficiency are defined in terms of 2000-3000 ideograms (each learned as a separate item), rather than the 50,000 or so words expected of literate persons in

Western cultures. Without minimal textual stimulus sets, idiographic writing systems also are not amenable to efficient printing technologies (e.g., typewriting, typesetting). Until the recent advent of lithographic offset printing technology, books and newspapers were rare and expensive in ideogram based written languages.

Without typewriter keyboard capabilities (e.g., ASCII), many computer applications involving language are not feasible. It is no coincidence that the U.S. has been computerizing office functions faster than manufacturing, whereas the Japanese have done the opposite. Only recently has IBM developed a keyboard for creating Japanese text, which involves a system mixing phonic (Katakana) and ideogram (Kanji) symbols, (akin to the combination of finger spelling and American Sign Language). Containing over 250 keys, a proficient operator can enter about five to ten symbols per minute. It is difficult to appreciate the enormity of the long term educational, economic and cultural consequences of adopting one textual verbal behavior system over another.

On the other hand, idiographic writing systems do have the advantage of wide generality of application across languages, unlike phonic based systems. For example, because most Asian nations share perhaps 50% of their ideograms, a visitor from one country (e.g., China) can read signs and papers displayed in the host country (e.g., Vietnam), and perhaps communicate by writing with many host inhabitants. The countries share written, but not vocal, verbal repertoires.

CONCLUSIONS

Teaching involves much more than enumerating lists of behavioral objectives and teaching these, and hoping for "generalization." Teaching for generalization begins with an analysis of the structure of the subject matter for stimulus-response patterns having great generality of application (Engelmann & Carnine, 1982), and then selecting teaching approaches that establish patterns to capitalize on these regularities. Possibilities for use of minimal recombinative repertoires and transformation of available repertoire patterns are carefully explored.

Data supporting use of these approaches come from research studies (Carnine, 1978) as well as large scale national demonstration projects (Becker & Engelmann, 1978). Two behavioral models were evaluated along with more than a dozen other theoretical approaches in the National Follow Through Project. Although the behavioral programs outperformed the other models, the Oregon behavioral model outperformed the Kansas model in all areas of academics, (Becker & Carnine, 1980). In many respects the two programs were similar in structure and features. But there was one crucial difference. Whereas the Kansas model allowed schools to adopt basal programs from lists of traditional curricula, the Oregon model developed its own basal curriculum, incorporating many of the generative strategies discussed here. Heavily used were strategies to efficiently establish abstract stimulus control, minimal recombinative generative repertoires, and transformational repertoires described above in relation to manipulative autoclitic frames, (cf. Engelmann & Carnine, 1982). This difference may have made the difference. Although these strategies were not derived from *Verbal Behavior*, many of the ideas are consonant with Skinner's analysis.

Today there is no doubt that behavior analysts have much to offer educators wishing to teach repertoires of maximum general application while using the minimum amount of instructional time and effort. Children are acquiring extensive repertoires with only minimal direct stimulus-response teaching, when what is taught is selected and sequenced strategically for maximum generality of application.

Vague notions of generalization have not suggested efficient teaching strategies. A wide range of phenomena that collectively were grouped together under the label "generalization" may be dealt with more effectively as distinct categories: stimulus and response generalization, abstraction and generic extension, stimulus equivalence, automatic reinforcement, generality of consequences, minimal recombinative response repertoires, and use of autoclitic frames to generate new recombinative patterns.

Although it is not completely clear how basic behavioral principles interact to produce the effects, instructional planners can currently make use of recombinative or generative repertoires to ensure a maximum amount of learning with a minimum amount of instruction. This is "smart teaching" or "strategic teaching." It may be one of the more important things applied behavior analysis has to offer education now.

REFERENCES

Baer, D.M. (1982). The role of current pragmatics in the future analysis of generalization technology. In R.B. Stuart (Ed.), *Adherence, compliance and generalization in behavioral medicine* (pp. 192-212). New York: Brunner/Mazel.

Bartlett, E.J. (1972). Selecting preschool language programs. In C.B. Cazden (Ed.), *Language in early childhood education* (pp. 37-71). Washington, D.C.: National Association for the Education of Young Children.

Becker, W.C. (1986). *Applied psychology for teachers: A cognitive behavioral approach*. Chicago: Science Research Associates.

Becker, W.C., & Carnine, D.W. (1980). Direct Instruction: An effective approach to educational intervention with the disadvantaged and low performers. In B.B. Lahey & A.K. Kazdin (Eds.), *Advances in clinical child psychology (Vol. 3)*. New York: Plenum.

Becker, W.C., Dixon, R., & Anderson-Inman, L. (1980). *Morphographic and root word analysis of 26,000 high frequency words*. Technical Report 1980-1. Eugene, OR: University of Oregon Follow Through Project.

Becker, W.C., & Engelmann, S. (1978). *Analysis of achievement data on six cohorts of low-income children from 20 school districts in the University of Oregon Direct Instruction Follow Through Model: TECHNICAL REPORT 78-1*. Eugene, OR: University of Oregon Follow Through Project.

Bereiter, C., & Engelmann, S. (1966). *Teaching disadvantaged children in the preschool*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Carnine, D. (1978). *Analysis of achievement data on six cohorts of low income children from 20 school districts in the University of Oregon Direct Instruction Model: APPENDIX A, Formative Research Studies on Direct Instruction*. Eugene, OR: University of Oregon Follow Through Project.

Carnine, D., & Silbert, J. (1979). *Direct instruction reading*. Columbus Ohio: Charles E. Merrill.

Cokin, J. (1986). Unifon. Sunday Morning with Charles Kuralt. Columbia Broadcasting Network, June 8, 1986.

Dixon, R., & Engelmann, S. (1979). *Corrective spelling through morphographs*. Chicago: Science Research Associates.

Engelmann, S., Becker, W.C., Carnine, L., Meyers, L., Becker, J., & Johnson, G. (1975). *Corrective reading program*. Chicago: Science Research Associates.

Engelmann, S., & Bruner, E. (1974). *Teacher's guide for Distar Reading I*. Chicago: Science Research Associates.

Engelmann, S., & Carnine, D. (1982). *Theory of instructional design: Principles and applications*. New York: Irvington Press.

Engelmann, S., & Osborn, J. (1977). *DISTAR language level I & II*. Chicago, IL: Science Research Associates.

Horner, R.H., Sprague, J., & Wilcox, B. (1982). General case programming for community activities. In B. Wilcox & G.T. Bellamy (Eds.), *Design of high school programs for severely handicapped students* (pp. 61-98). Baltimore: Paul H. Brookes.

Hutchings. L.B. (1976). Low stress algorithms. In *Measurement in mathematics*. Reston, VA: National Council for the Teachers of mathematics.

Mazurkiewicz, A.J. (1976). *Teaching about phonics*. New York: St. Martin's Press.

Mazurkiewicz, A.J., & Tanyzre, H. (1963). *The early to read -i.t.a. series*. New York: i/t/a Publications.

Miller, S., & Engelmann, S. (1980). *Cursive writing program*. Tigard, OR: C.C. Publications.

Peterson, N. (1978). *An introduction to verbal behavior.* Grand Rapids, MI: Behavioral Associates, Inc.

Pittman, Sir James. (1968). The Initial Teaching Alphabet in historical perspective. In A.J. Mazurkiewicz (Ed.), *New perspectives in reading instruction*. New York: Pittman.

Pittman, Sir James, with Mazurkiewicz, A.J., & Tanzer, H.J. (1964). *The handbook on writing and spelling in i.t.a.* New York: i/t/a Publications.

Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech Hearing Research, 14*, 5-17.

Silbert, J., Carnine, D., & Stein, M. (1981). *Direct Instruction mathematics*. Columbus, Ohio: Charles E. Merrill.

Skinner, B.F. (1957). *Verbal behavior.* Englewood Cliffs, NJ: Prentice Hall.

Skinner, B.F. (1969). *Contingencies of reinforcement: A theoretical analysis*. Englewood Cliffs, NJ: Prentice-Hall.

Skinner, B.F. (1981). Selection by consequences. *Science, 213*, 501-504.

Staats, A.W. (1971). *Child learning, intelligence, and personality: Principles of a behavioral interaction approach*. Kalamazoo, MI: Behaviordelia, Inc.

Stokes, T.F., & Baer, D.M. (1977). An implicit technology of generalization. *Journal of Applied Behavior Analysis, 10*, 349-367.

Stokoe, W.C. Jr., Casterline, D.C., & Cronberg, C.G. (1965). *A dictionary of American Sign Language on linguistic principles*. Wash. D.C.: Gallaudet College Press.

Wetherby, B. (1978). Miniature languages and the functional analysis of verbal behavior. In R.L. Schiefelbusch (Ed.). *Bases of language intervention* (pp. 397-448). Baltimore: University Park Press.

Wetherby, B., & Striefel, S. (1978). Application of miniature linguistic system or matrix-training procedures. In R.L. Schiefelbusch (Ed.), *Bases of language intervention*, (pp. 317-356). Baltimore: University Park Press.