CHAPTER 3

ARRANGING REINFORCEMENT CONTINGENCIES IN APPLIED SETTINGS: FUNDAMENTALS AND IMPLICATIONS OF RECENT BASIC AND APPLIED RESEARCH

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Arranged reinforcement contingencies are by definition contrived, but reinforcement contingencies are ubiquitous. If researchers do not design them, environments will provide them nevertheless.

In this chapter, we focus on how basic and translational research can inform the arrangement of reinforcement contingencies in applied settings. We have restricted our discussion to findings that have found their way into applied arenas in the sense that they have been used to some benefit in arranging practical contingencies or have been replicated with clinical populations. Many other chapters in this handbook are directly concerned with basic and translational research related to arranging reinforcement contingencies (see, e.g., Chapters 5, 7, and 8, this volume). We have tried not to tread too far into areas discussed in greater detail elsewhere in this handbook. Programmed reinforcement contingencies are probably nowhere more common than in arranging instructional contexts for children and for individuals with developmental disabilities, so much of our discussion focuses on these sorts of instructional arrangements.

The chapter is organized into four interrelated sections. Our emphasis is on best practices for applying reinforcement contingencies given what we know from basic research. Consider an educator thinking about how to arrange a reinforcement system in a given context. That individual has numerous decisions to make, including what reinforcer to use and what behavior or aspect of behavior to reinforce, according to what arrangement. Each question corresponds to a term of the three-term contingency or to relations among those terms, and each forms a section of this chapter.

The three-term contingency consists of antecedents, behavior, and consequences. Each term is worthy of consideration. Those antecedents called *discriminative stimuli* are treated in other chapters, so we consider them here only in passing. More crucial to our concerns are (a) the contingencies themselves, often characterized as schedules of reinforcement; (b) the responses targeted by the contingencies; (c) the reinforcers or other consequences arranged for them; and (d) the antecedents, sometimes called *motivational* or *establishing,* that change the effectiveness of consequences as reinforcers or punishers.

Our hypothetical educator may harbor concerns about possible harm stemming from the planned contingency and distress over the possibility that the planned contingency will fail to produce its anticipated outcome. For example, a consequence expected to serve as a reinforcer may instead function as a punisher, or it may not be effective because its application deviated in some way from the planned contingency. Some instances may best be

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understood in terms of deviations from well-established procedures (as in so-called detrimental effects of reward, discussed later in some detail; see also Cameron, Banko, & Pierce, 2001). We examine these and other ways in which reinforcement contingencies can seem to have effects opposite to those intended.

THE CONTINGENCIES: WHICH SCHEDULE SHOULD ONE USE?

A stimulus serves as a reinforcer if, when access to this stimulus is contingent on a response within some class (usually called an *operant class*), responses within that class become more probable because of the contingent production of the stimulus (Skinner, 1938, 1981). The term *reinforcer* identifies a member of such a stimulus class; the term *reinforcement* identifies either the contingency (e.g., "reinforcement was arranged for the child's correct responses") or the changes in behavior produced by the contingency ("reinforcement was demonstrated by the increase in the child's correct responses"). In specifying the reinforcement contingencies for an organism's behavior, researchers must include the context in which the behavior occurred, the operant class involved in the contingency, and the changes in responding that depend on the contingent production of the reinforcer (Ferster & Skinner, 1957). The temporal and behavioral conditions under which reinforcers are delivered have been called *schedules of reinforcement*.

Some Basic Schedules

The simplest arrangement is to reinforce every response; paradoxically, arranging a discrete consequence for each discrete response is sometimes called *continuous reinforcement*. However, both within and outside the laboratory, it is unusual for every response to be reinforced. Environments vary along many dimensions that often make reinforcers only intermittently available. These dimensions determine schedules of reinforcement and include but are not limited to the number of responses, the time when responses are emitted, and the passage of time without responses. We can review only a few basic schedule arrangements in this chapter. The interested reader will find more exhaustive treatments in Ferster and Skinner (1957) and Lattal (1991).

Classifications of schedules often break them down in terms of whether they are based on number of responses (ratio schedules) or on when responses occur (interval schedules), but these are only two of several categories we discuss. For example, reinforcers can be delivered without reference to behavior (e.g., time schedules) or on the basis of temporal spacing of responses (e.g., differential reinforcement of low rates or of high rates). Schedules can also combine different contingencies (as in alternative schedules, in which a reinforcer is delivered if responding satisfies either of two conditions). Table 3.1 summarizes the properties of some basic schedules.

Ratio Schedules

Fixed-ratio schedules. When every response produces a reinforcer in continuous reinforcement, the ratio of responses to reinforcers is fixed and equal to 1; this is a fixed-ratio (FR) 1 schedule. FR schedules deliver a reinforcer after the last of a fixed number of responses. In studies with nonhumans, FR schedules produce responding characterized by a pause at the start of each ratio (i.e., after the prior reinforcer) followed by rapid and fairly constant responding (Capehart, Eckerman, Guilkey, & Shull, 1980; Crossman, Bonem, & Phelps, 1987). The pause typically becomes longer with increases in ratio size (Crossman, 1968) and with increases in alternative sources of reinforcement (Derenne & Baron, 2002).

Overall response rate typically decreases as the FR becomes larger and as responding decreases reinforcers are delivered less often (but see Chapter 8, this volume, for a discussion of a different relation when responding within the current environment is the only source of the reinforcer). These relations are useful in assessing the effectiveness of reinforcers and in developing appropriate treatments. For example, one way to deal with problem behavior once the reinforcers that maintain it have been identified is to increase the amount of behavior required per reinforcer, thereby decreasing response rate and making more socially appropriate responses reinforced on denser schedules more likely. Another way would be to change response allocation by

TABLE 3.1

Basic Schedules

Name and abbreviation	Contingency	Comment
Variable interval (VI); random interval (RI)	*t* seconds, then 1 response	*t* varies; with random intervals, response rate is roughly constant.
Fixed interval (FI)	*t* seconds, then 1 response	*t* constant; generates increasing rates within intervals (scallops).
Variable ratio (VR); random ratio (RR)	*n* responses	*n* varies; high constant rates; large *n* may produce response breaks (strain).
Fixed ratio (FR)	*n* responses	*n* constant; generates postreinforcer pauses and high-rate runs.
Variable time (VT)	*t* seconds	*t* varies; response-independent reinforcers
Fixed time (FT)	*t* seconds	*t* constant; response-independent reinforcers
Continuous reinforcement (FR 1)	1 response	all responses reinforced; sometimes abbreviated *CRF*
Extinction (EXT)	—	Useful term for nonreinforcement even if the response has never been reinforced.
Limited hold (LH)	Reinforcer cancelled if no reinforced response within *t* seconds.	*t* constant if not otherwise specified; LH added to other schedules, cannot stand alone.
Differential reinforcement		
Of low rate (DRL)	*t* seconds without response, then one response	Maintains responding well because slower responding increases reinforcement.
Of high rate (DRH)	1 response within *t* seconds or less of last response	Alternatively, at least *n* responses within *t* s; hard to maintain because reinforcers stop when responding slows.
Of paced responding (DRP)	1 response between *t* and *t′* seconds of last response	Sets both upper and lower limits on response rates that can be reinforced.
Of other or alternative behavior (DRO or DRA)	*t* seconds without a response	Usually decreases rate of designated response (a negative punishment procedure).

Note. *t* = time. From *Learning* (4th interim ed., Table 10-1), by A. C. Catania, 2007, Cornwall-on-Hudson, NY: Sloan. Copyright 2007 by Sloan Publishing. Adapted with permission.

reducing the required ratio for more socially appropriate alternatives.

Variable-ratio schedules. Variable-ratio (VR) schedules arrange reinforcers for the last of a number of responses that vary from one reinforcer to the next. These schedules characteristically produce high response rates without the postreinforcement pauses seen with FR schedules. A VR schedule is often described in terms of the average ratio, but the particular ratios can make a difference. For example, a VR schedule that involves many short ratios balanced by a few very long ones may support more behavior than one with only a few short ratios balanced by many moderately long ones, even though both have the same mean ratio value.

In laboratory settings, such details can readily be automated, but arranging them in applied settings is often impractical. In general, the advantage of VR over FR schedules is that VR schedules are less likely to produce postreinforcement pauses (Andrzejewski, Field, & Hineline, 2001; Crossman et al., 1987; Mazur, 1983; Schlinger, Blakely, & Kaczor, 1990). Specifying the distribution of the ratios that make up a particular mean VR is important, but the effects of different distributions are likely to be seen only with extended exposure to the schedule. A simple arrangement is to generate a list of integers in an arithmetic progression (e.g., 2, 4, 6, 8, 10, . . .) in which the difference between the values is constant and to then shuffle items in the list. A VR 2 schedule consisting of just three ratios,

1, 2, and 3, qualifies as such a schedule and for some applications may be perfectly adequate (e.g., Foster, Hackenberg, & Vaidya, 2001). With VR schedules based on arithmetic distributions, reinforcement probability increases over successive responses within a ratio, eventually reaching 1.0 for the largest value. To compensate for this, VR progressions can be generated so as to approximate a constant probability distribution (see Catania & Reynolds, 1968; Fleshler & Hoffman, 1962), but contemporary technology often makes random scheduling of ratios more practical. Random-ratio (RR) schedules are a subcategory of VR schedules in which the probability with which a response will be reinforced remains constant over successive responses. Although its mean value can be specified, the maximum ratio value is indeterminate (Sidley & Schoenfeld, 1964). These schedules eschew preset ratios in favor of letting a random generator determine whether the current response should be reinforced; the mean ratio is given by the reciprocal of the probability (e.g., reinforcing responses with a probability of .05 generate an RR 20 schedule). Arranging an RR schedule outside the laboratory is as simple as rolling a die. For example, a six-sided die arranges RR 6 if a response is reinforced whenever the die roll results in a 6. Game stores sell many different-sided dice, ranging from four sides to 100.

Interval Schedules

Fixed-interval schedules. A fixed-interval (FI) schedule delivers a reinforcer contingent on the first response after some constant time period has elapsed. An FI schedule generates positively accelerated response patterns (i.e., the response rate increases as time passes within the interval, producing a visual pattern generated by cumulative records that is sometimes called *scalloping*; Ferster & Skinner, 1957). Pauses after reinforcement and the pattern of responding over time in the interval depend on the duration of the FI (e.g., Capehart et al., 1980). Prolonged exposure to an FI schedule sometimes produces pauses followed by high rates. Because responding is sensitive to time within the interval, FI schedules have often served as baselines for studying temporal discrimination (e.g., Machado, Malheiro, & Erlhagen, 2009).

Variable-interval schedules. Variable-interval (VI) schedules similarly arrange reinforcers contingent on the first response after a specified time, but the time varies from one reinforcer to the next, and these schedules generally produce moderate and relatively stable rates of responding with few pauses. The function relating response rate to VI reinforcement rate is negatively accelerated, that is, the higher the reinforcement rate is, the smaller the increment in response rate produced by a given added increment in reinforcement rate will be. Similar to VR schedules, VI schedules are identified by mean interval. They have been widely used in behavioral research because variables that affect response rate (e.g., drug administration) produce relatively small changes in the rate at which reinforcers are delivered.

As with VR schedules, the distribution of intervals can be generated in different ways. This distribution can affect VI responding, so it should be selected with care (Catania & Reynolds, 1968). For example, increasing shorter intervals relative to moderate ones will make response rates soon after the last reinforcer higher than at those occurring at later times. With a finite distribution of intervals, the probability that a response will be reinforced increases as time passes in the interval. The Fleshler and Hoffman (1962) formula for approximating a constant probability distribution is one way to address this concern, but the variant known as random interval (RI) avoids the problem because no longest interval can be specified (Millenson, 1963). In RI schedules, reinforcers are arranged (or set up) by repeatedly sampling probabilities (e.g., every 10th of a second). Even with low probabilities, the probability that a reinforcer has been set up grows as time passes without a response. The mean time between reinforcers is determined by the ratio t/p, where t is the cycle duration and p is the probability; for example, a sampling probability of .005 with cycles of 0.1 seconds will yield VI 20 seconds.

Arranging Schedules for Human Behavior: Some Caveats

Basic research on reinforcement schedules has typically been conducted with readily repeated responses of brief duration, such as pigeons' key

pecks or rats' lever presses. These responses are free operant in the sense that they are unconstrained except by the contingencies that maintain them. The organism is not removed from the situation between responses, nor is the opportunity to respond constrained by removing relevant stimuli, as in procedures based on discrete trials. Only some applied settings allow comparable contingencies. Laboratory procedures may maintain schedule contingencies over extended durations and many thousands of responses, whereas applied interventions are typically more limited in scope. Getting dressed, grooming oneself, toileting, or completing an arithmetic problem all take time, and these and many other tasks intrinsically involve trials or quasitrials. Expecting contingencies arranged for such complex response classes to produce effects similar to those seen in the research laboratory is therefore often unrealistic. Furthermore, the feasible range of schedule parameters in applied settings is typically much narrower than that explored with nonhuman organisms.

Another problem with extrapolating from basic schedule research with nonhumans to human behavior is that humans engage in verbal behavior. The contingencies involved in maintaining verbal behavior, especially verbal behavior that involves descriptions of one's own behavior, interact with nonverbal behavior in complex ways, especially because verbal behavior itself is also subject to contingencies. Thus, human performances maintained by schedules often look very different from nonhuman performances maintained by equivalent schedules (e.g., Catania, Lowe, & Horne, 1990; Catania, Matthews, & Shimoff, 1982; Shimoff & Catania, 1998). A detailed account is beyond the scope of this chapter, but it is reasonable to say that in verbally competent humans (children perhaps as young as 5 years as well as adults), it is often easier to shape verbal behavior related to performance than to directly shape the performance itself.

Other Schedules With Applied Relevance

Along with the fundamental ratio and interval cases, basic researchers have examined performances under an enormous variety of alternative and combined schedule arrangements. Many complex schedules have yet to be used in applied work, but descriptions of these schedules can be found in Table 3.2. We consider a few cases with established utility in applied settings, either as direct arrangements of applied reinforcement contingencies or as tools for the analysis of applications, with others introduced elsewhere when relevant.

Differential reinforcement schedules. Differential reinforcement simply means that some responses are reinforced and others are not. Differential reinforcement can target various properties of response classes, including topography, temporal parameters (e.g., response duration), magnitude, and so forth. In applied settings, differential reinforcement is perhaps most common in shaping (see Shaping and Percentile Schedules section) and in treating problem behavior. Some varieties of differential reinforcement are used to reduce problem behavior. Differential reinforcement of zero or other behavior (DRO) targets the absence of responding or unspecified alternative responding by delivering reinforcers after some time without a response. Differential reinforcement of low rate (DRL) and differential reinforcement of high rate (DRH) target responses based on temporal parameters (Staddon, 1965). In DRL schedules, a response is reinforced only if a minimum time has passed since the last response (the interresponse time). These schedules maintain responding at a low rate, which is useful, for example, when responding occurs under appropriate conditions but needs to be slowed down (e.g., as in overly rapid eating; Wright & Vollmer, 2002). In DRH schedules, a response is reinforced if a minimum number of responses is emitted within a given time (e.g., within the past *t* seconds), thus ensuring that responding persists at a pace not otherwise sustained in the absence of the contingency. This is useful, for example, when responding occurs under appropriate conditions but too slowly (e.g., as in excessively slow eating; Girolami, Kahng, Hilker, & Girolami, 2009).

Differential reinforcement of alternative behavior reinforces members of one response class while extinguishing responses outside that class. In contrast to DRO, DRA reinforces a specific alternative response rather than just any other response,

TABLE 3.2

Schedule Combinations

Schedule	Definition	Example
Multiple	A during S^A alternates with B during S^B.	mult VI EXT: VI (A) during red (S^A) alternates with EXT (B) during green (S^B).
Mixed	A and B alternate but without correlated stimuli.	mix DRL FI: DRL (A) alternates with FI (B), both during blue.
Chained	During S^A, completing A produces S^B; during S^B, completing B produces reinforcer.	chain VR FR: completing VR (A) during blue (S^A) produces yellow; completing FR (B) during yellow (S^B) produces food.
Tandem	Without correlated stimuli, completing A produces B and completing B produces reinforcer.	tand VR DRH: Completing VR (A) produces DRH (B), and completing DRH produces food, both during yellow.
Concurrent	A operates for one response; B operates for another response.	conc VI VI: One VI (A) operates for presses on left button; another VI (B) operates for presses on right button.
Conjoint	A and B operate at the same time but independently for a single response (as with concurrent schedules but without different responses).	conjt VI avoidance: VI (A) and avoidance (B) operate simultaneously for presses on a single key.
Second order	Completing A is reinforced according to B (reinforcing the second-order schedule according to C creates third-order schedule, etc.).	FI (FR): Successive FRs (A) are treated as response units reinforced according to an FI schedule (B).
Alternative	Reinforcer depends on completing either A or B.	altern VR VI: Responding is reinforced on satisfying either VR (A) or VI (B) contingency, whichever occurs first.
Conjunctive	Reinforcer depends on completing both A and B.	conjunc FR FI: Responding is reinforced on satisfying both FR (A) and FI (B) contingencies.
Interlocking	Reinforcer depends on completing some combined function of A and B.	interl FR FT: Responding is reinforced when the sum of responses (A) plus elapsed seconds (B) reaches some constant value.
Progressive	Some schedule parameter changes systematically over successive reinforcers or blocks of reinforcers.	progressive FI: After every *n*th reinforcer, time in seconds is added to the value of an FI.

Note. For convenience, we define each case in terms of just two arbitrary component schedules, A and B, but combinations can include any number of components. S = stimuli; superscripts identify the schedule, A or B, each one accompanies. DRH = differential reinforcement of high rate; DRL = differential reinforcement of low rate; EXT = extinction; FI = fixed interval; FR = fixed ratio; VI = variable interval; VR = variable ratio. From *Learning* (4th interim ed., Table 11-1), by A. C. Catania, 2007, Cornwall-on-Hudson, NY: Sloan. Copyright 2007 by Sloan Publishing. Adapted with permission.

thereby increasing the rate of some responses while reducing that of others. For example, if problem behavior is maintained by a certain class of reinforcers, therapists can establish and strengthen a more appropriate response that produces that same reinforcer. Differential reinforcement in the treatment of problem behavior is discussed in Chapter 14 (this volume), so we consider such schedules only when relevant. A special case of differential reinforcement called *shaping* (of successive approximations to some target response) is described in more detail later.

Response-independent (time-based) schedules. Fixed-time (FT) and variable-time (VT) schedules deliver stimuli known in other contexts to be reinforcers solely on the basis of time, independent of responding. Technically speaking, FT and VT are not reinforcement schedules at all, in that they do not arrange reinforcers contingent on responding. For a stimulus to be considered a reinforcer, it must increase the responding on which it is contingent. The stimuli typically chosen in FT and VT schedules, however, are those previously shown to be effective reinforcers (Lattal, 1972; Zeiler, 1968).

FT and VT schedules are useful for studying the variables that reduce response probability when a response contingency is weakened. For example, Madden and Perone (2003) superimposed FT schedules onto ongoing VI schedules, thus weakening

the contingency between the target responses (moving a joystick) and delivery of the reinforcers (points later exchangeable for money). They observed that target responses declined relative to when the responses were maintained on the VI schedules alone or when the supplemental reinforcers were delivered only immediately after the target responses. These schedules are easy to implement and reduce response probability without removing access to reinforcers, so they have become commonplace in applied studies and clinical practice for treating problem behavior. Time-based schedules obviate difficulties associated with other forms of intervention. For example, when problem behavior is reduced by FT schedules, it is not accompanied by the extinction bursts that sometimes accompany extinction in isolation (Vollmer et al., 1998; although note that time-based schedules may enhance response persistence if they increase the overall rate of reinforcement under given conditions; see Nevin, Tota, Torquato, & Shull, 1990; Chapter 5, this volume). Time schedules have also provided baselines against which to assess effects of other contingencies. Because they involve reinforcer delivery but no response–reinforcer contingency, they are useful in separating effects of the contingency from effects of mere reinforcer presentations (Rescorla & Skucy, 1969; see also Thompson, Iwata, Hanley, Dozier, & Samaha, 2003, on the relative utility of time-based and other schedules as control procedures in applied settings).

Concurrent schedules. Schedules are called *concurrent* when two or more operate simultaneously and independently for different response classes (e.g., consider the different contingencies operating for presses on a doorbell button and those on a nearby elevator button). Concurrent schedules, essential to studies of choice and relative response allocation (Fantino & Romanowich, 2007; Fisher & Mazur, 1997; Herrnstein, 1961; Reynolds, 1963), have often been used in applied settings to gauge the relative effectiveness of reinforcers varying along dimensions such as rate, quality, and magnitude. We couch our discussions of preferences and the effectiveness of reinforcers in terms of response allocation under concurrent schedules.

Delay Contingencies

Reinforcement contingencies are most effective when reinforcers are delivered promptly after target responses, but within limits delayed reinforcers also sustain responding. In fact, earlier responses that preceded the reinforced response usually also participate in the effects of the reinforcer. Analyses in terms of delay contingencies can therefore reveal important properties of schedules. Much of the terminology of reinforcement schedules was developed ad hoc as different contingencies were invented and explored experimentally (Skinner, 1938, 1956), and other systems were developed to organize schedules more systematically (e.g., Schoenfeld & Cole, 1972). It may be most appropriate, however, to categorize schedules not on the basis of their formal properties but rather in terms of interactions between responses and contingencies as schedules take hold of behavior.

When a reinforcer follows a response, its effect depends on its relation not only to that response but also to other responses preceding it; all are followed by the reinforcer even though only the last response produced it and even though the delay between response and reinforcer is longer for earlier than for later ones (Catania, 1971; Dews, 1962; see Catania, 2005, for a theoretical treatment). Such relations are important in applied as well as basic settings, especially when inappropriate as well as appropriate responses can follow each other closely in time. For example, according to this analysis if an error is immediately followed by a reinforced correct response in an instructional procedure, that reinforcer will probably strengthen the error along with the correct response at least temporarily.

Consider how the delayed reinforcement of earlier responses within a reinforced sequence affects the interaction between responses and reinforcers. When reinforcers depend on number of responses, the responses per reinforcer remain constant, but increased response rate will mean that all responses are more closely followed by the reinforcer (shorter delays); these shorter delays will strengthen responding still further and so lead to higher and higher response rates. When reinforcers depend on a response at the end of a given interval, however, the time to the reinforcer remains constant, which

means that if response rate increases, the responses per reinforcer will also increase. At the same time, some responses late in the interval will be closer to the reinforcer, but earlier ones will still be far from it (long delays). The strengthening effects of the reinforcer will be balanced by its increasing cost and will therefore lead to more moderate rather than higher response rates. These dynamics are described in more detail in Catania (2005).

Other aspects of delayed reinforcement merit attention. Mathematical models of self-control describe how delay influences reinforcer effectiveness (Grace, 1999; Mazur, 1987), which generally decreases monotonically as delay increases. Candidate delay functions include hyperbolic and exponential decay, for which best fits depend on both data and such details as how reinforcer effectiveness is measured (see Volume 1, Chapter 14, this handbook; Chapters 7 and 8, this volume). Within some range of delays, delayed reinforcers can maintain responding in both humans and nonhumans (e.g., 30 seconds in both Okouchi, 2009, and Lattal & Gleeson, 1990). Contingencies operating across delays may also explain why some interventions seem ineffective despite being well constructed. For example, a 5-second DRO contingency may strengthen responses other than the target response, but if the target response often occurs just 6 seconds before reinforcer delivery, it may be maintained by delayed reinforcement.

Schedule Contingencies and Resistance of Behavior to Change

Schedule contingencies not only determine the rate at which target responses are maintained, to the extent that they also produce different rates of reinforcement, they may also determine response fragility or resistance to change (Nevin & Grace, 2000; see also Chapter 5, this volume). These two measures, response rate and resistance of responding to change, are independent properties of behavior. Depending on schedules and other variables, some high response rates can be very fragile (as in rapid extinction after very large FRs), whereas some low rates can be extremely persistent (as in extended extinction responding after DRL reinforcement). Resistance to disruption by procedural changes is a property of behavior revealed not only during extinction but also during other interventions, such as introducing reinforcers for alternative responses.

Some properties of schedule contingencies themselves, along with such dimensions as reinforcer magnitude, length of exposure to a schedule, and motivational variables, may determine resistance to change. For example, if a ratio schedule maintains high response rates and rates decrease for any reason (e.g., a minor beak injury in a pigeon), reinforcers will be produced less often, thus reducing response rates still further and satisfying the contingency less often still, and so on. Nevertheless, ratio responding might recover because responses will eventually produce reinforcers in ratio schedules even if they are emitted slowly. With DRH, slow responding never produces reinforcers, so responding may not recover at all after a period of slow responding. With interval schedules, however, reinforcers become available at particular intervals, so changes in response rate over a large range may only slightly affect how often reinforcers are delivered. Thus, more stable responding tends to be maintained by interval schedules rather than by ratio schedules. With DRL, reinforcers depend on a response preceded by some minimum time without responding, so reinforcers are typically produced more often as response rate decreases, making DRL responding durable over time (Ferster & Skinner, 1957).

THE RESPONSE: WHAT RESPONSE SHOULD ONE REINFORCE?

Agents responsible for arranging reinforcement contingencies generally enter the instructional context with an idea of which response class they want to strengthen. Those response classes, however, may vary in terms of how well established they are, ranging from not at all established to fully established but unmotivated. How then does one determine whether the lack of responding is a skills deficit (the individual simply has not learned the skill) or a performance deficit (the skill is intact, but the person is unmotivated to respond under appropriate stimulus conditions)? Performance deficits can be accurately distinguished from skills deficits in an educational

context on the basis of whether supplemental reinforcement for correct responding rapidly increases accuracy (Lerman, Vorndran, Addison, & Kuhn, 2004). If an appropriate reinforcement contingency very rapidly eliminates a performance deficit, the skill must already have been learned. Skills deficits, however, may require different interventions depending on the learner's abilities and whether some of the skill has already been learned.

Shaping and Percentile Schedules

In shaping, some property of responding is gradually changed by differentially reinforcing successive approximations to target behavior (Catania, 2007; Skinner, 1951). Shaping is used when target responses are sufficiently complex or of sufficiently low probability that they are unlikely to be emitted without this gradual intervention. Numerous instances in the applied behavior-analytic literature involve a great variety of response properties (e.g., voice volume, Fleece et al.,1981; drug abstinence, Dallery & Glenn, 2005; communication responses, Lerman, Kelley, Vorndran, Kuhn, & LaRue, 2002).

In practice, shaping is often (and properly) viewed as an art form (Lattal & Neef, 1996), mastered only by those who have had many opportunities to try it. Shaping is often contingency shaped, in the sense that the most effective shaping typically arises from the shaper's substantial experience with shaping rather than from learning some specific set of rules (Galbicka, 1994). One sometimes overlooked contribution of basic research to shaping is the percentile schedule, used as a systematic way to decide which approximations to reinforce and how often to do so. Percentile schedules deconstruct shaping into its components by specifying changes in reinforcement criteria (e.g., based on latency, effort, location, or duration) as behavior moves toward the shaping target (Galbicka, 1994). To begin, some sample of behavior is collected (e.g., the last 100 responses). The behavior analyst then specifies that to be reinforced, the next response must fall into some portion of the sampled distribution (e.g., above the 70th percentile). For example, in the shaping of more fluent reading of words on a computer screen, the next correct reading would be reinforced only if its speed (1 per latency) exceeded the speed at the 70th percentile of the last 100 speeds sampled. After this reading is reinforced (or not), its speed is added to the sample, and the oldest one in the distribution is dropped. Thus, the reinforcement criterion changes as progress is made toward the target. This elegant approach to shaping also allows the behavior analyst to specify reinforcement probability in advance throughout shaping. In this example, the probability that the next response will exceed the 70th percentile value and therefore be reinforced is roughly 30%.

Although easily managed with computer programs in a laboratory, percentile schedules demand moment-to-moment analysis of data and so are often impractical in applications. Nevertheless, their effects can be approximated by some rules of thumb, such as mainly reinforcing responses closer to the target than any others emitted so far. Such rules must be tempered. The skilled shaper, for example, relaxes that rule if many responses have been unreinforced, so as not to jeopardize the progress so far with de facto extinction.

Clinically and educationally relevant responses have been shaped with percentile schedules, such as increased durations of work on academic tasks, with percentile criteria based on the preceding 20 task engagements (Athens, Vollmer, & St. Peter Pipkin, 2007), and longer durations of eye contact for participants diagnosed with fragile X syndrome, with a percentile schedule based on just the three immediately preceding responses (S. S. Hall, Maynes, & Reiss, 2009).

Novel Responding and Response Diversity

Shaping often hones response topography by differentially reinforcing increasingly narrow forms of the response. Ultimately, response diversity decreases. Paradoxically, shaping appears to work because the extinction component of shaping increases response variability (see Neuringer, Kornell, & Olufs, 2001), thereby permitting novel response forms to contact reinforcement. Applied researchers have taken advantage of the variability induced by extinction to establish such new behavior as untrained topographies of toy play (e.g., Lalli, Zanolli, & Wohn, 1994).

Response diversity has become increasingly important in the study and practice of behavior analysis through the prominent and widespread use

of behavior-analytic principles and procedures in early intervention for autism spectrum disorders (see Chapter 12, this volume). A core diagnostic symptom of autism spectrum disorders is restricted and repetitive behavior, characterized by "stereotyped patterns of behavior, interests and activities" (American Psychiatric Association, 2000, p. 71). As has long been understood, variability is a property of responding sensitive to reinforcement (Page & Neuringer, 1985; see Volume 1, Chapter 22, this handbook, for an extended treatment). A common arrangement to increase response variability is a type of percentile schedule called the *lag-reinforcement schedule*. The lag is the number of responses separating the current response from an earlier one like it. For example, repeatedly playing the same note on a piano is highly stereotyped because zero different notes are played between the most recent note and the prior one (lag 0). However, playing 10 different notes before getting back to the first one (lag 10) is much more variable. In a lag *x* reinforcement schedule, the current response is reinforced if it differs from the last *x* preceding responses along the specified dimension. The variability of pigeons' sequences of key pecks was maintained with variability requirements as stringent as lag 50 (Page & Neuringer, 1985).

As with percentile schedules in general, lag reinforcement schedules have increasingly been used in applied contexts to increase diversity in a variety of response classes, including toy play such as building block structures (Napolitano, Smith, Zarcone, Goodkin, & McAdam, 2010), verbal responses to social questions (Lee, McComas, & Jawor, 2002; Lee & Sturmey, 2006), and selection of classroom activities (Cammilleri & Hanley, 2005). Applied studies typically use lag requirements that are fairly easy to meet, including lag 1 schedules, in which reinforcement is contingent on a response that differs only from the immediately preceding one (Lee & Sturmey, 2006). Even with such minimal lag contingencies, novel responding and creativity can be enhanced through differential reinforcement.

Reinforcement Within Prompted Response Sequences

"Pure" shaping of entirely novel responses, or shaping without prompts, may be relatively uncommon in applied settings. When skills deficits are apparent, instructional or motivational strategies will often involve some verbal instruction and prompting with regard to the target. For example, in what is often termed *least-to-most prompting,* the instructor delivers verbal instruction on the correct response (e.g., "Turn the handle to the left") followed by modeling a correct response. If these fail to evoke correct behavior, they are often followed by physical guidance in completing of the response. Such sequences raise the question of where in the sequence the reinforcer should be delivered. If only unprompted correct responses are reinforced, the instructor risks delivering infrequent reinforcers, because unprompted correct responses are rare. At the other extreme, reinforcing responses that are correct only because they have been physically guided risk strengthening behavior that will not generalize beyond the learning setting because it consists only of passive compliance with prompts.

Applied researchers have approached this issue by varying the reinforcement delivered after prompted versus unprompted responses. For example, during nondifferential reinforcement within instructional trials, both praise and high-quality food reinforcers were contingent on either prompted or unprompted responses (Karsten & Carr, 2009). During differential reinforcement, when praise alone was contingent on prompted responses, whereas high-quality food reinforcers were contingent on unprompted responses, unprompted responding generally increased. When independent accurate responding is promoted by arranging higher reinforcement rates for independent than for prompted responses (e.g., Olenick & Pear, 1980; Touchette & Howard, 1984), independent responding is more rapidly acquired, and prompts can be minimized or made less intrusive (see a review by Vladescu & Kodak, 2010).

So-Called Hidden Costs of Reward

Perhaps the most vehemently debated aspect of reinforcement has its source in the social psychology literature on the so-called hidden costs of reward, also referred to as the *overjustification effect* or the *detrimental effect of extrinsic reward on intrinsic motivation* (Lepper, Greene, & Nisbett, 1973). Some of

these critics have cautioned educators against using reinforcement, suggesting that it reduces creativity and intrinsic motivation (e.g., Kohn, 1993; Pink, 2009). For example, if someone who enjoys completing puzzles for their own sake receives extrinsic rewards for doing so, the claim is that the intrinsic interest in completing puzzles will decline once the extrinsic reward is withdrawn (Deci, 1971; Greene & Lepper, 1974). These accounts are based on research that has shown variable and inconsistent effects, typically of small magnitude (Cameron et al., 2001; Cameron & Pierce, 1994; Eisenberger & Cameron, 1996). That has not dissuaded its proponents from citing it in support of arguments against reinforcement and other behavior-analytic tools.

An intrinsic reward is naturally related to the responses that produce it, whereas an extrinsic one is arbitrarily related to them (e.g., music is an intrinsic outcome of playing an instrument; the music teacher's praise is extrinsic to the playing). Events presumed to be effective reinforcers because their function has been instructed have been called *extrinsic reinforcers* (as when a child is told it is important to earn good grades), but labeling them is no guarantee they will be effective. This matters because the literature on the detrimental effects of extrinsic reward rarely includes studies using reinforcement as defined in behavior analysis. Often, the rewards are not delivered contingent on the relevant behavior, and no evidence shows that their delivery increases responding (see Dickinson, 1989). Nonetheless, despite much contrary evidence, the argument that extrinsic outcomes undermine the effectiveness of intrinsic ones persists and still affects the use of operant contingencies in schools and other settings (Cameron et al., 2001; Cameron & Pierce, 1994; Eisenberger & Cameron, 1996). Here we merely point out why the issue is irrelevant to our applied concerns.

One fairly consistent finding is that overjustification effects are more pronounced when behavior already occurs at a high level without extrinsic reward (Cameron et al., 2001; Deci, Koestner, & Ryan, 1999). These findings are significant because applied behavior analysts do not ordinarily design interventions to deliver reinforcers contingent on behavior that already occurs frequently. In fact, arranging such contingencies may well reduce responding, even during reinforcement, let alone during a postreinforcement period. The initial conclusion might be that the stimulus is not a reinforcer, but this reduction in responding might happen for many reasons even though the stimulus may be effective as a reinforcer under other circumstances. For example, when intrinsic outcomes are powerful, separate and less preferred added reinforcers may interfere with the effectiveness of the original reinforcer (Roane, Fisher, & McDonough, 2003). Alternatively, the delivery of some reinforcers may require time and effort (handling costs; Madden, Bickel, & Jacobs, 2000) in preparing them for consumption or, through the discriminative property of reinforcers, may evoke other responses that interrupt or are incompatible with the behavior being measured (Frank-Crawford et al., 2012). Either process can decrease responding relative to responding in situations in which it is uninterrupted by reinforcer delivery.

Another issue is equating reinforcers with bribes in the literature on hidden costs of reward (Kohn, 1993), but the bribes invoked by critics of the practice of reinforcement seldom involve direct effects of reinforcers. There are good reasons to advise parents against specifying consequences when asking a child to do something (e.g., "Put away your toys and you can play a computer game"), but those reasons are different from those offered by the critics. When parents complain that their child only cooperates with requests when there is an immediate and explicit payoff, stimulus control is the problem: The child has learned to comply only when the parent makes an adequate offer.

A bribe specifies behavior and its consequences, so offers of bribes set the occasion for particular contingencies. The frequently bribed child soon discriminates between bribes being in effect and bribes not being in effect. The bribing parent will eventually discover that the child complies only when bribes are offered. If initiation rests with the briber, one should not expect the child to initiate appropriate behavior. In such cases, reinforcement merely strengthens compliance with bribes, which is hardly a desirable way to use reinforcers. The parent who has heard the language of bribes applied to the

practice of reinforcement and is reluctant to reinforce a child's appropriate behavior must learn not to accompany the contingencies with statements of those contingencies (which is probably also good advice for teachers and clinicians).

The claimed deleterious effects of extrinsic reward are only inconsistently demonstrable and are small and transient when found (Cameron et al., 2001; Cameron & Pierce, 1994); problems are more likely when extrinsic rewards are not contingent on performance than when they are (Eisenberger & Cameron, 1996). The alternative, to forgo reinforcers in cases in which no intrinsic reinforcers maintain the behavior of concern, is unacceptable. To assume that students with limited skills will work effectively without positive outcomes is irresponsible (Heward, 2005). Extrinsic reinforcers can build behavior that will allow students to contact the natural contingencies generated by successful performance.

THE REINFORCER: WHICH REINFORCER SHOULD ONE CHOOSE?

In clinical interventions, the aspect of reinforcement contingencies perhaps least informed by basic research is that of which stimulus will be delivered contingent on the target behavior. Basic research has used varied stimuli shown to have reinforcing effects, including water, food, heat, access to females, escape from time out, electrical brain stimulation, and all manner of pharmacological agents (Crawford, Holloway, & Domjan, 1993; Jenkins & Moore, 1973; Katz, 1979; Wasserman, Hunter, Gutowski, & Bader, 1975). The sustained value of food and other primary reinforcers is ensured by such operations as maintaining an organism at 80% of its free-feeding weight; such motivating operations cannot be used with humans in most applied settings.

The effectiveness of a reinforcer depends on the behavior allowed or occasioned by that reinforcer. Food, for example, allows eating, and food deprivation affects the effectiveness of a food reinforcer by raising the probability of eating given food. In general, a particular consequence serves as a reinforcer if the behavior it occasions is restricted below its baseline rate (Timberlake & Allison, 1974). Furthermore, its effectiveness varies with the probability of the to-be-reinforced response relative to the response occasioned by the reinforcer. For example, whether a rat's eating will be reinforced by an opportunity to run on a wheel or wheel running will be reinforced by an opportunity to eat can be determined by varying the relative probabilities of wheel running or eating by depriving the organism of access to, respectively, a wheel or food.

Implementing the motivational antecedents that will make a stimulus reinforcing is often impracticable in applied settings. Much effort has therefore been expended to develop, refine, and validate methods for predicting which stimuli will function as reinforcers. These methods are reviewed extensively elsewhere (e.g., Cannella, O'Reilly, & Lancioni, 2005; Hagopian, Long, & Rush, 2004; Logan & Gast, 2001), so in what follows we provide only a brief overview of some procedures. Later, we describe a potential model for efficiently and effectively selecting reinforcers.

Preference and Reinforcer Assessment

Preference assessment. Procedures to identify items that may serve as effective reinforcers involve multiple steps, often starting with nominations from the people themselves or, when individuals may not be reliable self-informants, perhaps because of limited abilities, from parents, teachers, or other caregivers. With several instruments, surveys, and checklists developed for this purpose (e.g., Fisher, Piazza, Bowman, & Amari, 1996; Sarafino & Graham, 2006), the process could end here, but teachers, caregivers, and students (with or without disabilities) are not always accurate in suggesting which stimuli will function effectively as reinforcers (Cote, Thompson, Hanley, & McKerchar, 2007; Green et al., 1988; Northup, 2000). Thus, the next step is often to assess preferences among items systematically with a stimulus preference assessment. Such assessments may repeatedly present an entire array of items simultaneously (DeLeon & Iwata, 1996; Windsor, Piche, & Locke, 1994), or they may present the items one at a time (e.g., Pace, Ivancic, Edwards, Iwata, & Page, 1985) or in pairs (Fisher et al., 1992).

The most selected items are then taken as those most likely to be effective reinforcers. Assessment variants measure the duration of engagement with items when presented individually (DeLeon, Iwata, Conners, & Wallace, 1999) or simultaneously (Hanley, Iwata, Lindberg, & Conners, 2003; Roane, Vollmer, Ringdahl, & Marcus, 1998), on the assumption that behavior occasioned by the item will predict its effectiveness as a contingent reinforcer.

Presentations of single stimuli are perhaps simplest and permit evaluation of any number of items, but they may be more likely to produce false positives because such low-effort responses may inaccurately predict reinforcing effects under more stringent response requirements or with different response classes. Presenting items together, thereby allowing choices on each trial, may provide more sensitive indices of preference (Fisher et al., 1992), but counterbalancing presentations of multiple items makes assessments far more time consuming. For example, assessing all pairs of just 16 items (as in Fisher et al., 1992) requires 120 trials and so can take upward of 2 hours. When all stimuli are presented simultaneously, either on every trial (Windsor et al., 1994) or without replacement across trials (DeLeon & Iwata, 1996), more stimuli can be evaluated in less time. Thus, such procedures are useful for frequent assessment, but the number of items in a single array may be limited by how well learners can scan and select items within large arrays. Furthermore, assessments with all items available on each trial (Windsor et al., 1994) or continuously available during duration-based assessments (Roane et al., 1998) may yield engagement with just a single item, providing reasonable certainty that the selected item is the most highly preferred but little information about the potential utility of other items.

Reinforcer assessment. In research, but perhaps less so in practice, preference assessments are often followed by what has come to be known as *reinforcer assessment*. The rationale is that stimulus preference assessments may predict viable reinforcers, but the effort of simply engaging an item is so small that items thus chosen may not function as reinforcers for more effortful and perhaps more meaningful target behavior. Thus, the validity of stimulus preference assessment outcomes is often tested by delivering the selected items contingent on a unique response and determining whether contingent delivery increases responding above baseline levels.

When multiple items are assessed as reinforcers with either preference or response rate measures, stimuli from the top end of a preference hierarchy generally engender more responding than stimuli from the middle or bottom ends of the hierarchy (e.g., Carr, Nicolson, & Higbee, 2000). Similarly, with concurrent contingencies, arranging continuous access to high-preference stimuli for staying on one side of a room and continuous access to items selected less often for standing or sitting in another part, more time was typically spent in the areas associated with high-preference stimuli (Piazza, Fisher, Hagopian, Bowman, & Toole, 1996).

Concurrent choices, as in Piazza et al. (1996), are highly sensitive to differences in reinforcer effectiveness. The interactions that make such differences easy to see with concurrent responding, however, may not operate when reinforcers are contingent on single responses. For example, when differently preferred stimuli were concurrently available to children with intellectual and developmental disabilities contingent on separate responses, the most preferred stimuli supported higher response rates than did the less preferred ones (Roscoe, Iwata, & Kahng, 1999). When the less-preferred stimuli were tested individually, however, most children responded at rates indistinguishable from those maintained in the concurrent arrangement by the high-preference stimuli. Thus, although some stimuli may draw higher levels of response allocation than others in concurrent arrangements, it does not follow that the less-preferred stimuli will not serve as reinforcers.

These results are again reminders that researchers cannot base reinforcer assessments on response rates but must also consider the resistance of responding to change, as when introducing reinforcement of an alternative response. These are different properties of behavior that depend on different variables. We speak of preference in terms of relative rates of responding, as in accounts of

matching within concurrent performances (Fisher & Mazur, 1997; Killeen, 1972), whereas we speak of reinforcer effectiveness in terms of resistance to change or, in Nevin's account (e.g., Nevin, 1992), momentum. Given a choice, $1,000 would ordinarily be preferred to $500, but if either were the only consequence arranged for a single response, distinguishing between the reinforcing effectiveness of these two amounts would probably be difficult. Someone who could earn money by pressing a button would probably press as quickly for $500 as for $1,000. In fact, presses that produced only $10 or $100 might be as rapidly emitted. Yet if the button stopped working, pressing that had produced just $10 would probably cease more quickly than pressing that had produced far larger amounts.

Two reinforcers that generate similar rates with modest response requirements may not support such rates under more stringent contingencies, as when PR schedules require more responding with each successive reinforcer. The PR break point is the schedule requirement beyond which responding is no longer maintained. Across participants with intellectual disabilities, preference assessments were well correlated with PR break points (DeLeon, Frank, Gregory, & Allman, 2009). In educational settings, perhaps the most important question is whether one reinforcer or reinforcement arrangement results in more rapid mastery of relevant tasks than another.

Reinforcer Choice and Variation

Successful reinforcer assessments predict the reinforcing stimuli that can immediately be integrated into instructional or work contexts. Why then should researchers be concerned with whether lower ranking stimuli function effectively as reinforcers? One answer is that having a variety of effective stimuli available is useful. Both humans (e.g., Tiger, Hanley, & Hernandez, 2006) and nonhumans (e.g., Catania & Sagvolden,1980) prefer conditions with opportunities to choose among contingent reinforcers (free choice) over those with only a single contingent reinforcer available (no choice), even with reinforcers matched across free- and no-choice conditions. Reinforcing effects can be enhanced by providing reinforcer choice or variation, as when constant versus varied edible reinforcers were contingent on correct responding during an academic task with three individuals with developmental disabilities (Egel, 1981; see also DeLeon et al., 2001; Graff & Libby, 1999, for other methods of stimulus variation). During constant reinforcement, the same edible was contingent on every correct response, but during varied reinforcement, successive reinforcers varied over three different edibles. Responding decreased during constant reinforcement but not during varied reinforcement. Reinforcer choice or variation does not, however, always enhance performance (e.g., Geckeler, Libby, Graff, & Ahearn, 2000; Lerman et al., 1997), so researchers need to know more about the cost–benefit trade-offs of providing choice.

Praise and Social Reinforcers

Praise and other forms of social reinforcement offer advantages relative to the edible and tangible stimuli often used in nonhuman research. For example, praise is more natural and less intrusive in classrooms, need not interrupt ongoing responding, can be delivered with little delay, obviates the cost and effort required to deliver other reinforcers, and may be less subject to satiation effects. Some have argued that praise can increase intrinsic interest in the task (Eisenberger & Cameron, 1996). Still, praise is not universally effective, particularly in special-needs populations (e.g., Lovaas et al., 1966; Stahl, Thomson, Leitenberg, & Hasazi, 1974), so it should be assessed along with other potential consequences before incorporation into a program.

Unlike tangible stimuli, social reinforcers are not easily tested with preference assessments because they may be difficult to represent in a stimulus array. A child may easily understand that reaching for or pointing to a food item on a table results in delivery of that item, but what can the child with limited abilities reach for to produce the attention of a caregiver? Preference assessments have thus resorted to names or pictures of options in efforts to include social stimuli and other less tangible outcomes (Conyers et al., 2002; Graff & Gibson, 2003; Kuhn, DeLeon, Terlonge, & Goysovich, 2006). Such procedures are sometimes effective, but relative to separate assessments with tangible stimuli, the success

of those using verbal or pictorial representations varies across individuals. For example, verbal, pictorial, and tangible preference assessments with children capable of complex visual and auditory discriminations provide better predictors of reinforcers than similar assessments conducted with children who have less sophisticated abilities (Conyers et al., 2002). More promising, brief reinforcer assessments have sometimes conveniently demonstrated which social consequences can be effective reinforcers, as when 1-minute test periods were each associated with 2 seconds of different potential social reinforcers, such as praise, tickles, or head rubs (Smaby, MacDonald, Ahearn, & Dube, 2007).

Effects of praise may vary as a function of its content and context. Some texts suggest that praise should mention specific praiseworthy aspects of the praised performance. For example, rather than delivering a generic "well done," a teacher might specify exactly what was well done, as in "You did an excellent job applying your multiplication facts." Although this recommendation is supported by face validity and conventional wisdom, few studies have actually evaluated it, and behavior-specific praise has sometimes been confounded with other interventions such as error correction (e.g., Fueyo, Saudargas, & Bushell, 1975). A related issue is whether praise targets personal attributes or performance. Compared with children praised for their intelligence, fifth graders asked to complete a moderately easy task and praised for their effort were more likely to choose more difficult tasks that would allow them to display new abilities than easier tasks that might display their intelligence (Mueller & Dweck, 1998). Furthermore, children praised for effort were rated as more persistent in performing later, more difficult tasks and rated those tasks as more enjoyable.

Token Reinforcement Systems

Preference and reinforcer assessments have been used primarily with special populations for whom it might otherwise be difficult to identify, a priori, effective reinforcers. Other populations enter applied settings or experimental environments with readily established reinforcers. Monetary rewards come immediately to mind, as do various other consequences available in organizational settings for typically developing humans. In educational and other therapeutic contexts, token reinforcement systems often approximate the mechanics of monetary reward. When primary reinforcers cannot be easily arranged, token reinforcement takes advantage of conditional reinforcers correlated with other, more effective reinforcers.

Mechanics of token reinforcement. In token reinforcement, responses produce tokens according to a token production schedule (e.g., in FR 10, every 10th response produces a token; in FI 1 minute, the first response after 1 minute produces a token). The token may then be exchanged for other reinforcers (as when money put in a vending machine produces a can of soda). The exchange between tokens and these other reinforcers is also determined by a schedule. In other words, the behavior that produces tokens according to one schedule is embedded in a higher order schedule that specifies when tokens are exchanged for other reinforcers (Bullock & Hackenberg, 2006; Byrd & Marr, 1969; Hackenberg, 2009; Webbe & Malagodi, 1978; Yankelevitz, Bullock, & Hackenberg, 2008).

As with behavior maintained by simple schedules of reinforcement, behavior maintained by token reinforcement schedules is sensitive to schedule type and to schedule contingencies for both token production and token exchange (Foster et al., 2001; Hackenberg, 2009). Interactions between token production and token exchange schedules have been studied in some detail with pigeons (Bullock & Hackenberg, 2006); for example, increasing the token exchange ratio sometimes dramatically reduced the responding maintained by token production (see also Foster et al., 2001).

Behavior maintained by token reinforcement schedules is functionally comparable to behavior maintained by monetary consequences (Pietras, Brandt, & Searcy, 2010), and as with loss of money, contingent token loss can serve as a punishing aversive consequence that reduces responding (Raiff, Bullock, & Hackenberg, 2008).

In one variation of a token reinforcement schedule, pigeons could exchange individual tokens or could accumulate up to 12 tokens (Yankelevitz et al.,

2008). Consider individuals who are paid after completing some task and can either immediately spend their earnings at a store or can accumulate more earnings. If they must walk to the store, whether they spend immediately or save will depend on how far they must walk. The longer the walk, the greater the cost of exchange or, here, the cost in travel time. Analogously, pigeons accumulated multiple tokens rather than spending them immediately when exchange requirements became large.

Advantages of token reinforcement. Token reinforcement schedules have been used extensively in clinical settings, probably because they have several practical advantages over the primary reinforcers for which they can be exchanged. For example, they are often more portable and durable than other tangibles, and unlike edibles they are reusable. Perhaps most important, they maintain their effectiveness in the face of circumstances that diminish the effectiveness of many other reinforcers, including the stimuli for which they can be exchanged. Increasing the number of commodities that tokens can buy makes responding relatively independent of motivational variations. For example, money can buy food but will typically remain an effective generalized reinforcer even after a satiating meal. The reinforcers produced by the tokens still matter, however. When children with intellectual disabilities could exchange tokens for only a few types of reinforcers, token production depended on the highest valued reinforcer available and varied with the satiation level for the reinforcers for which they were exchanged (Moher, Gould, Hegg, & Mahoney, 2008).

Studies of temporal discounting have suggested that as a function of delay, the reinforcing effectiveness of money (a generalized conditioned reinforcer) is discounted, or decreases less steeply, than that of directly consumable reinforcers (Charlton & Fantino, 2008; Estle, Green, Myerson, & Holt, 2007; Odum & Rainuad, 2003). That is, as delay increases, money retains its value to a greater extent than food. Charlton and Fantino (2008) suggested that it may be useful to conceptualize reinforcers as falling along a continuum with directly consumable and metabolized reinforcers that are steeply discounted by delay at one end and reinforcers such as money that are later exchangeable for other reinforcers at the other. Although largely untested in applied settings, the implication for arranging reinforcement contingencies is that token reinforcers may better maintain their effectiveness despite delays than the directly consumable reinforcers for which they may be exchanged.

REINFORCER EFFECTIVENESS AND THE RELATIVITY OF REINFORCEMENT

Reinforcer effects must be assessed within the context in which they are embedded. One cannot talk about reinforcer efficacy in absolute terms. For example, if one reinforcer is preferred to another, it does not follow that the latter will be ineffective. Reinforcers preferred in one context may not be preferred in others. The effectiveness of reinforcers fluctuates across time, so allowing choices among reinforcers and variations within classes of reinforcers makes it more likely that some will remain effective across a range of circumstances. We now consider how the context in which reinforcers are delivered can influence their effectiveness.

Unit Price and Behavioral Economics

Reinforcers that support small response units may not support larger ones. The relation between a response and its reinforcing consequences is analogous to that between money and what it purchases. For that reason, some response–reinforcer contingencies have been described in the language of economics. Behavioral economics has interpreted reinforcement effects in terms generally available within U.S. culture and has sometimes highlighted relations that might otherwise have been overlooked. Economics, however, analyzes systems created by human cultures, and for our purposes the behavioral relations underlying those systems are more fundamental. In any case, behavioral economics is treated in more detail in Chapter 8 (this volume), so we restrict ourselves here to a few examples bearing specifically on reinforcer effectiveness.

The behavior that produces a reinforcer can be regarded as its unit price, given by the ratio of cost (responses or effort required) to benefit (amount of

reward or commodity). Demand for a commodity is typically measured in terms of consumption (reinforcers produced) as a function of unit price. The economic law of demand states that as the unit price for a commodity increases, demand for (consumption of) that commodity decreases. Furthermore, the effect of price changes on consumption varies across commodities. Two commodities may be consumed equally at low cost, but if price increases for both, consumption of one may fall off more rapidly than consumption of the other (consumption of the first is said to be more elastic). For example, rhesus monkeys consumed roughly equal numbers of saccharin water and food pellet reinforcers when either required 10 responses (FR 10), but with larger ratios, consumption of saccharin water declined far more rapidly than that of food pellets (Hursh, 1991). With small response requirements, these reinforcers seemed equivalent, but increases in their unit prices demonstrated that one supported more behavior than the other over a range of conditions.

The function relating reinforcer effectiveness to response requirement or cost is relevant in applied educational or therapeutic contexts because learners must sometimes be weaned from artificially rich contingencies to more stringent response requirements. To establish appropriate performance rapidly as treatment begins, the therapist often starts with reinforcing every response. For reasons of time, effort, or resources, maintaining such rich contingencies is usually impractical, so once the response class is established, the change agent often moves quickly toward increasingly intermittent reinforcement schedules.

Here the distinction between open and closed economies has special relevance. This distinction is based on whether current reinforcers are also available outside of the experimental or therapeutic context (open economy) or are available only within that context (closed economy). For example, teachers who offer reinforcers readily available outside of the classroom may have less effective reinforcers on hand than those who dispense reinforcers available nowhere else. Thus, whether an economy is open or closed may determine how more stringent response requirements influence reinforcer consumption. Other things being equal, consumption declines more rapidly with cost increases in open than in closed economies (e.g., G. A. Hall & Lattal, 1990; Hursh, Raslear, Bauman, & Black, 1989; Roane, Call, & Falcomata, 2005), so reinforcers may remain more effective during schedule thinning if they are not also available in other contexts.

Reinforcer consumption across increasing response requirements is also affected by what is concurrently available. In a classic example, rats' consumption of mixed-diet pellets decreased both with increasing ratio requirements and with the availability of either sucrose or mixed-diet pellets contingent on a separate response (Lea & Roper, 1977). Similar effects have been demonstrated among people with intellectual disabilities (DeLeon, Iwata, Goh, & Worsdell, 1997; Tustin, 1994). The implication is that during schedule thinning in academic or therapeutic contexts, reinforcer efficacy may vary as a function of other and perhaps unscheduled sources of reinforcement. For example, off-task behavior is an oft-reported problem in school settings, presumably because other forms of stimulation compete with the reinforcers maintaining on-task behavior (as when talking to a peer competes with attention to classroom assignments). Teacher praise and attention for on-task behavior may displace behavior maintained by peer attention if both teacher and peer attention are delivered on dense schedules, but the shared properties of teacher and peer attention may make the effects of teacher attention fragile if on-task behavior is later reinforced according to an increasingly lean schedule. It may be beneficial if reinforcers arranged for targeted behavior are dissimilar from other reinforcers concurrently available.

Detailed treatments of trade-offs between costs and benefits as analyzed in terms of unit price have shown that decreased responding as a function of increasing costs demanded by practical considerations may be avoided by increasing benefits to offset increases in response requirements (see Delmendo, Borrero, Beauchamp, & Francisco, 2009; Madden et al., 2000; Madden, Dake, Mauel, & Rowe, 2005; Roane et al., 2003). Such relations have implications for applications in both academic and work settings but are beyond the scope of this chapter.

Incentive Shift Phenomena

As already noted, value is not an inherent property of a stimulus; it depends on the context in which that stimulus is delivered. Perhaps no preparation has shown this more clearly than the incentive shift experiments of Perone and colleagues. For example, rat or pigeon behavior well maintained by small reinforcer magnitudes is disrupted when randomly alternating with larger reinforcer magnitudes (Perone & Courtney, 1992). This disruption occurs after a large reinforcer when a stimulus signals that the upcoming reinforcer will be small. Animals stop responding for disproportionately long periods in such rich-to-lean transitions, compared with other transitions such as lean to lean. When pigeons could escape from the stimulus signaling the upcoming reinforcer amount, they did so predominantly at rich-to-lean transitions (Perone, 2003). In other words, these transitions became aversive. The paradox is that they were aversive only in contexts in which smaller reinforcers alternated with larger ones. Access to lean schedules of reinforcement or to small reinforcer magnitudes is a reinforcer when the alternative is no reinforcers or equivalent reinforcers, but if juxtaposed with richer schedules or larger reinforcers, these conditions become aversive. Similar effects have been observed in individuals with intellectual disabilities (Williams, Saunders, & Perone, 2011).

Motivational Antecedents

Motivational events are those that alter the reinforcing effectiveness of stimuli and thus the likelihood of the responding those stimuli maintain (Laraway, Snycerski, Michael, & Poling, 2003; Michael, 1982). Some examples involve learned behavior (e.g., one's car breaking down increases the reinforcing effectiveness of tools required to fix the car), but the simplest cases involve relative states of deprivation or satiation with respect to that stimulus. For example, water deprivation increases both the effectiveness of water as a reinforcer and responding that has in the past led to water (e.g., searching for a water fountain). Deprivation and satiation effects have been demonstrated in preference assessments using food (Gottschalk, Libby, & Graff, 2000) or access to activities (McAdam et al., 2005) with both typically developing children and individuals with intellectual disabilities. Relative to control conditions, both food and activities were generally selected less often after their continuous access and more often after their prolonged unavailability.

Preference assessment hierarchies have limitations. Despite conventional wisdom, do not assume that reinforcers lose their effectiveness after meals or other events sometimes regarded as satiating, and when concerned about potential satiation effects, test for individual differences because such effects may be highly idiosyncratic. For example, for adults with intellectual disabilities, deprivation had more consistent effects than satiation with food assessments conducted before or after meals and with music and attention assessment conducted after continuous access or restricted access (Vollmer & Iwata, 1991; see also Zhou, Iwata, & Shore, 2002). Significantly, in many tests satiation did not reduce responding, suggesting that reinforcers often remain effective in applied settings under conditions conventionally thought to make them ineffective.

Changes in Preference and Effectiveness Across Extended Time and Experience

Stimulus preferences and reinforcer effectiveness are dynamic across time and experience. The motivational effects just discussed may influence reinforcer effectiveness locally but may not be relevant to the long-term effectiveness of a reinforcer. Studies that examined consistencies of preference assessments across months (Ciccone, Graff, & Ahearn, 2007; Zhou, Iwata, Goff, & Shore, 2001) have shown that consistency may be highly idiosyncratic—preference hierarchies for some individuals remain fairly stable, whereas for others those at one time are very different from those at a later time. What sorts of experiences with relevant stimuli might produce such altered preferences? Two possible variables are the events correlated with stimulus access and their overall accessibility from day to day. Given that mere interaction with stimuli can have effects, even how often an activity is chosen in a preference assessment might make a difference. For example, preference for an activity may be enhanced when engaging in that activity is reinforced after it has been chosen (Hanley, Iwata, & Lindberg, 1999) or

when already preferred stimuli are delivered according to response-independent schedules during engagement in that activity (Hanley, Iwata, & Roscoe, 2006; Hanley, Iwata, Roscoe, Thompson, & Lindberg, 2003). Unrestricted daily access to an activity (open economy) reduces its selection during preference assessment (Hanley et al., 2006). Moreover, effects of assessment procedures are often transient, as when effects of unrestricted daily access are quickly reversed after daily access is restricted (closed economy).

Stimulus preference may also be influenced by the effort historically required to produce those stimuli. In an effect called *within-trial contrast* (Zentall & Singer, 2007), "reinforcers that follow relatively aversive events become preferred over those that follow less aversive events" (Singer, Berry, & Zentall, 2007, p. 275). One example sometimes discussed in terms of work ethic is that stimuli reliably preceded by more effortful behavior may become preferred over those preceded by less effortful behavior (e.g., Clement, Feltus, Kaiser, & Zentall, 2000; Friedrich & Zentall, 2004; Kacelnik & Marsh, 2002; Klein, Bhatt, & Zentall, 2005; but see Arantes & Grace, 2008; Vasconcelos & Urcuioli, 2009; and Vasconcelos, Urcuioli, & Lionello-DeNolf, 2007, for replication failures).

Work ethic effects have usually been studied when responses involving different efforts produce the same reinforcer but are associated with distinct stimuli (e.g., with pigeons, when high-effort and low-effort responses each produce the same amount of grain, one option signaled by one key color and another signaled by a different key color). Preference is shown for discriminative stimuli associated with higher effort requirements, such as the key color historically associated with greater effort. From an applied standpoint, a more pertinent question is whether these effects occur with reinforcers that are, themselves, qualitatively distinct (e.g., high-effort responding produces one reinforcer, whereas low-effort responding produces another). Some evidence has suggested that the effort historically required to produce a distinct reinforcer is positively related to the subsequent effectiveness of that reinforcer in both humans (Birch, Zimmerman, & Hind, 1980; DeLeon et al., 2011) and nonhumans (Johnson & Gallagher, 2011).

These findings may have implications for reinforcer selection in applied settings. First, reinforcers for which more effort is required may remain more durable relative to those that require less effort. It is therefore important to know whether interventions based on response-independent reinforcer deliveries are likely to lose their effectiveness more rapidly than those in which reinforcers are earned (notice that this distinction is similar to one we invoked in interpreting the hidden costs of reward and related misunderstandings of the properties of reinforcement). Another research question is whether weak reinforcers can be strengthened by manipulating response requirements, thereby expanding the range of available reinforcers. Consider also the implications for situations in which one may want to shift preferences. It might seem odd to want to do this, but in some circumstances it may prove beneficial. For example, many children display extreme food selectivity, including both those who are typically developing and those who have developmental delays. From a nutritional perspective, this often favors undesirable food choices that contribute to obesity, diabetes, and other adverse health outcomes. Manipulations of effort expenditure have helped to enhance the value of lower calorie foods in mice (Johnson & Gallagher, 2011). Can an understanding of the variables that determine preferences help researchers to shift preferences away from less nutritious foods and toward more nutritious ones (see, e.g., Horne et al., 2004; Lowe, Horne, Tapper, Bowdery, & Egerton, 2004)?

CONCLUSION: WHY DID THE SO-CALLED REINFORCEMENT CONTINGENCY NOT WORK?

In our clinical work, parents, teachers, and other caregivers have occasionally reported, "I tried positive reinforcement but it didn't work. The behavior didn't change." In formal terms, of course, this never happens. Reinforcement is defined by its effect on the response on which it is made contingent. What those educators, clinicians, and parents actually observed is that although a stimulus was delivered,

perhaps contingent on a desired response or response property, responding remained the same or maybe even decreased. None of this, obviously, invalidates the concern that the response or response dimension was not altered by the contingency. Assuming the contingency was executed with fidelity, this may have happened for any of several reasons. Some have to do with contrived external contingencies in which contingencies were not needed, as described in our treatment of the detrimental effects of extrinsic reinforcement on intrinsic motivation. Some involve procedural mismatches between the response and its outcome. We outline a few potential candidates here; our list is, of course, not exhaustive.

1. The stimulus used was not a reinforcer (calling a stimulus a reinforcer does not make it one). It was perhaps chosen arbitrarily or based on conventional wisdom but never directly evaluated for its reinforcing efficacy. It was then plugged into the relevant contingency and failed to produce an increase. This may happen often, for example, with social praise. A teacher or other change agent may assume that praise is a valuable commodity across the board, but if that individual's history is not one in which praise has at least periodically been accompanied by other reinforcers, then praise alone may simply be ineffective. Preference, reinforcer assessment, or both should be used to systematically determine or at least estimate the likely effectiveness of the stimulus as a reinforcer before it is incorporated into the relevant context.
2. The stimulus was not a reinforcer under the specific conditions within which it was arranged. That is, the item delivered contingent on the target response was insufficiently effective relative to that response, such as when a toy is effective during an assessment but cannot compete with a computer game available in the learning situation. It may have been tested for reinforcer effectiveness under separate (perhaps less stringent) conditions and found to be effective, but that efficacy did not extend to the current conditions. In the given condition it was too little, too late, or too inconsistent. It may therefore be important not only to test reinforcer effects but also to test them under conditions that approximate the conditions of their use in the relevant context.
3. The stimulus used was no longer a reinforcer under these conditions. It was once a reinforcer under these conditions, but its effectiveness has since been altered by some other event or events, such as satiation or developmental changes. The use of ineffective stimuli in the relevant context can be avoided by repeated preference assessments across time.
4. A response–reinforcer contingency was arranged but was not contacted. For example, the requisite performance was too difficult or too effortful to meet reinforcement requirements, so it rarely occurred. Smaller, less stringent steps may be needed to shape and bring the behavior into contact with the contingency.
5. The stimulus followed the wrong response. For example, researchers have on occasion tried to increase on-task behavior by arranging contingencies for responses that formally fit the usual definition of on-task behavior, such as sitting at one's desk or looking at work materials. Such responses can occur without any concomitant increase in actually doing the work, which for the strengthening of on-task behavior is the crucial target. The reinforcer must depend directly on the behavior of interest rather than on other behavior that is incidentally correlated with it.

In light of these considerations, the need to balance reinforcer effectiveness and the practical necessities of arranging reinforcement contingencies, and some of the previously mentioned advantages and disadvantages of different classes of consequences, Figure 3.1 shows one possible decision tree for selecting reinforcers in applied settings. It assumes that reinforcers that require fewer resources are the most practical (e.g., social reinforcers), but that practicality must also be balanced with effectiveness. Because social reinforcers are readily available, inexpensive, and involve few (if any) negative side effects from consumption, they are the first-tier reinforcer in an applied setting. If initially ineffective, the advantages of social reinforcers are so plentiful that one may try to increase their effectiveness

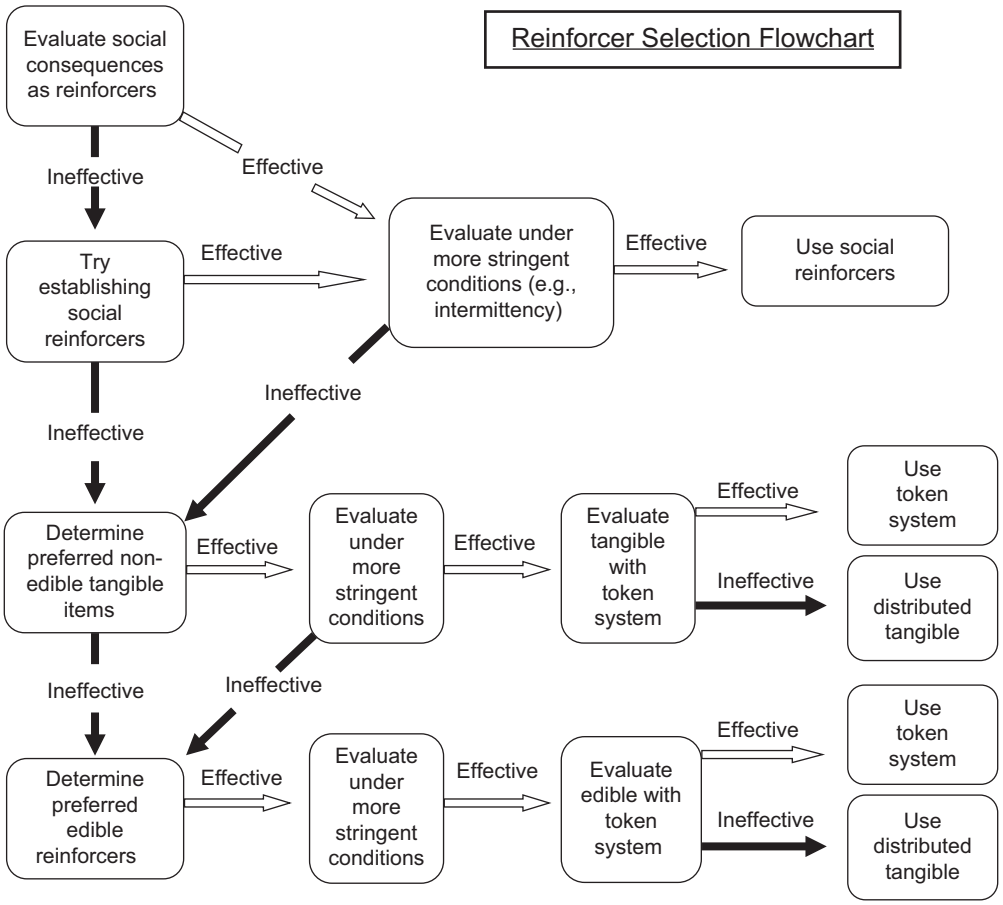

FIGURE 3.1. A decision flowchart for selecting reinforcers in applied settings.

through stimulus-stimulus pairing or other arrangements designed to establish them as reinforcers. The decision tree also assumes that the most useful reinforcers are those that maintain their effectiveness across increasingly stringent response requirements (as when schedules are thinned to make them feasible in applied settings) or over lapses in the integrity of a schedule (as when circumstances cause some reinforcers to be delayed). If social consequences are ineffective, however, then attempts should be made to identify activity-based tangible (nonedible) reinforcers. A candidate activity reinforcer should be evaluated under intermittent conditions and, if it remains effective, should be embedded within a token system. Use of a token system allows for minimization of the interrupting effects of reinforcer deliveries to ongoing behavior. If a token system is ineffective, the activity reinforcer can be delivered in a distributed fashion (after each schedule completion). Edible reinforcers, owing to their impracticality in applied settings, should be the last resort. Similar to the process used with activity reinforcers, any candidate edible reinforcer should be evaluated under intermittent conditions and, if possible, embedded within a token system.

Reinforcement Parameters and Response Acquisition

Applied research has yet to thoroughly explore the effects on behavior acquisition of many of the variables we have considered. Much translational work has retained the dependent measures of basic research, such as relative response allocation and rates of established responses rather than the course of acquisition of new behavior. In academic settings, reinforcement contingencies are often arranged to promote learning, that is, the acquisition of previously unlearned responses. Whether

manipulations such as providing more highly preferred stimuli, conducting frequent preference assessments, or arranging for reinforcer choice will meaningfully affect the acquisition of educational targets remains to be seen. For example, just because a high-preference stimulus and a low-preference stimulus support equal responding in FR schedules, it does not follow that these stimuli will be equally as effective in shaping or otherwise establishing new behavior. Just because more responding is allocated toward free choice than toward no choice within concurrent schedules, it does not follow that the availability of free choice will enhance shaping or other procedures for establishing new behavior. We need to know more about how these variables may influence the creation of novel behavior.

Individualized Learning Arrangements in Applied Settings?

We began this chapter by noting that researchers must attend to each component of the three-term contingency when arranging reinforcement contingencies. We have seen how changes in each component can affect various measured outcomes. We also know that different individuals may respond differently to changes in any term of the contingency. In theory, one should be able to optimize arrangements on the basis of such individual differences. For example, some children are relatively more sensitive to reinforcer delay, whereas others are relatively more sensitive to reinforcer rate (Neef & Lutz, 2001; Neef, Shade, & Miller, 1994). Extending the analysis of individual differences to all aspects of instruction is eminently reasonable. The details of behavior in a learning trial can be broken down on the basis of variations in prompting procedures, variations in pacing, the presence of distractor stimuli, the interspersal of previously mastered tasks, variations in consequences, reinforcement of prompted responses, and so on. Some children require physical guidance, but others balk at being touched. For some children, rapid trial presentations promote rapid learning, but for others a slower pace is better. From the nonhuman laboratory to the applied human setting, organisms come with varied histories and varied capacities. One size does not fit all, so in classrooms as in any applied setting, interventions must be individually tailored. Thus, obvious tasks for translational and applied behavior analysis are designing and developing assessments and other tools that help educators, practitioners, and caregivers to arrange optimal contingencies for each learner.

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