EQUIVALENCE CLASS EXPANSION VIA CLASS-SPECIFIC REINFORCMENT IN CHILDREN WITH AUTISM

By

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Abstract

The present study expanded the research on three-term contingencies, equivalence class formation, and class-specific reinforcement with children diagnosed with autism. In the first part of the study, two conditional discriminations were trained with naïve participants, or re-trained for participants who had been involved in an earlier study. The conditional discriminations were trained with compound (multi-element) class-specific reinforcers, and performances on tests for equivalence showed that three equivalence classes had formed. For the two participants in Experiment 1, three simple discriminations were trained with the same class-specific reinforcers used during conditional discrimination training to determine if the new discriminative stimuli would be added to the existing classes. The compound class-specific reinforcers resulted in class expansion for one participant. For the one participant in Experiment 2, three additional three-term contingencies were trained by presenting the discriminative stimuli established in Experiment 1 as class-specific consequences. These class-specific consequences resulted in acquisition of the Experiment 2 three-term contingencies, and there was also some evidence that class-expansion had occurred. Experiment 3 targeted the four participants who did not acquire conditional discriminations at the start of the study. Two sets of three simple discriminations were trained, all with compound class-specific reinforcers, to determine whether training three-term contingencies might facilitate acquisition of four-term contingencies. Acquisition of the three-term contingencies occurred rapidly for all four participants. In the next step planned for this experiment, conditional discriminations between the stimuli from the two sets of simple discriminations will be trained.

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Dedication

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Stimulus equivalence is a behavioral process that allows physically dissimilar objects to be treated equally, for example, when a child is able to relate the written word "cat" to the actual animal (e.g., Sidman, 1992; Sidman & Tailby, 1982). Psychological research on stimulus equivalence is the study of how environmental stimuli come to be treated as equal or equivalent. Research on this phenomenon developed from a study designed to determine the origins of reading comprehension (Sidman, 1971).

Research in stimulus equivalence is not focused on whether or not the phenomenon exists; daily demonstrations of symbolic behavior where an abstract word or symbol is used to represent another object clearly demonstrate the existence of equivalence relations (Sidman, 1992). These relations are often not explicitly taught, but can emerge on their own after only a few relations are learned. Stimulus equivalence research is aimed at discovering how such learning occurs and what prerequisites are necessary for equivalence relations to form (Sidman, 2000).

Research on where equivalence relations come from has significant practical applications in the field of education. Kent, a seventeen-year-old with mental retardation who participated in the seminal research on stimulus equivalence (Sidman, 1971) had been unable to read prior to that experiment. The study of how equivalence relations are formed applies directly to teaching methods used in both special and regular education classrooms (e.g., Stromer, Mackay, & Stoddard, 1992).

> During the final test session, the excitement in the laboratory was palpable. We were all outside the experimental cubicle, jumping up and down with glee as we watched correct choice after correct choice registering on the recorder. . . . when the boy had completed the tests, Os [Cresson] could contain himself no longer.

He grabbed the retarded boy in a bear hug and cried out, “Goddammit Kent, you can read!” (Sidman, 1994a, p. 34).

Terminology and Procedures

The study of equivalence relations involves contingencies; a contingency is a relationship between two events where the occurrence of one event is dependent upon the occurrence of the other (Sidman, 1986). In other words, a contingency is an if A, then B, if not A, then not B paradigm. Contingencies can contain two or more terms or parts. One contingency examined in stimulus-equivalence research is the three-term contingency, which consists of a discriminative stimulus, a response, and a reinforcer. The discriminative stimulus is so named because it must be selected in contrast to other stimuli present. The process or method of selecting the discriminative stimulus is known as the response. Finally, a reinforcer is any consequence that increases a behavior, in this case, the behavior of responding to the discriminative stimulus. An example will clarify the definitions of these components; drivers discriminate between the right and left sides of the road, drive as a response, and are reinforced through arriving at their destination safely. Because one discriminative stimulus is always correct, making the contingency easy to learn, three-term contingencies are referred to as simple discriminations (Sidman, 1986).

Stimulus-equivalence research typically employs four-term contingencies (e.g., Sidman & Cresson, 1973), which consist of the same parts contained in a three-term contingency with one additional term, a conditional stimulus. In some situations, additional information is needed for the correct discriminative stimulus to be selected. Four-term contingencies provide such information, a context, in the form of the conditional stimulus. In the example previously described, the context of the country determines which side of the road will lead to the driving response. Because the conditional stimulus determines when select three-term contingencies hold true, four-term contingencies are known as conditional discriminations (Sidman, 1986).

One common technique for teaching the contingencies just described is known as match-to-sample (e.g., Sidman, 1971; Sidman & Cresson, 1973). Current research utilizes match-to-sample computer software which presents all stimuli and, in many cases, the reinforcers (e.g., Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989). The match-to-sample teaching format can be compared to a multiple-choice test question. In experiments designed to teach four-term contingencies, a sample stimulus, the "question" portion of the contingency, appears on the computer screen. Several discriminative stimuli, the multiple choices, also appear on the screen. Just as different multiple-choice test questions each have a different correct answer, each sample stimulus must be matched with a different correct discriminative stimulus. The response used to select the appropriate "answer" is moving the mouse over the discriminative stimulus and clicking it. Depending on the trial type, a reinforcer, such as a visual display on the computer screen, will follow selection of the correct discriminative stimulus, while an alternative consequence, such as the sound of a buzzer and a blank screen, follows selection of an incorrect stimulus (e.g., Ashford, 2003). Match-to-sample procedures can also be combined in teaching and testing procedures with three-term contingencies. In such procedures, the discriminative stimuli appear without a conditional stimulus.

An Example Experiment and Early Research

The training and testing phases of an experiment occur in sessions, often computerized; an experiment can be one lengthy session or multiple brief sessions. In a basic stimulus-equivalence training and testing procedure, the experimenter designs procedures to help the participant form classes or groups of stimuli (e.g., Sidman & Tailby, 1982). The stimuli used in equivalence research can be either recognizable, common objects (e.g., a picture of a cat), or arbitrary, non-recognizable forms to ensure that any relations that emerge are not the result of learning that occurred outside the experiment. In addition, arbitrary stimuli are generally used when the research is geared more toward theoretical implications rather than applied.

An alpha-numeric labeling system is applied to the stimuli to enable comparison of different experiments and to provide an easy reference system for researchers within an experiment. Each class is designated by a number and each stimulus within the class is given a letter. The following example experiment will consist of three classes, labeled 1, 2, and 3. Two conditional discriminations will be taught, resulting in a total of six trained relations or defined relationships between stimuli. The relations are defined because the participant receives feedback for his or her response in the form of reinforcers, such as a visual display on the computer screen. Trained relations are referred to as baseline relations because they are the first relations a subject is exposed to and they become a foundation from which probe relations are derived. Therefore, if a subject's performance on baseline trials does not meet a specified criterion, their performance on probe trials is unlikely to meet the necessary criterion as well.

The two trained relations in the example experiment that follows are A→B and B→C. The solid arrows between the stimuli indicate that the relations between them are directly taught. The stimuli listed before the solid arrow will be sample, or conditional, stimuli and the stimuli following the solid arrow will be discriminative stimuli, or comparisons. The A stimuli are the written words *FELINE* (A1), *CANINE* (A2) and *REPTILE* (A3). The first trained conditional discrimination, A→B, will teach participants to match these words to corresponding pictures of a cat (B1), dog (B2), and lizard (B3), respectively. Next, the B→C conditional discrimination will teach participants to match the B stimuli just described to a second set of pictures containing a lion (C1), wolf (C2), and crocodile (C3).

When the participant has mastered the trained, or baseline, relations through demonstrating a high rate of correct responding (e.g., 90% or more of all trials in a session), the experimenter will use probe or test trials to determine if equivalence classes have formed, meaning that the stimuli function interchangeably. Unlike training trials, probe trials do not include performance feedback for the participant. Four different probe trial types determine the existence of equivalence classes. For example, having learned to match *FELINE*→cat (A1→B1) and cat→lion (B1→C1), performances on probe trials will determine whether, given any of the three trained stimuli in the 1 class, the other class 1 stimuli will be selected, though all possible relationships between the stimuli have not been explicitly trained.

The three basic equivalence probes are based on the three properties of the mathematical equivalence relation: reflexivity, symmetry, and transitivity (Sidman & Tailby, 1982). While researchers disagree on where stimulus-equivalence relationships come from, they do agree on the basic definition of equivalence which states that a group of stimuli are equivalent if the relationships between them demonstrate the properties of reflexivity, symmetry and transitivity.

Reflexivity probes require a participant to match a stimulus to itself, for example, matching the printed word *FELINE* to itself, or A1⇢A1; reflexive relations are therefore also referred to as identity matching. The dashed arrow between the stimuli indicates that the relationship is emergent. Reflexivity probes indicate a participant's ability to recognize a stimulus as unique from other stimuli. Symmetry probes reverse the original trained relations so that instead of matching A→B, the participant must match B⇢A, for example, matching cat⇢*FELINE* (B1⇢A1) instead of *FELINE*→cat (A1→B1). Reversing the trained relations demonstrates flexibility in the function of the stimuli, as they switch roles from the sample stimulus to the comparison stimulus and vice versa. Transitivity probes follow the logic that if A→B and B→C, then A⇢C, and therefore require the matching of class stimuli which had not previously been presented together. For example, if *FELINE*→cat (A1→B1) and cat→lion (B1→C1), then *FELINE*⇢lion (A1⇢C1) (Sidman & Tailby, 1982).

One additional relation known as the equivalence probe is a combined test for symmetry and transitivity (Sidman, 1992). In the example experiment, reversing the transitivity probe to test for C⇢A or, for example, lion⇢*FELINE* (C1⇢A1) includes one of the symmetry probes in conjunction with a transitivity probe and is therefore referred to as an equivalence probe. If this experiment were actually conducted, after teaching six individual relations (two conditional discriminations for each of the three classes), an additional 18 relations emerge without additional training (six symmetric relations, two for each class, three transitive relations, one for each class, and nine reflexive relations, three for each class). The number of untrained, emergent relations that result from equivalence training procedures show the benefit of stimulus equivalence as a teaching procedure (e.g. Sidman, Kirk, & Willson-Morris, 1985). The following experiments do not follow the exact procedures outlined in the example experiment, but are nonetheless examples of basic equivalence training and testing procedures and some of the earliest research conducted on this phenomenon.

The seminal research in stimulus-equivalence (Sidman, 1971) included one participant with severe mental retardation, Kent, age 17. Sidman and Cresson (1973) replicated the study with two additional participants with severe mental retardation in the form of Down Syndrome, B.A., age 19, and J.W., age 18. The experiment was designed to teach reading comprehension, and the stimuli included spoken three-letter words (A stimuli), illustrations of those words (B), and the corresponding printed words (C). The participants were first taught to identity-match each of the 20 three-letter words, or C→C, followed by auditory comprehension training which involved matching spoken words→illustrations (A→B). The symmetrical relation of picture naming was also taught (B→A). Receptive reading was taught next through teaching the participants to match the spoken words to the printed words, or A→C.

This experiment is unusual in that the trained relations differ from those normally used in equivalence research. However, after the extensive training procedures, which required almost seven months to complete, two additional critical relations emerged. The participants were able to match the printed words to their corresponding pictures, C⇢B, demonstrating reading comprehension through correctly matching the word to its pictorial representation. They were also able to match the printed words with their oral names, C→A, which is oral reading.

Sidman and Tailby (1982) conducted a more traditional equivalence experiment with normally developing children ages 5 years 0 months to 7 years 6 months using arbitrary stimuli, Greek letters. Three conditional discriminations were trained. The first discrimination involved matching three spoken Greek names to the corresponding capital Greek letters, or A→B, and the second conditional discrimination required matching those same Greek names to the lowercase form of the letters, or A→C. A third conditional discrimination was also trained in which participants were taught to match three other Greek letters to the lowercase forms of the original letters (D→C). Reflexivity or identity matching relations were trained in the pre-test phase and were therefore not included as part of the testing phase.

Many different probe trials were presented because three conditional discriminations were trained instead of the traditional two. The symmetry probes included B→A, C→A, and C→D, and the transitivity probes included D→B, B→D, and A→D. In this experiment, the A and C stimuli are nodes, meaning they are the common elements in relations between two other stimuli. In order for B and D to be equivalent, the following relations logic must exist: if A and B are equivalent, and A and C are equivalent, then B and C must also be equivalent. Further, if B and C are equivalent, and D and C are equivalent, then B and D must also be equivalent. Six of the eight participants successfully completed all training and testing procedures, and their success demonstrated that reinforcement can result in emergent learning. The new behavior that emerged on these unreinforced probe trials could only have resulted from the baseline reinforcement contingency.

Theories on the Origin of Equivalence Relations

Researchers agree on the mathematical definition of stimulus equivalence. What remains a highly debated topic is where equivalence relations come from (e.g., Sidman, 2000). There are three prominent theories on the origin of equivalence relations, and the prerequisite skills seen as necessary for this to occur.

Naming theory asserts that a participant must be able to produce a name for each stimulus before they can form a class (Lowe, Horne, Harris, & Randle, 2002). A name is a bi-directional relationship involving an object or event, speaker behavior, and listener behavior. Children learn naming behavior through repeatedly hearing an adult say the name of an object and eventually attending to the object as they name it themselves. Social reinforcement aids in the development of naming skills. Naming can be covert or overt and can encompass modalities other than spoken language, such as signing.

Two types of naming are believed to lead to equivalence-class formation (Horne & Lowe, 1996). Common naming involves the categorization of several objects through the use of a single name. According to this theory, a child could, for example, form an equivalence class by labeling a housecat, lion, tiger, and panther with the common name "feline." By producing a common name, the child will behave in the same way toward each class member (within a given context), thereby treating the stimuli equivalently. The second type of naming is referred to as intra-verbal naming. Intra-verbal naming occurs when object names are spoken in succession repeatedly so that the first name in the chain becomes a discriminative stimulus for the next name and so on until all names have been spoken (Horne & Lowe, 1996). Based on this method of naming, the feline stimuli could become a class if the participant learned the intra-verbal chain “cat, lion, tiger, panther.” According to the theory, naming is necessary for equivalence relations to emerge; therefore, only humans are able to demonstrate equivalence.

Relational frame theory promotes the notion that the formation of equivalence relations is learned or operant behavior, and, therefore, a history of reinforced relational responding is necessary before equivalence relations can emerge (Hayes, Fox, Gifford, Wilson, Barnes-Holmes, & Healy, 2001). Relational responding involves reacting to stimuli in terms of how they relate to one another, as opposed to their individual, unique properties. Relational frames such as “taller than” must be explicitly taught using multiple exemplars in order for the relation to be applied to new stimuli. For example, rhesus monkeys were trained to pick the taller of two stimuli presented, and, after several training pairs, were able to pick a novel tall stimulus over a familiar stimulus that was previously a correct tall stimulus. Their responding presumably occurred because they had abstracted the relational frame of “taller than” and were attending to critical height features as opposed to the actual, absolute, stimuli as a result of multiple exemplar training (Hayes, et al., 2001). Equivalence relations are considered one type of frame (e.g., “is equal to”) and represent only one type of relation for which relational frame theory is said to account.

A context is necessary in order for a relation to be applied to new stimuli. Through exposure to multiple exemplars, subjects are able to distinguish between the relevant contextual features and irrelevant physical features of stimuli in order to apply relations such as “heavier than” or “lesser than.” According to these authors, any species is capable of learning such relations; thus, relational frame theory asserts that both humans and nonhuman animals can demonstrate equivalence relations.

The third major theory of how equivalence relations form is Murray Sidman's reinforcement contingency theory, which suggests that equivalence relations are a direct result of the reinforcement contingency (Sidman, 2000). In other words, equivalence relations form as a direct result of the reinforcement procedure used during the teaching or baseline phase. A reinforcer is any consequence that increases the probability that a behavior will occur, such as verbal praise, a visual display on the computer, or food. Reinforcers can be single items, such as delivery of a piece of popcorn after a correct choice on a baseline trial, or compound reinforcers, such as both a visual display on the computer screen and delivery of a piece of popcorn after a correct choice on a baseline trial (e.g., Ashford, 2003). Because reinforcement is a behavioral process observed in species other than humans, reinforcement contingency theory asserts that human populations, both with and without language capabilities, and nonhumans alike may demonstrate equivalence.

While naming theory and relational frame theory assert that specific prerequisite skills must be learned before equivalence relations can emerge, Sidman's reinforcement contingency theory defines equivalence as a fundamental behavioral process, placing equivalence in a category of processes which includes reinforcement. Such processes cannot be broken down into more simplistic behaviors and are never explicitly taught (Sidman, 2000). Just as a child does not require instruction to respond to reinforcement, such as verbal praise from a parent, the process of forming relationships between stimuli is not taught; rather, it constitutes emergent behavior. The reinforcement contingency that exists between specific stimuli either in everyday life or in an arranged equivalence training and testing procedure is sufficient to allow for acquisition of relations between those specific stimuli.

There are two important points in the reinforcement contingency theory which play a key role in the present study. First, Sidman asserts that any contingency, three- or four-term, can produce equivalence. Additionally, all members of a contingency, including the conditional stimulus (in a four-term contingency), discriminative stimulus, response, and reinforcer can become members of an equivalence class (e.g. Sidman 2000).

Human Participants

The emergence of stimulus-equivalence relations has been observed in a wide range of human populations. The seminal research included one young adult with mental retardation (Sidman, 1971). Persons with various developmental disabilities from all age ranges have participated in stimulus-equivalence research (e.g. Ashford, 2003; O’Donnell & Saunders, 2003). In addition, normally developing children (e.g., Pilgrim, Chambers, & Galizio, 1995) and adults (e.g., Pilgrim & Galizio, 1995) have served as participants.

While participants with developmental disabilities have often been involved in stimulus-equivalence research, O’Donnell and Saunders (2003) examined equivalence studies involving such participants and found that the research with this population is limited in several aspects. At the time the paper was published, only 20 studies that included such participants with developmental disabilities, with a total of 55 participants, had been conducted since the publication of Sidman and Tailby’s study in 1982. The main reason for the slow rate of publication is the length of time required for each study (see Sidman, 1971). O'Donnell and Saunders intended their analysis to promote systemization and improvement in certain aspects of future research in this area. One such improvement includes documenting how the participants were chosen and specific details about their skill levels, particularly language abilities, including expressive language.

Of those studies including participants with developmental disabilities, there is a relatively high frequency of participants with Down Syndrome, leaving other disabilities, particularly those in the severe and profound categories, underrepresented. At the time of publication, only four of the 55 participants included in the studies under review had autism. According to the Individuals with Disabilities Education Act, or IDEA, autism is defined as

> A developmental disability significantly affecting verbal and nonverbal communication and social interaction, generally evident before age 3, that adversely affects a child's educational performance. Other characteristics often associated with autism are engagement in repetitive activities and stereotyped movements, resistance to environmental change or change in daily routines, and unusual responses to sensory experiences (Knoblauch & Sorenson, 1998).

Testing this population provides an opportunity for equivalence relations to be seen in individuals with severe language deficits, or possibly the absence of language, in which case the research would provide evidence relevant to the theory that language is necessary for equivalence relations to emerge (O'Donnell & Saunders, 2003).

Applications

Persons with developmental disabilities such as autism do not perceive the world in the same way that their peers do. Therefore, it is unsurprising that they require modifications and varied teaching programs. Schriebman (2000) evaluated methods for teaching persons with autism and concluded the following:

> Several treatment protocols that have substantial empirical validation emphasize the carefully controlled structure of the learning situation. Discrete Trial Training is perhaps the most highly structured form of trial presentation. A trial (or learning event) consists of a concise instruction or question, the child's response, and a specific consequence, the nature of which is determined by the child's response. Learning trials are typically presented in blocks (p. 374).

The match-to-sample teaching and testing procedure used in stimulus equivalence research falls into the category of discrete trial training just described, demonstrating its functional application as a method of teaching that could be employed in schools on a daily basis.

Stromer, et al. (1992) provided a general description of stimulus-equivalence and direct classroom applications of the procedures that both regular and special education teachers can utilize. While in an experimental setting, participants are usually tested individually, Stromer et al. describe procedures that allow teachers to work with a large group of students. The procedures do not need to be computerized; a teacher can place stimuli on index cards, which would allow them to distribute trials one at a time to a group of students. Another option is to divide students into teams to create a competitive and motivating context.

Language arts subject matter lends itself easily to a stimulus-equivalence teaching and testing format (e.g. Sidman, 1971; Sidman & Cresson, 1973). Stromer et al. (1992, p. 226) describe a sample experiment that uses “single words whose referents can be represented visually, as in picturable nouns, action verbs, colors, quantities, and so on.” A referent is defined as the object or definition to which a single word corresponds. Because stimulus-equivalence procedures can be used to teach concepts ranging from colors to advanced vocabulary, the procedure is applicable as a teaching method for students with a wide range of ages and abilities. Equivalence procedures have been effectively implemented in actual classrooms to teach a variety of concepts including reading, (e.g., Sidman, 1971; Sidman & Cresson, 1973) spelling, (e.g., Graham, 1983; Mackay, 1985; Stromer & Mackay, 1992), fractions (Lynch & Cuvo, 1995) and money skills (e.g., McDonagh, McIlvane, & Stoddard, 1984). In addition to utilizing the procedure as an actual teaching method, Stromer et al. (1992) suggest using stimulus-equivalence methodologies to assess students both before and after a lesson and to teach prerequisite skills prior to a lesson.

While regular education teachers may easily be able to initiate an equivalence program for teaching reading and language arts skills, special education teachers may have students missing the necessary prerequisite skills for such a procedure. Sidman (1977) emphasizes the importance of training these skills also, beginning with motivating students through reinforcing attention to the task and progressing through the small steps needed to help the student adjust to the requirements of the task.

After the participants in Sidman’s first study (1971) completed the experiment, they had a 20-word reading vocabulary. Exposing students to prerequisite skill training and equivalence procedures may help prevent them from being labeled “unteachable” and provides a foundation that teachers can use to build future objectives and lessons.

Animal Subjects and an Introduction to Class-Specific Reinforcement

The development of equivalence relations is clearly evident in a wide variety of human populations. Various populations of nonhuman animals have served as subjects in equivalence research as well (e.g., Miyashita, Nakajima, & Imada, 2000), but the demonstration of equivalence relations in these populations is highly debated (e.g., Lowe, et al., 2002).

The most convincing evidence of the formation of equivalence classes with animal subjects comes from studies using class-specific reinforcement (e.g. Kastak, Shusterman, & Kastak, 2001, see below). Studies involving class-specific reinforcement, used with both nonhuman and human populations, provide a unique reinforcer for each class of stimuli. If the sample experiment described earlier were to incorporate class-specific reinforcement, a correct choice on a baseline trial with stimuli from the feline class would result in, for example, stars flashing across the computer screen. A correct choice on a baseline trial with stimuli from the canine class would result in triangles flashing, and a correct choice on a baseline trial with stimuli from the reptile class would result in circles flashing across the screen. Class-specific reinforcers can be single or compound; for example, the unique visual components could be associated with unique sound components on the computer as well, thereby becoming compound reinforcers (e.g., Ashford, 2003).

Class-Specific Reinforcers: Facilitating Discrimination

One purpose of class-specific reinforcement is to facilitate discrimination of the stimuli within each class. Sidman (2000) asserts that class-specific responses and reinforcers have practical applications when incorporated into the standard equivalence training and testing paradigm, as they assist students who are slow to demonstrate, or who fail to demonstrate, equivalence. Persons with disabilities are among those who require extensive training to demonstrate equivalence relations.

Miyashita, Nakajima, and Imada (2000) conducted a study with three retired race horses to examine the effects of three different reinforcement contingencies. These included class-specific reinforcement, a common reinforcer where one reinforcer was used for correct responses involving all stimulus classes, and random reinforcement. The horses were trained to press one of two levers on either side of a lighted panel, depending on the color of light presented. When the light presented was yellow, the correct response was pressing the lever on the right-hand side, and when the panel displayed a blue light, the correct response was pressing the lever on the left-hand side.

The reinforcement contingencies were varied in three different phases. In the class-specific reinforcer phase, also referred to as the differential outcome phase, pressing the right lever in the presence of the yellow light was reinforced with delivery of a food pellet, while pressing the left lever in the presence of the blue light was reinforced with carrot pieces. During the random reinforcement or mixed outcome phase, either of the two food reinforcers could be delivered after a correct trial, regardless of light color. Finally, the common reinforcer phase contained two sub-phases, one in which the reinforcer was always a carrot and one in which it was always a food pellet. All three horses experienced the class-specific reinforcement and random reinforcement phases, but only one horse completed the common reinforcer phase. Responses were allowed to stabilize across several sessions before a different phase was introduced. Each horse completed the phases in a different order.

Each animal's performance demonstrated that the class-specific reinforcers aided discrimination learning. All three horses achieved 80-90% correct responding during sessions of this phase, while performance dropped to the 60-75% range during the other phases. Re-experiencing the class-specific phase enabled performance to recover after sessions of the other two phases.

Kastak, et al. (2001) used compound class-specific reinforcers (two different types of fish, capelin and herring, and tones of two distinct frequencies) to train two California sea lions in a stimulus-equivalence procedure, the details of which will be discussed in a later section. The trained discriminations were acquired rapidly with class-specific reinforcement.

Class-Specific Reinforcers and Equivalence-Class Formation

In addition to influencing discrimination learning, class-specific reinforcement procedures are also relevant to equivalence-class formation. Sidman proposes that in experiments where a single, common reinforcer is used, all stimuli could initially become one large class by virtue of their relationship to the reinforcer. In other words, because each correct stimulus selection produces the same reinforcer, the stimuli may be treated as if they are all related. Eventually, in order for separate classes to form, the reinforcer must no longer function as a class member. The contingency takes precedence over the common reinforcer, forcing it to drop out of the class (Sidman, 2000). (This same reasoning would also apply to the common response, typically, clicking each stimulus with a mouse.)

When conditional discriminations are trained with class-specific reinforcers, there is no conflict in the contingency or overlap across all experimenter-designated classes. Data also indicate that class-specific reinforcers may function as class members (e.g., Dube, McIlvane, Mackay, & Stoddard, 1987; Sidman, 2000). They do this by taking on the same functional properties as the other stimuli in the class. In other words, subjects will respond to a class-specific reinforcer in the same way as they would respond to any other member of that particular class (e.g., Ashford, 2003).

Dube, et al. (1987) conducted a study with two adults with mental retardation; D.L., 23, had moderate mental retardation and M.C., 43, had Down Syndrome. As in the Miyashita, et al. (2000) study, class-specific reinforcement in the form of two distinct edible reinforcers was used. The class-specific reinforcement remained in place for the duration of the study, and a reinforcer preference test was used to determine two food reinforcers of equal value for each participant prior to the study.

The stimuli were divided into two classes, each consisting of a spoken nonsense name, an arbitrary object, and a dissimilar arbitrary symbol. In Experiment 1, participants were taught identity matching with all of the visual stimuli, and they also learned two conditional discriminations for those stimuli. The trained conditional discriminations were A→B and B→C, but the group of stimuli corresponding to the A, B, and C designations was different for each participant. D.L. was trained to match the auditory names to their corresponding nonsense symbols, then to match the nonsense symbols with their respective arbitrary objects. M.C. was taught to match the nonsense names with the appropriate arbitrary objects, then to match the arbitrary objects with the corresponding nonsense symbols. Correct choices were reinforced with the appropriate class-specific food. Both participants achieved perfect scores on probe tests for symmetry, and transitivity, demonstrating equivalence-class formation.

Experiment 2 was designed to test for class membership of the class-specific edible reinforcers. Each participant was trained to identity-match two new stimuli. Correct responses on these trials were reinforced with the class-specific foods used in Experiment 1. Probe tests were used to determine if the new stimuli had become members of the previously established classes because of their relation to the class-specific reinforcers. In other words, each participant had two existing classes: $A_1B_1C_1$ and $A_2B_2C_2$, which were associated with reinforcers R_1 and R_2, respectively. In order to determine if R_1 and R_2 were also members of the class, the participants were trained to match $D_1 \rightarrow D_1$ and receive R_1, and to match $D_2 \rightarrow D_2$ and receive R_2. Probe trials determined whether the participants would match the D stimuli with the corresponding A, B, and C stimuli. Because the D stimuli had never been associated with any other class members, the only means by which they could become equivalent was through their relation with the class-specific edible reinforcers, thereby indicating that the reinforcers were also class members. These probe scores were in fact perfect, suggesting that the reinforcers were indeed class members.

Following this first set of probes, in Experiment 3, Dube, et al. (1987) retrained identity matching of the D stimuli with reversed contingencies so that matching $D_1 \rightarrow D_1$ resulted in R_2 and matching $D_2 \rightarrow D_2$ resulted in R_1. On probe tests, D.L. and M.C., after some inconsistencies, matched D_1 to A_2, B_2, and C_2 and D_2 to A_1, B_1, and C_1. When the reinforcers were reversed again for the two classes, the D stimuli also reversed and joined the opposite classes, re-emphasizing the ability of the reinforcers to assume the function of class members.

Experiments 1, 2, and 3 were conducted with similar results with two new participants, P.N., age 20, and J.N.B., age 14, both males with moderate mental retardation (Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989). This study included compound class-specific reinforcers containing an edible item, visual display on the computer, and a short musical tune. Both the Dube, et al. (1987) and Dube, et al. (1989) studies provided indirect evidence that the class-specific reinforcers had become members of the equivalence classes.

Ashford (2003) conducted a study similar in format to Dube, et al. (1989), which included explicit tests to determine if the class-specific reinforcers had indeed become class members. Eleven participants with developmental disabilities, including autism, were included in Experiment 1, in which they received training for two conditional discriminations. Some participants were taught A→B and A→C relations while the remaining participants were taught to match A→B and C→D, so that there were no sample or comparison elements in common between the conditional discriminations. Several participants received class-specific reinforcement and others received random reinforcers. Reinforcement included an audio-visual display on the computer, and an edible component. Reinforcer preference tests were used to determine the edible reinforcers for each participant.

Six participants who met the acquisition requirements in Experiment 1 (at least two sessions with 90% accuracy) continued on to Experiment 2 where they completed probes to determine if the trained relations had led to the formation of equivalence classes. These probes included symmetry, combined equivalence, and reflexivity, presented in that order. Participants who had received training with A→B and C→D relations completed probes for emergent relations between the two conditional discriminations, as there is no established probe that would meet the mathematical definition of transitivity. Additional probes were given to see if the visual components of the class-specific reinforcers had become class members. Small images of the computerized visual displays, as well as pictures of the edible reinforcers were presented as either samples or comparisons with A, B, C, and, if appropriate, D stimuli in these probe trials.

Five of the six participants clearly demonstrated equivalence-class formation. Of those five participants, three had received class-specific reinforcement in Experiment 1; the probe performances of all three participants indicated that the visual components of the class-specific reinforcers had joined the classes. For one participant, WJ, the reinforcers had acted as nodes or common elements between the A→B and C→D trained conditional discriminations.

The purpose of Experiment 3 was to expand the participants' existing classes through training identity-matching with two new stimuli, E and F. Three participants who had successfully completed Experiments 1 and 2 were included in this experiment. Correct selection of the stimulus identical to the sample on a given trial was reinforced with one component of the compound class-specific reinforcer. SV received the computerized audiovisual display for correct selections on E→E identity trials while JY and WJ received the edible reinforcer on those trials. During F→F identity matching trials, the participants received the components that had not been presented on E→E trials.

Class-expansion probes determined whether the new stimuli had become members of the existing classes. E and F stimuli were presented with A, B, C, and, where appropriate, D stimuli. In addition, probes were presented to determine if participants would match the corresponding E and F stimuli to each other. Correct responses on probe trials would indicate that individual elements of the reinforcers had acted as nodal stimuli because they were the only basis for relations between the new stimuli and members of the existing classes. All three participants demonstrated that class expansion had occurred with at least one of the new stimulus sets.

Sound probes were also presented during this experiment to examine whether the auditory component of the class-specific reinforcers had become class members. In addition to trials including all of the baseline stimuli, images of the visual components of the reinforcers were presented as comparisons in one type of probe trial. The responses of all participants were class-consistent, indicating that the auditory component of the class-specific reinforcers was also a class member. Interestingly, participant JY correctly matched the F stimuli to the appropriate sounds, even though baseline trials with the F stimuli were only reinforced with the primary edible reinforcers.

In addition to expanding previous research with class-specific reinforcement, (e.g., Dube, et al., 1987; Dube, et al., 1989), the results of this study indicate further possibilities for the use of stimulus-equivalence procedures in the classroom. Because each element of a compound class-specific reinforcer can potentially become an equivalence-class member, teachers can include relevant stimuli in the reinforcer to drastically increase the number of relations that emerge after only two conditional discriminations have been trained (Ashford, 2003). This increases the power of stimulus-equivalence as a teaching procedure because the number of emergent relations that result from training only a few discriminations increases, particularly when compound class-specific reinforcers are employed (Sidman, 2000).

If the example experiment described earlier were to include single component class-specific reinforcers, 21 new emergent relations are possible in addition to the 18 that would result from a common reinforcer, producing a total of 39 emergent relations without training any additional relations. The 21 emergent relations would include three reflexive relations between reinforcers, one for each class, matching each class member to the appropriate reinforcer or R (A⇢R, three relations, one for each class, B⇢R, three relations, and C⇢R, three relations), and symmetrically matching each reinforcer to the appropriate class members (R⇢A, three relations, one for each class, R⇢B, three relations, and R⇢C, three relations).

Three-Term Contingencies

As indicated in the preceding review, much of the research in stimulus-equivalence has involved four-term contingencies. The formation of equivalence relations cannot be observed directly; their existence is inferred if the three mathematical properties of reflexivity, symmetry, and transitivity characterize the relations between specific stimuli (e.g., Sidman, 1994a). Four-term contingencies must be involved in order to use these standard tests for the formation of equivalence classes. However, studies on class formation involving both animals and humans have also employed three-term contingencies during training. Until recently, Sidman disputed the possibility that three-term contingencies might produce equivalence relations (Sidman, 2000). Because three-term contingencies do not lend themselves easily to standard equivalence probes, different methods have been used to test for the existence of equivalence classes resulting from simple discrimination training.

One such method involves a reversal procedure developed by Vaughan (1988). Six homing pigeons served as participants in the study. The stimuli were 40 pictures of trees, each of which was unique. The pictures were divided into two groups of 20, where one group was designated as positive and the other negative. When the pictures were displayed one at a time via projector, if the pigeons responded to a positive class member by pressing a lighted key, food reinforcement was provided. Responses to a negative class member were not followed with food. After the pigeons successfully responded to only the positive class members, the reinforcement contingencies were changed so that the positive members became negative and the negative members became positive. This pattern continued until the contingencies were reversed a total of 95 times.

After each reversal, the probability of a response to a positive rather than a negative class member was measured. Correct responses did increase slowly with each successive reversal so that, eventually, after experiencing only a few trials with a contingency reversal, the pigeons changed their responses to the other photographs in accordance with the new contingency. The subjects' responding demonstrated the formation of two stimulus classes as a result of training with three-term contingencies. They divided a single set of stimuli, 40 tree photographs, into two sets of 20 through responding to members of the same set in the same way. This pattern of responding is called a partition. The classes that emerged here are referred to as functional classes because the stimuli within a set are related, not because of stimulus-stimulus relations, but because they control the same response which yields the same reinforcer. This study provides a clear example of class-formation in the absence of four-term contingencies.

Sidman, Wynne, Maguire, and Barnes (1989) conducted a study designed to determine whether or not functional classes derived from three-term contingencies might also meet the mathematical definition of equivalence and, thereby, involve the same behavioral process. The participants included PJV and JDB, two male students in their late teens with autism, and DJK, a student in speech pathology. The stimuli consisted of odd and even numbers for PJV and JDB, as assessment prior to the experiment revealed that this was a concept they did not understand, and uppercase and lowercase Greek letters for DJK. During baseline trials on which a reinforcer could be earned for correct responding, that reinforcer consisted of a beep indicating that a point had been added to the participant's score. DJK and PJV exchanged their points for pennies at the end of each session; JDB, however, did not require the additional monetary reinforcer to maintain accurate responding.

After completing a pre-teaching phase to familiarize the participants with the procedures, each participant was trained with three two-choice simple discriminations. The experimenter divided the stimuli into odd and even classes for PJV and JDB and into classes A and B for DJK. One of these classes was designated as positive; when a stimulus in this class was chosen on a given trial, the participant received a reinforcer. The stimuli in the other class were designated as negative, and selection of one of these stimuli on a given trial did not yield a reinforcer. When participants were choosing the stimuli designated as positive on 95% of the trials in a session, the contingencies were reversed so that former positive stimuli became negative, and previously negative stimuli became positive. This portion of the experiment sought to answer the question of whether stimuli associated with the same consequence (i.e., reinforcement or no reinforcement) would become members of a functional class. The performance of all three participants demonstrated the formation of two functional classes because they responded differently to the stimuli when the reinforcement contingencies were reversed. When a reversal occurred, the participants changed their responding so that they were selecting the group of stimuli that produced the reinforcers. Ideally, a participant would receive no indication that the reinforcement contingencies had been reversed, and, it would not be possible for them to choose the correct stimulus on the first trial involving a reversal. In this study, however, the experimenters had to change the computerized session in order for the contingency reversal to take place. Switching seats while the experimenter changed the session served as a stimulus indicating that a reversal was about to occur; therefore, the participants were able to respond correctly even on the first trial of a reversal.

The next part of the experiment was designed to test whether conditional relations between members of the same functional class would emerge. To ensure that the participant would attend to the sample on this task, reinforced identity-matching trials for each stimulus were provided first. Performances on these trials indicated that reflexive relations had formed for each stimulus. However, the fact that responses on these trials were reinforced must be taken into account; true reflexivity test trials are not reinforced.

During conditional discrimination trials, a sample stimulus was presented with two comparison stimuli. One stimulus belonged to the same functional class as the sample stimulus and the other did not. The goal of these probe trials was to see if the participants would make class-consistent selections of functional class stimuli when they were presented in a conditional discrimination format. Conditional discrimination probe trials were interspersed with baseline trials, but reinforcers were not given on either baseline or probe trials, a procedure known as tests in extinction (Sidman, et al., 1989). DJK's probe performance was completely consistent with class formation and PJV made only 2 inconsistent choices on 36 trials. Originally, JDB only made class-consistent selections on 24/36 trials; however, after five additional test sessions were administered, his score improved to 33/36 trials. Therefore, the probe performances for all three participants demonstrated the emergence of conditional relations from functional class members. This in and of itself, however, was not sufficient to qualify the relations as equivalence relations. Tests for symmetry and transitivity were still necessary. To provide for these tests, two conditional discriminations were trained between two existing class members (one from each of the two classes) and two new stimuli. PJV and DJK demonstrated the formation of equivalence classes by matching the new stimuli to class members with which they were not explicitly trained; in order for the new stimuli to join the class, the stimuli with which they were trained must already have been equivalence-class members.

JDB learned to match the new stimuli to the existing class members during training, but the new stimuli were not matched to other members of the classes, and the conditional relations demonstrated in the previous tests also broke down. When separate sessions of reinforced baseline trials were given, his performance recovered, but deteriorated once again when mixed sessions with nonreinforced baseline and probe trials were reintroduced.

DJK and PJV next learned two new conditional relations each, where two additional new stimuli were trained to the new stimuli from the previous phase. Probes were given to determine if these new stimuli would join the existing classes, indicating that the conditional relations trained between the two newest sets of stimuli were also equivalence relations. DJK completed 36/36 probes correctly and PJV completed 18/18 probes correctly, indicating the formation of new equivalence relations.

The last part of the experiment asked whether the four newest stimuli were also members of the original functional classes (i.e., those formed on the basis of the three-term reinforcement contingencies and the reversal procedure). Simple discrimination trials were presented once again, this time including the new stimuli, in the test-in-extinction format. Both participants once again had nearly errorless probe performances; it was clearly evident that the members of each functional class were equivalent for PJV and DJK. However, Sidman et al. (1989) had this to say about the performance of JDB:

> The third [participant] in the present experiment formed functional classes without being able to demonstrate equivalence relations between class members. Why this subject differed from the others is not known, but the lesson he taught is clear: A set of stimuli partitioned into subsets of functionally equivalent members does not represent the same behavioral process as conditional-discrimination tests for equivalence relations, even with human subjects (Sidman, et al., 1989, p. 273).

In addition, Sidman, et al. (1989) asserted that “If the two kinds of equivalence need not coexist, it follows that even when they do, a conclusion that they represent the same behavioral process is not justified" (pp. 273). As stated earlier, however, Murray Sidman reevaluated his position on this issue, later retracting the assumptions made in this 1989 study (Sidman, 1994a). He now promotes the possibility that three-term contingencies can lead to the formation of equivalence relations because, both behaviorally and mathematically, it is a logical argument, and because two participants demonstrated this relation. In order for a group of stimuli of any kind to be divided, a specific characteristic must be the basis of such division; the items placed in each subgroup must be equivalent in some way (1994a). If a group of several objects were to be divided into two distinct subgroups, the objects in each subgroup would be equivalent with respect to a certain characteristic. Because Sidman reversed his position in support of the idea that functional classes are also a form of equivalence relations, the original evaluation of JDB's performance was also re-examined. The failure of participant JDB to demonstrate equivalence was likely the result of the procedures used in the study, namely, the tests in extinction format (1994a). Sidman had noted this possibility in the study itself; "the [participant] started to respond as though the instructions 'No beeps and no points,' meant, 'do everything wrong'" (Sidman, 1994a, page 438).

Kastak, et al. (2001) followed procedures similar to Vaughan (1988) in Experiment 1 of their study with Rocky and Rio, two California sea lions. Two sets of stimuli, ten letters and ten numbers, were presented in designated pairs during phase 1. The two sets alternated as positive and negative; responses to members of the positive set resulted in reinforcement, consisting of a tone and a randomly selected piece of fish, either capelin or herring, while responses to members of the negative set resulted in the auditory word "no." Each time the sea lions reached a 90% criterion (i.e., each time the sea lions responded to positive set members on 90% or more of the trials in a session), the contingencies were reversed so that the positive set became negative and the negative set, positive. This pattern repeated several times.

In phase 2, the letters and numbers were no longer presented in predetermined pairs and could appear in different combinations. Class-specific reinforcement, described earlier, was initiated in phase 3. Capelin or herring were each paired with a distinct tone and one of the sets of stimuli, so, for example, when the number set was positive and Rio correctly responded to a number on a given trial, he received capelin and a 587-Hz tone; during sessions when the letter set was positive, correct responses to number stimuli resulted in herring and a 293-Hz tone. These tones were different than the tone in Phases 1 and 2. Both Rocky and Rio demonstrated the formation of functional classes; that is, their patterns of responding to stimuli changed after the reinforcement contingencies were reversed. As in Vaughan's (1988) study, the subjects altered their responses depending on the reinforcement contingency present on the first trial during a reversal. If selection of a number stimulus produced reinforcement on a given trial, the subjects responded to number stimuli on subsequent trials.

Experiment 2 transformed the simple discriminations mastered in Experiment 1 into conditional discriminations with a sample stimulus. A sample, either a number or a letter, and two comparisons, one number and one letter, were presented on each trial. If the sample was a number, choosing the number comparison was reinforced, whereas if the sample was a letter, selecting the letter comparison was reinforced. To ensure continued participation, reinforcement was not discontinued during probe trials. Only the first presentation of each probe trial was counted toward their probe score because performance on all subsequent presentations of the trials could have been due to direct reinforcement. Rio's first trial probe score was 86.6% correct responding, and Rocky's first trial probe score was 90.5% correct responding.

In order to demonstrate equivalence relations, a novel number and letter stimulus were added to each class through training conditional discriminations between the new stimulus and an existing member of each class. Probes were given to determine if the subjects would match the new number and letter with the remaining nine members of each class, and thereby demonstrate equivalence. Probe scores were again determined using only the first presentation of a novel trial. Rocky scored a 91% on these trials and Rio scored a 100%, clearly demonstrating that equivalence relations had emerged.

Purpose of the Present Study

Kastak, et al. (2001) created conditional discriminations with novel stimuli to determine if the number and letter stimulus sets trained with simple discriminations had become equivalence-classes. Another method of determining if the stimuli trained in simple discriminations have formed equivalence relations is to expand previously established classes. The procedure is similar to that of Dube, et al. (1987), Dube, et al. (1989), and Ashford (2003) with the exception that the new stimuli to be added to the established classes are trained with three-term contingencies rather than four-term contingencies.

The present study further explores the utility of three-term contingencies and class-specific reinforcement for equivalence-class expansion in individuals with autism. Until Ashford (2003), no study had tested for the formation of equivalence relations in children with autism with teaching procedures that included class-specific reinforcement.

The current study will expand this research with participants with autism and class-specific reinforcement, and will also include some of the same participants. Another interesting aspect of this study is how the participants, having completed training sessions with four-term contingencies, will react when they encounter three-term contingencies for the first time.

Experiments 1 and 2 will determine if existing equivalence classes can be expanded via three-term contingencies trained with class-specific reinforcement. This study will provide direct tests of aspects of Sidman's reinforcer contingency theory, including the possibility that three-term contingencies produce equivalence relations (Sidman, 1986). Each participant will be trained with two conditional discriminations using compound class-specific reinforcement. If probe performances reveal that equivalence classes have formed between the members of each conditional discrimination, Experiment 1 will begin by training three simple discriminations with new stimuli but the same compound class-specific reinforcers. Class-expansion probes will determine if the new stimuli are matched with the appropriate members of the existing classes, thus addressing the possibility that equivalence relations have emerged with the new stimuli as a result of the three-term contingency training.

In addition, Experiment 1 will further test the possibility that reinforcers can become class members (Sidman, 2000). Performances on reinforcer probes will determine if each component of the compound class-specific reinforcers have joined the appropriate classes. If Experiment 1 is successful, Experiment 2 will then use the abstract stimuli trained in Experiment 1 as class-specific consequences in a procedure designed to establish a new set of simple discriminations, and may provide additional evidence related to Sidman's theory. Furthermore, Experiment 2 will allow evaluation of the functions of antecedent stimuli and reinforcers in a contingency. The novel abstract stimuli from Experiment 1 were only presented as discriminative stimuli, due to the format of simple discriminations. During probe trials, these stimuli were used as conditional and discriminative stimuli. In Experiment 2, however, the novel stimuli from Experiment 1 will be used as visual consequences. The abstract stimuli will appear on the computer screen after correct selections of members of a second set of novel stimuli. If probe-test performances demonstrate that class expansion has occurred as a result of this training, they will provide evidence that conditional stimuli, discriminative stimuli, and reinforcers can change their functions within a given contingency.

The results of this study will have direct applications to the field of education, particularly special education, because three-term contingencies are easier to learn than the four-term contingencies typically employed in stimulus-equivalence research (e.g., Sidman, 1986). Equivalence research specifically targeting class formation involving three-term contingencies has been studied more extensively in animal research (e.g. Kastak, et al., 2001; Vaughan, 1988) than in studies with human participants.

General Method

Participants

Nine students, eight males and one female, returned permission slips signed by a parent allowing them to participate in the study. All of the participants were diagnosed with autism and were enrolled in classrooms specifically for students with autism at two local elementary schools. Before the permission slips were distributed, the purpose of the study was explained to the classroom teachers, and they gave permission for the project to be conducted with their students during the school day.

The participants ranged in age from 5 years 9 months to 10 years 8 months. Each participant's exact age as well as the experiments in which he or she participated is presented in Table 1; participants were assigned a number based on their age and are referred to by that number throughout the study. All participants completed a Peabody Picture Vocabulary Test-Third Edition to determine listening comprehension skills. The PPVT-III measures receptive vocabulary or the level of language acquisition and is a screening test for verbal ability (Dunn & Dunn, 1997). PPVT-III scores are also presented in Table 1. Two participants, 4 and 8, were removed from the study at an early stage as a result of behavior problems; therefore, their data are not included.

Apparatus and Setting

All training and testing sessions were conducted on a Macintosh laptop computer (screen size 8.5 inches by 11.25 inches) with a match-to-sample software program that displayed all stimuli and the audio-visual components of the compound class-specific reinforcers (Dube, 1991). Three clear plastic cups, each with a photograph of one of the participant's edible reinforcers attached to the rim, were placed in front of the laptop on a sheet of paper with three columns, one for each cup. Selections of stimuli were made with either an optical mouse or the touchpad in front of the laptop keyboard, whichever the participant chose to use. One of three tally sheets (Figures 1, 2, and 3) was placed on the left or right side of the laptop with a pen or crayon; the tally sheet used depended on the participant and/or experiment. The participant sat directly in front of the laptop and

Table 1.

Participant Ages Peabody Test Scores, and Experiments

Participant number	Age (years-months)	Peabody age equivalent	Experiment
1	5-09	3-00	3
2	6-09	3-08	3
3	6-10	5-08	3
4[a]	8-01	2-05	-
5	9-01	3-06	3
6	7-5*	3-07	1
7	7-7*	4-10	1 and 2
8[a]	9-10	-	-
9	9-1*	6-11	-

Note. The age calculated for each participant is their age at the start of their participation in the current study. Participants 4, 6, 7, 8, and 9 started in October 2003 while participants 1, 2, 3, and 5 started in September 2004. Participant numbers were assigned chronologically from youngest to oldest.

[a]These participants could not continue in the study due to behavior problems.

Participant 8 did not complete a Peabody test before his participation in the study was ended.

*These participants' ages and Peabody scores were taken from the Ashford (2003) study. They were approximately two years older at the start of the present study.

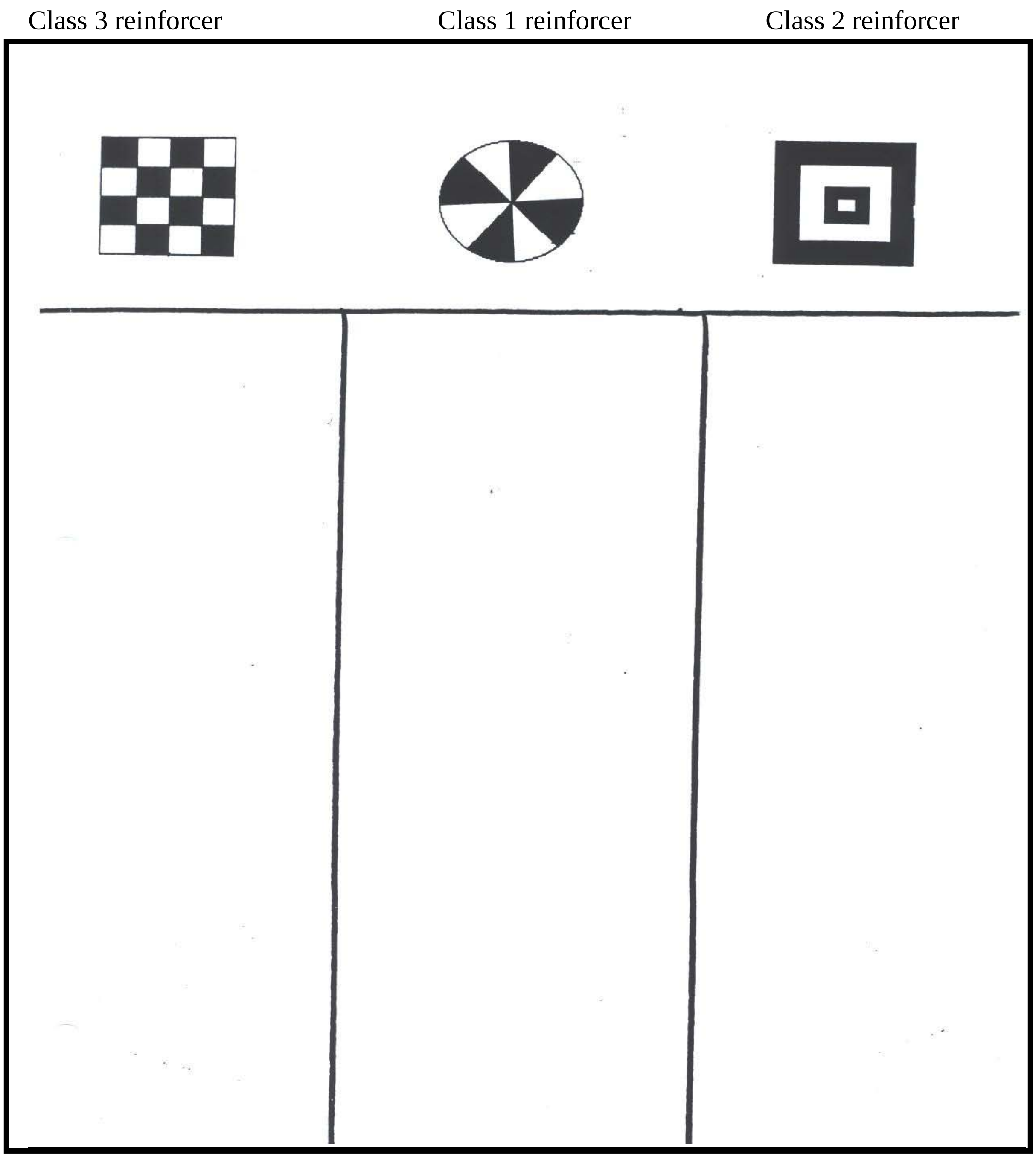


Figure 1. Baseline Tally Sheet

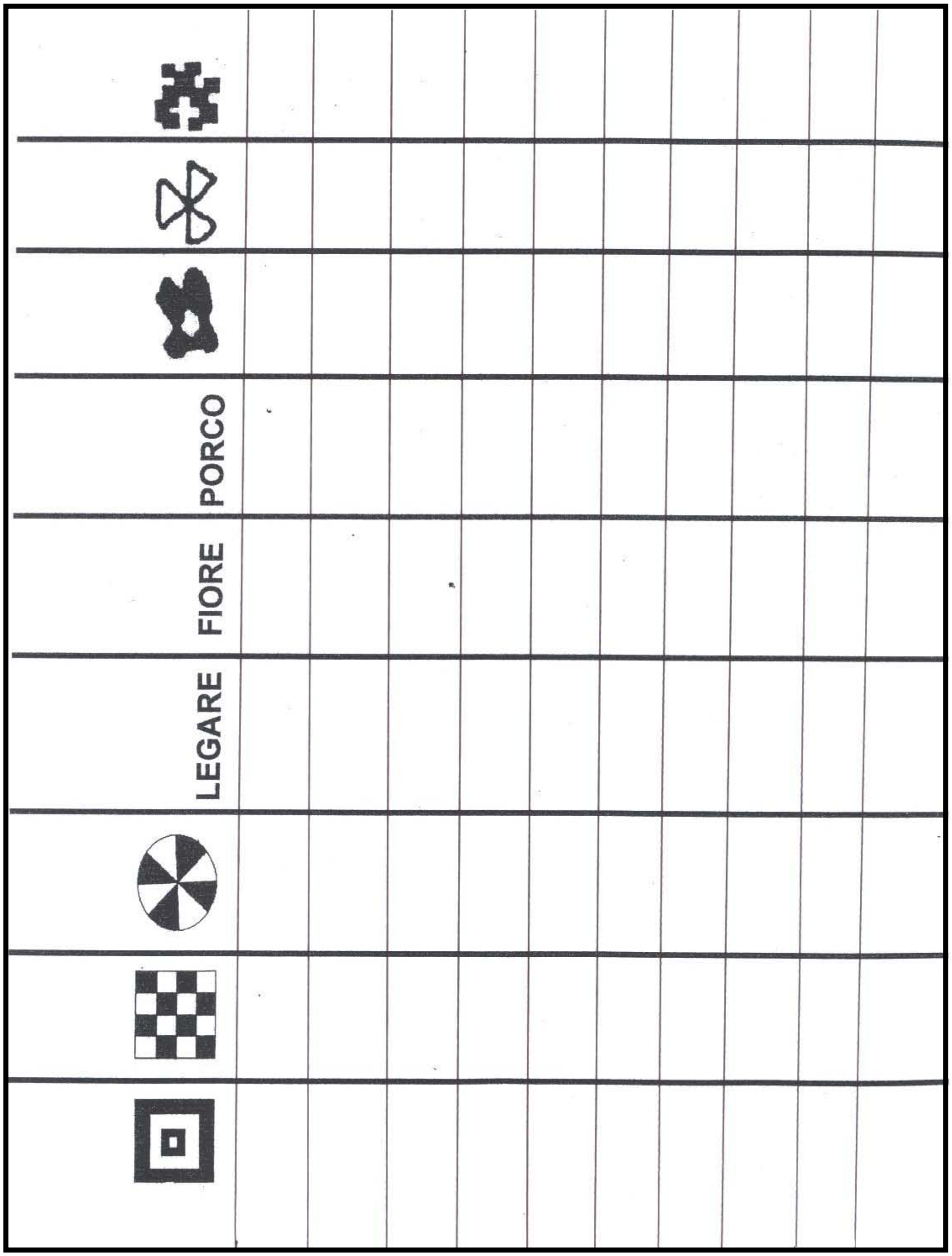


Figure 2. Extended Tally Sheet

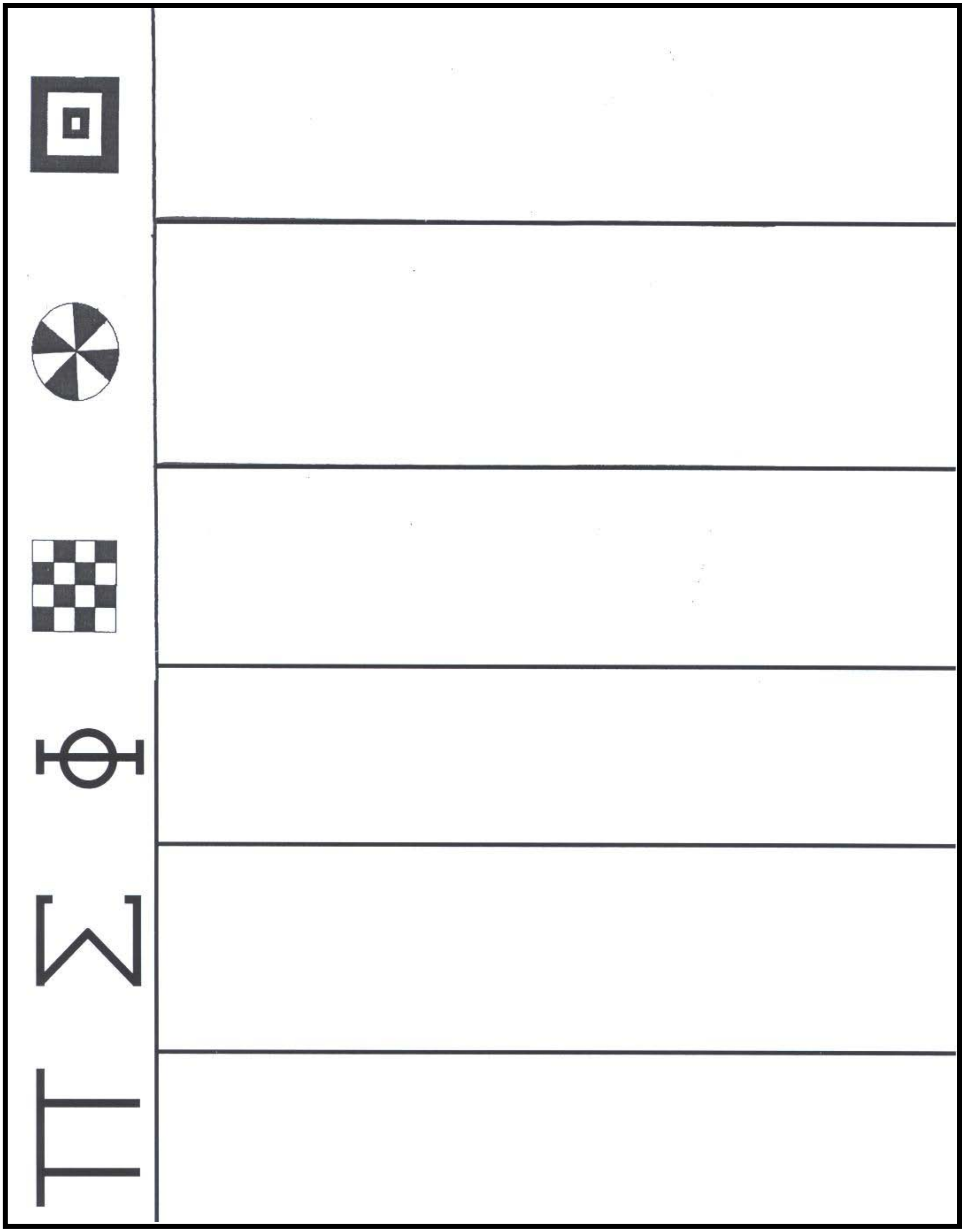


Figure 3. Experiment 1 Tally Sheet

the experimenter sat at their side. Sessions were conducted in either a quiet location within the classroom itself, a separate classroom, or the cafeteria.

Procedure

General Procedure

Reinforcer preference test and mouse training

At the start of the study, the experimenters visited the classrooms to build rapport with the participants. A reinforcer preference test was completed for each participant to determine three foods of approximately equal preference from a pool of six snack foods. The procedure for the reinforcer preference test was as follows: six foods were placed in clear plastic bags in a line on the table in front of the participant, and the participant was told to select one to eat. When the participant indicated a particular food, the experimenter removed one piece of it and let him or her eat it while the bags were positioned for the next trial. All six foods were presented for 12 trials, balanced for position so that each food appeared an equal number of times in all six possible positions. If the participant chose the same food at least five times within those 12 trials, it was removed because it was too highly preferred. When three foods appeared to be equally preferred, (i.e., they had been selected on approximately the same number of trials), those three foods were presented in pairs, balanced across 12 trials so that each food appeared with the remaining two an equal number of times and was positioned on the right or left side the same number of times. If all three foods were still chosen on approximately the same number of trials, they were assigned as that participant's primary reinforcers. Table 2 lists the three foods each participant received for correct responses on reinforced baseline trials. During this pre-experimental phase, the participant was also given a few

Table 2.

Primary Class-Specific Reinforcers by Participant

Participant 1	2	3	4	5	6	7
Apple cereal	Cookie cereal	Fish crackers	Fruit snack	Popcorn	Apple cereal	Pretzel
Cookie cereal	Apple cereal	Cookie cereal	Pretzel	Fish crackers	Popcorn	Popcorn
Fruit snack	Fruit snack	Pretzel	Potato chip	Pretzel	Fruit snack	Apple cereal

Table continues

Table 2 continued

8	9
Cookie cereal	Pretzel
Fruit cereal	Popcorn
Apple cereal	Apple cereal

Note. The primary edible reinforcers are listed in order of the class to which they corresponded; the first snack listed was assigned to the 1 class, the second snack listed corresponded to the 2 class, and the last snack listed was assigned to the 3 class.

minutes to play “the color game” on the laptop; the color game was an entertaining children’s computer game unrelated to the experimental test sessions, which were referred to as “the black and white game” because all computerized stimuli and reinforcers were black and white. Allowing the participants to play the color game provided the experimenters with a method of evaluating whether the participants’ mouse skills were accurate enough to allow them to begin experimental sessions. Some participants required additional mouse training while others started experimental sessions rapidly.

Conditional discrimination training

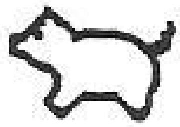
Participants completed three or four sessions a week during the school day, except during holidays or other absences. Each session lasted approximately 10-15 minutes. A single computer was used for all sessions. Each Friday, participants played the color game as a reinforcer for cooperative behavior during the week’s sessions. Participants who completed more than one session each day earned more frequent access to this game; only participants whose behavior did not prevent them from sitting in front of the computer for additional time were offered the opportunity to complete consecutive sessions within a single day. In addition to extra opportunities to play the color game, participants could choose a food item (one that they were not receiving as a class-specific primary reinforcer) to eat if they completed more than one session in a single day.

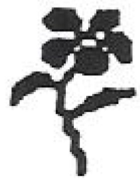
One at a time, each participant went to “computer time” at the request of the classroom teacher or experimenter. The participant could decline to participate on a given day; in addition, because, for many participants, the opportunity to use the laptop was reinforcing, the teachers could prevent a participant from completing a session on a given day if his or her behavior had not met the classroom expectations.

Each participant started the experiment with training for two conditional discriminations. Participants 4, 7, and 8 were trained with an A→B A→C baseline, and the remaining six participants were trained using an A→B C→D baseline. Each letter designated a set of three distinct stimuli; thus, the participants were trained with six different stimulus pairs: $A_1 \rightarrow B_1$, $A_2 \rightarrow B_2$, $A_3 \rightarrow B_3$, and either $A_1 \rightarrow C_1$, $A_2 \rightarrow C_2$, $A_3 \rightarrow C_3$ or $C_1 \rightarrow D_1$, $C_2 \rightarrow D_2$, and $C_3 \rightarrow D_3$.

During each participant's first baseline session, the experimenter stated that there was a new game to play on the computer. When the experimenter started the session, a stimulus appeared in the center of the white computer screen. All stimuli were black and white, approximately 1 inch by 1 inch abstract, nonsense shapes or recognizable, common objects and their German or Italian names. The A→B A→C stimuli are presented in Figure 4 and the A→B C→D stimuli are presented in Figure 5. The experimenter asked the participant, "Do you see a picture in the middle of the screen?" When the participant agreed, the experimenter responded, "Click on it." Clicking on the sample stimulus with the mouse produced three comparison stimuli. This response was required to increase the probability that the participant was attending to the sample stimulus. The comparison stimuli appeared in three of the four corners of the screen; one of the corner positions remained empty on every trial, and the location of the empty corner varied unsystematically. After the comparison stimuli appeared, the experimenter asked, "Do you see three other pictures in the corners?" When the participant agreed, the experimenter gave one simple instruction: "Pick one" or "Click on one."

A_1 **A_2** **A_3**





B_1 **B_2** **B_3**

SCHWEIN BLUME SCHLIPS

C_1 **C_2** **C_3**

PORCO FIORE LEGARE

Figure 4. $A \rightarrow B$ $A \rightarrow C$ Stimuli

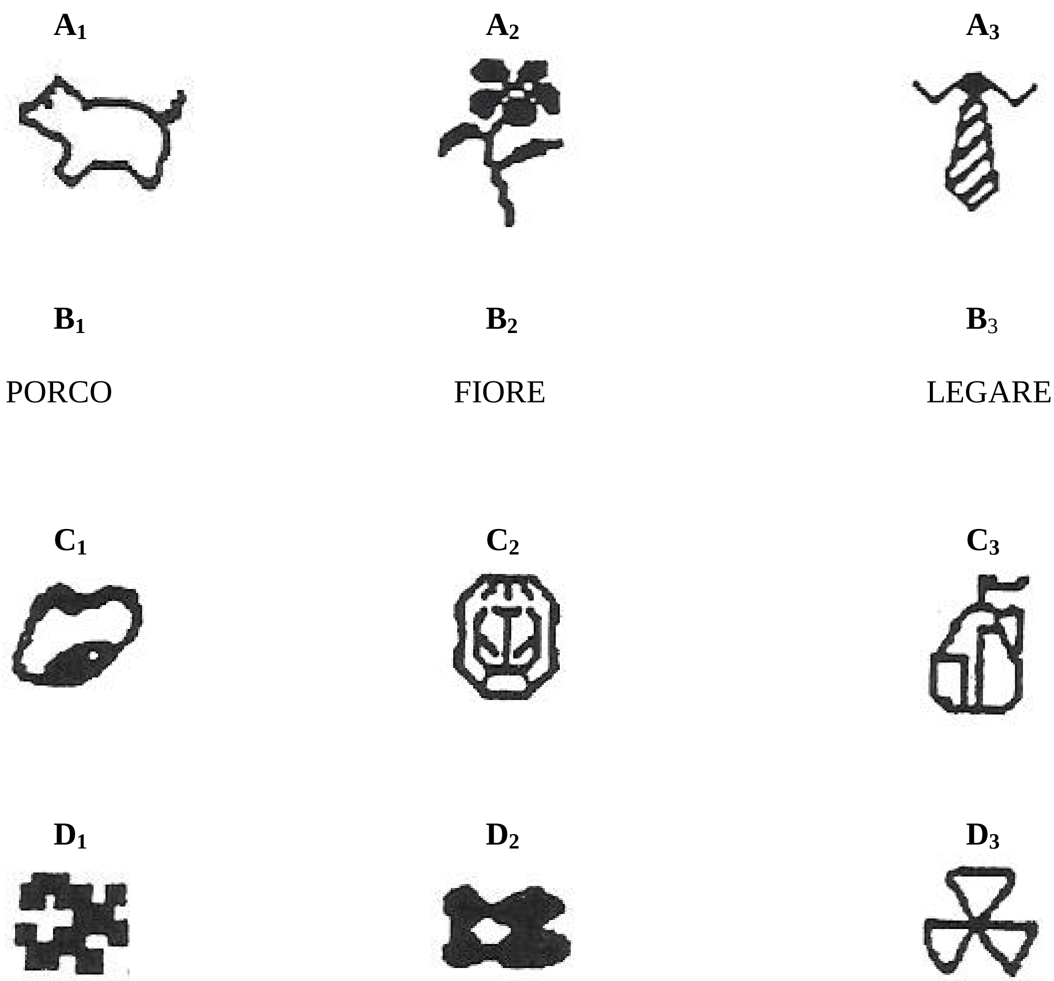


Figure 5. A→B C→D Stimuli

Presentation of all stimuli was balanced for frequency of appearance and position. All baseline sessions met the following criteria: each stimulus appeared the same number of times. Comparison stimuli appeared in each of the four corners of the screen on an equal number of trials. No more than two trials with the same sample stimulus could appear consecutively. Lastly, the corner of the screen where the correct stimulus appeared altered so that all four corners of the screen were correct for the same number of trials, and the correct stimulus could not appear in the same position during more than two consecutive trials.

After the participant selected one of the comparison stimuli by clicking it with the mouse, consequences were presented. If the participant picked one of the two incorrect stimuli based on the sample stimulus, all stimuli disappeared and the computer produced the sound of a buzzer and an inter-trial interval of 1.5 seconds. But if, by chance, the participant picked the correct stimulus, they received the appropriate compound class-specific reinforcer, which included a distinct audio-visual display on the computer and one of the three edible reinforcers assigned to that participant. The edible was delivered into the appropriate cup in front of the laptop. The audio-visual display played for several seconds, then the screen was blank for the inter-trial interval of 1.5 seconds. Each of the three experimenter-designated stimulus classes was assigned a specific audio-visual display and food item as the compound class-specific reinforcement; this remained constant throughout the experiment.

The participant was required to make a mark on the baseline tally sheet (Figure 1) underneath the appropriate picture of the visual reinforcers (see labels in Figure 1). In addition, the participants also had to make a mark in front of the cup into which the experimenter placed the edible reinforcer for that trial. The instructions given to teach participants how to make these marks were as follows: when the audio-visual display disappeared from the computer screen, the experimenter pointed to all three of the pictures on the baseline tally sheet and asked “Which one did you see?” The participant chose the correct picture and was asked to “make a mark” underneath it with either a pen or crayon. The experimenter then pointed to all three of the cups and asked “Which one did you get?” Again, the participant was instructed to “Make a mark.” If a particular participant had difficulty marking the tally sheets or tried to draw when given a writing utensil, they were instead asked to point to the appropriate image of the visual reinforcers which were enlarged and placed on a piece of black construction paper.

These were the only instructions the participant received relative to the actual experiment. Throughout the session, the experimenter encouraged the participants with comments such as “You’re doing good work” or “Good marking” and maintained their attention to the task; however, no instructions of any kind were given regarding which stimuli the participant should select. As participants became increasingly familiar with the task, the experimenter faded instructions on marking or pointing so that the only instruction given was an indication that the participant could begin the session.

All baseline and probe programs had two versions which differed only in the order of trial presentation. In the second version of each program, the first half of the trials were switched with the second half to control for the possibility that the participants were recalling the position of the correct stimulus after repeated exposure to the same program. Participants received baseline training with one conditional discrimination at a time. The criterion for mastery was set at 90% correct responding for two consecutive sessions. This criterion remained in place throughout baseline training. The match-to-sample computer program scored each session when the participant completed it by producing a text file which listed each trial completed within a given session, the stimulus the participant chose, and the correct stimulus. At the end of this file was the percentage of trials on which the participant chose the correct stimulus. The experimenter could record the score provided by the program and also inspect each trial if necessary to detect any unusual patterns of responding. Once participants reached the mastery criterion, they began training with the next conditional discrimination. Table 3 outlines the conditional discrimination training phases of the experiment. If, after 10 sessions of training with one or both of the conditional discriminations, the participant did not show acquisition trends (i.e., the scores were not approaching 90% correct responding), they proceeded to Experiment 3. The exception was Participant 9, who completed numerous phases in the experiment to help him acquire the conditional discrimination baseline relations because his performances were unique (see results).

After reaching the mastery criterion for each of the conditional discriminations presented individually, the participant received sessions in which trials from both discriminations were mixed together. When the participant reached the mastery criterion for correct responding on sessions of mixed baseline conditional discrimination trials, the reinforcement density was decreased to 75%, then 50%. When the reinforcement density was reduced, if students responded correctly, reinforcers were available only for a specific percentage of trials (75% or 50%). Reducing the reinforcement density prepared the students for probe sessions, which tested for the emergence of relations that were not directly trained. Reinforcers were never available on these trials; if the participant were

Table 3.

Conditional Discrimination Training and Testing

Session type	Stimuli (AB AC baseline)	Stimuli (AB CD baseline)	Number of trials
AB Training	*AB*	AB	24
AC[a] Training	AC	-	24
CD[b] Training	-	CD	24
Mixed Baseline	AB and AC	AB and CD	36; 18 of each type
Mixed Baseline 75% S^{Rc}	AB and AC	AB and CD	36; 18 of each type
			9 unreinforced
Mixed Baseline 50% S^{R}	AB and AC	AB and CD	36; 18 of each type
			18 unreinforced
Symmetry Probes	AB, AC, BA, and CA	AB, CD, BA, and DC	18 baseline, 6 probes
Transitivity Probes	AB, AC, BC	AB, CD, AC, BC, AD, CD	18 baseline, 6 probes (AB, AC baseline)
			24 baseline, 12 probes
			(AB, CD baseline)

Table continues

Table 3 continued

Session type	Stimuli (AB AC baseline)	Stimuli (AB CD baseline)	Number of trials
Reflexivity Probes	A→B, A→C, A⇢A, B⇢B, C⇢C	A→B, C→D, A⇢A, B⇢B, C⇢C, D⇢D	18 baseline, 9 probes (AB, AC baseline) 24 baseline, 12 probes (AB, CD baseline)

Note. All of the above sessions contained conditional discrimination trails only. The underlined relations represent baseline; all remaining relations are probe trials.

[a]This training session only applies to participants with an A→B A→C baseline.

[b]This training session only applies to participants with an A→B C→D baseline.

[c]The notation S^R is an abbreviation for reinforcement

to receive feedback on probe trials, the relations could not be labeled "emergent." Probe trials were mixed with baseline trials with a 50% reinforcement density.

Class formation probe trials

Symmetry, transitivity, and reflexivity probes were presented, in that order, to test for the formation of equivalence classes. Probe trials were interspersed with baseline trials within each probe session. While during baseline sessions, the participant alternated between the two versions of a single type of training, probe sessions were completed differently in that the participant completed one of each type, symmetry, transitivity, and reflexivity, then completed a second set of all three types (so the order of the trials could be varied).

The computer program provided separate scores for baseline and probe trials within each session; the probe trials were not counted when the computer calculated the baseline percentage. Instead, probe trials were listed with either a plus or minus symbol next to them, where a plus sign indicated that the participant chose the appropriate stimulus and a minus sign indicated that he or she had not selected the correct stimulus. Data for each type of probe were evaluated for stability separately through inspection of graphs of each participant's baseline and probe scores.

When all performances were stable, reinforcer probes were given to determine if all three elements of each of the compound class-specific reinforcers had become class members. There were four types of reinforcer probes. One type presented the visual portion of the compound class-specific reinforcers as either sample or comparison stimuli with A, B, C, and, if appropriate, D stimuli to determine if the participant could match each of the three visual reinforcer components with the stimuli from the class to which it corresponded. Class-consistent responses on these probes would suggest that the visual component of the class-specific reinforcers were also equivalence class members.

A second type of reinforcer probes presented images of the edible reinforcers as either samples and comparisons with each letter group of stimuli to determine if that portion of the class-specific reinforcers had joined the classes. These probes were different for each participant because the three edible reinforcers were assigned on an individual basis via the reinforcer preference test. The third set of reinforcer probes presented the auditory components of the reinforcers as samples with each letter group of stimuli separately to determine if the sounds were equivalence class members. During these probe trials, a diamond-shaped stimulus appeared as the sample in the center of the screen (Figure 6). When the participant clicked on it, one of the three class-specific auditory reinforcers played repeatedly. The participants had to click a second time for the three comparison stimuli to appear in the corners of the screen. The sound continued to repeat until the participant selected one of the comparison stimuli, at which point the screen went blank for an inter-trial interval. The final type of reinforcer probe determined if participants could match the visual image of the computerized display to the image of the edible reinforcer appropriate for each class. Each image was presented as a sample stimulus on some trials and as a comparison stimulus on other trials. When the image of one of the three computerized displays was the sample, the images of all three of that individual participant’s edible reinforcers were the comparison stimuli, and the reverse was true when the edible reinforcer images were the sample stimuli. If a participant’s probe performances demonstrated class formation with stimuli and reinforcers, he or she proceeded to Experiment 1.

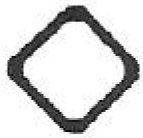


Figure 6. Sound Probe Sample Stimulus

Previous Experimental History

Participants 4, 5, 6, 7, 8, and 9 were part of Christy Ashford's (2003) study on compound class-specific reinforcement. Although the conditional discrimination training in the present study is identical to that used in Ashford's study, these participants have a more complex experimental history. Participants 6 and 7 had formed nine- and eight-member equivalence classes, respectively. The stimuli in these classes included the stimuli trained in the baseline conditional discriminations as well as two additional stimulus sets, labeled E and F. In addition, each component of the class-specific reinforcers had joined their respective classes.

Participant 9 had a highly complex history. After mastering the two trained conditional discriminations, A→B and C→D, reflexivity and symmetry relations emerged between the stimuli; however, transitivity relations between the two conditional discriminations failed to emerge, despite exposure to a number of sessions designed to bring about class formation.

In the present study, participants 4, 6, 7, 8, and 9 were retrained with the same conditional discriminations they received training for in Ashford's (2003) study, using the same compound class-specific reinforcers presented during their training in that study. Participant 5 was removed from Ashford's study as a result of behavior problems. He had only completed some training with one conditional discrimination and had demonstrated possible signs of acquisition on sessions where only two comparison choices were presented. One set of participant 5's stimuli, the A stimuli, were identical to those used in the present study. He was treated as a new participant in the current study and completed a new reinforcer preference test. When each participant had either established or re-established a baseline of two conditional discriminations, they started simple discrimination training in Experiment 1. The stimuli and use of three-term contingencies were new to all participants; none of the participants had previously been exposed to simple discrimination trials.

Conditional Discrimination Baseline Retraining Results

Before each participant's results are discussed, it should be noted that, because the participants were tested in their traditional (as opposed to year-round) public school classrooms, all experiments were halted during summer and other holiday breaks; in other words, the school calendar placed restraints on the testing schedule. After summer break, it was necessary to re-train all relations to ensure that the classes were still intact. As a result, some participants have more than one set of data from a single phase or experiment in the study. The present study started approximately five months after testing for Ashford's (2003) study was completed.

Both participants 6 and 7 were part of that study. Participant 6 was trained originally with an A→B C→D conditional discrimination baseline, and he reacquired the baseline relations rapidly (see first panel of Figure 9). Next, the participant completed three blocks of symmetry, transitivity, and reflexivity probes (i.e., each type of probe was given once, then the sequence was repeated two times) and one extra session of symmetry probes to determine if the three classes had been maintained. His performance on these probes was class-consistent (see top, left panel of Figure 10). Following class-formation probes, the participant completed reinforcer probes to determine if all three components of the compound class-specific reinforcers had also become class members.

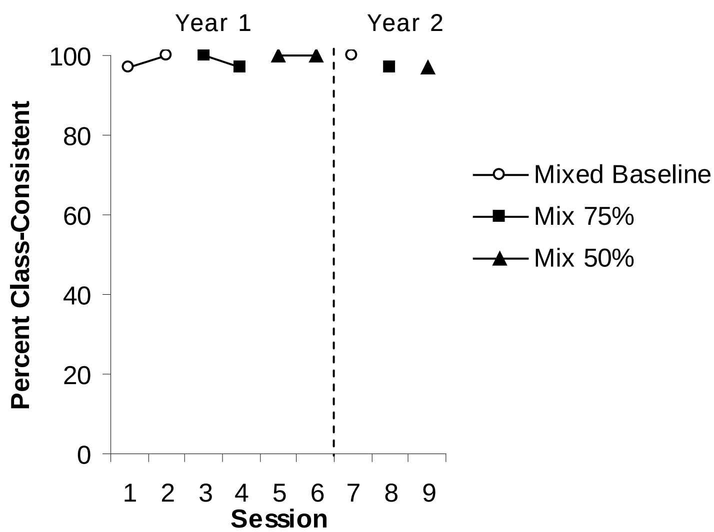


Figure 9. Participant 6 Conditional Discrimination Training

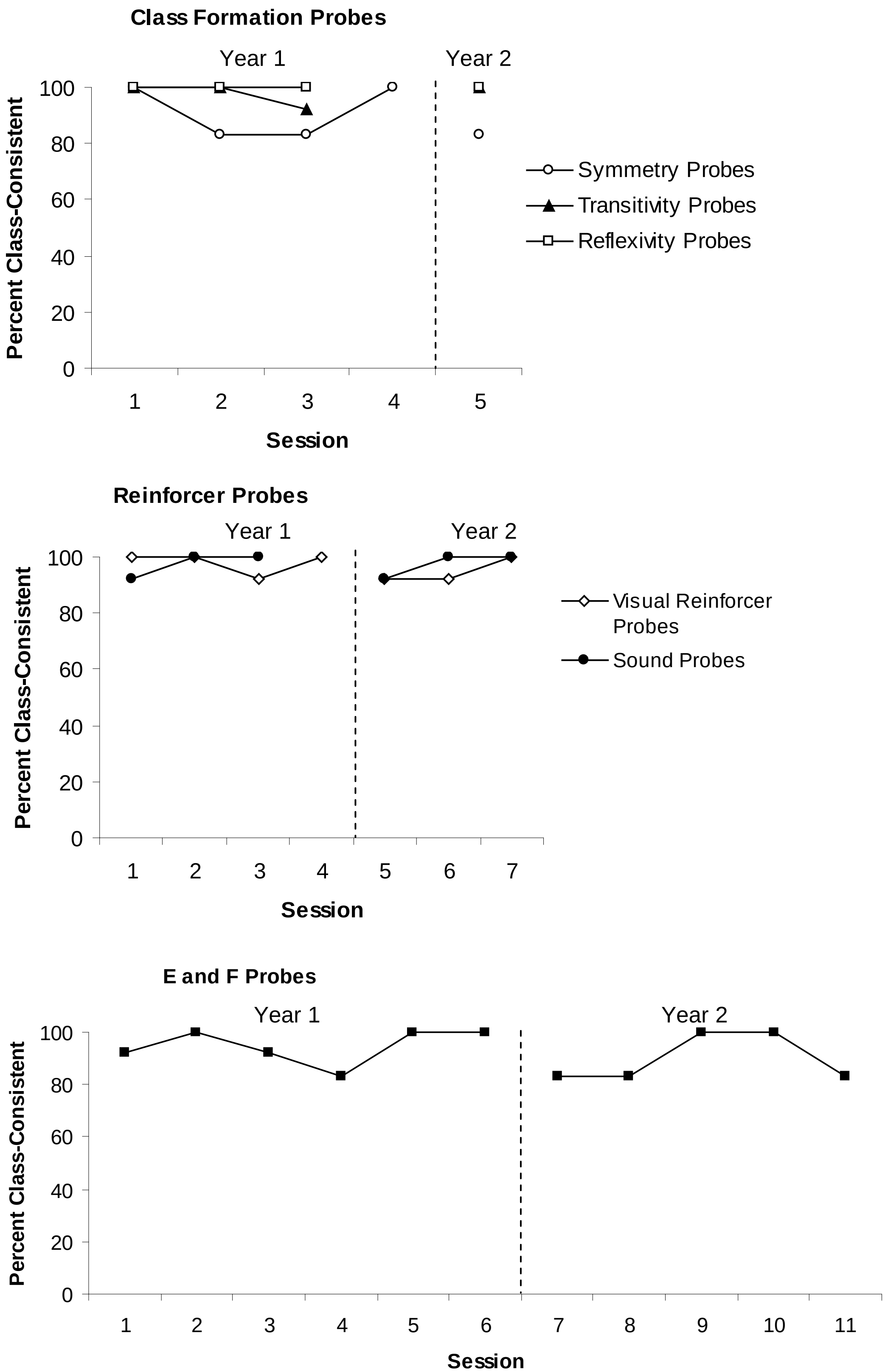


Figure 10. Participant 6 Conditional Discrimination Phase Probes

Figure 10 (middle left panel) shows that his performance on these probes was also class-consistent.

Participant 6 also demonstrated previously established class-expansion relations. After mastering the two conditional discriminations, participant 6 completed reinforced identify matching trials with two additional stimulus sets, E and F. Each stimulus set had three members, E_1, E_2, E_3 and F_1, F_2, and F_3 which corresponded to the 1, 2, and 3 classes via the class-specific reinforcers. These stimuli are presented in Figure 11. In the 2003 study, only one component of the compound class-specific reinforcers was used to reinforce correct selections of E and F stimuli. During E identity-matching trials in 2003, participant 6 received only the audio-visual displays on the computer, for a correct response. When participant 6 made a correct selection on F identity matching trials, he received only the edible reinforcer appropriate to that stimulus. When these relations were retrained in the current study, the elements of the reinforcers were not separated; participant 6 received all three elements of the compound-class specific reinforcers for correct selections of identical E and F stimuli on reinforced identity-matching trials.

After E and F identity relations were re-trained, class-expansion probes determined if the stimuli had become members of the existing classes. These probes presented an E or F stimulus as a sample stimulus on some trials and all three E or F stimuli as comparison stimuli on other trials with the A, B, C, and D stimuli. The participant's probe performances were highly class-consistent (see bottom, left panel of Figure 10).

Participant 6 completed a brief version of the conditional discrimination training and testing phase again at the beginning of the next school year (his participation took

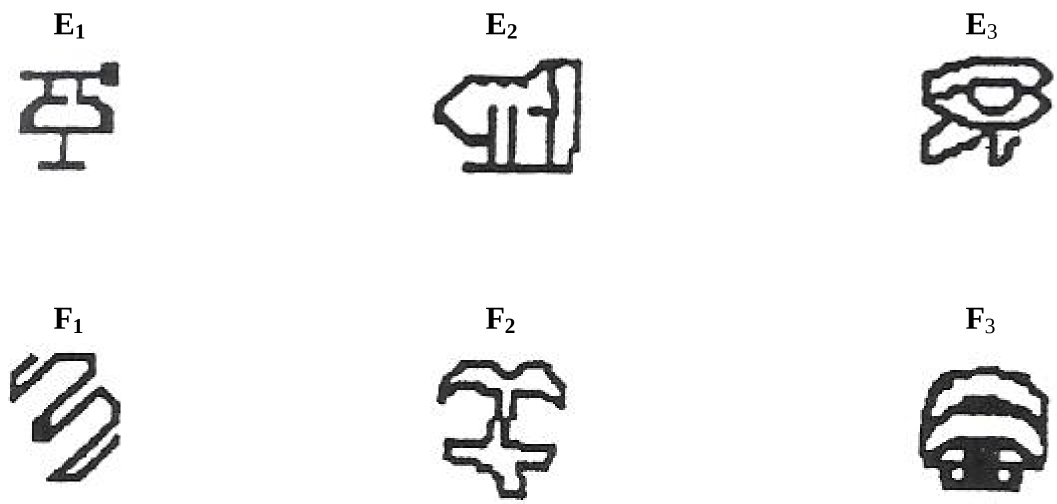


Figure 11. E and F Stimuli

place over two full school years). His baseline was nearly errorless throughout this retraining period (see Figure 9, top right panel), and all probe performances were class-consistent (See Figure 10, middle and bottom right panels).

Participant 7 was trained with an A→B A→C conditional discrimination baseline. He also met the mastery criterion on all sessions of the mixed baseline phase fairly quickly, although his scores fluctuated throughout most of the baseline and mixed baseline phases (see Figure 12, left panel). His responses on class formation and reinforcer probes were class-consistent (see Figure 13, left panels). Due to experimenter error, this participant did not complete sound probes. In the interest of time, participant 7 did not complete class-expansion re-training and testing with the E and F stimuli in the current study. Participant 7 remained in the study for two full school years. At the start of the next school year, he reacquired the baseline immediately, and was therefore only required to complete one session at each reinforcement density (see Figure 12, top right panel). Responses on class formation and reinforcer probes were once again class-consistent; the scores are presented in Figure 13, (right panels).

Participant 9 received training with an A→B C→D baseline. These relations were re-established in only three sessions and nearly errorless scores were maintained as the availability of reinforcers for correct responses was decreased (see Figure 14, left panel). As in Ashford's experiment, this participant's symmetry and reflexivity probe performances were nearly perfect. His performance on transitivity probes, however, fluctuated greatly (see Figure 15, top left panel). Interestingly, participant 9 used an extended tally sheet (Figure 2) and could accurately mark the corresponding B and D stimuli on the tally sheet, although B⇢D relations were presented as probe trials. B and D

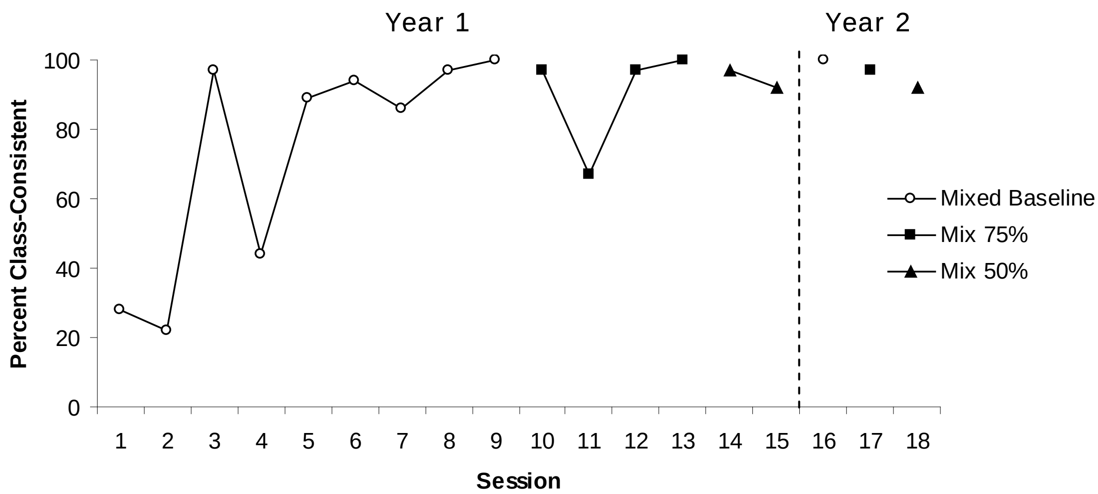
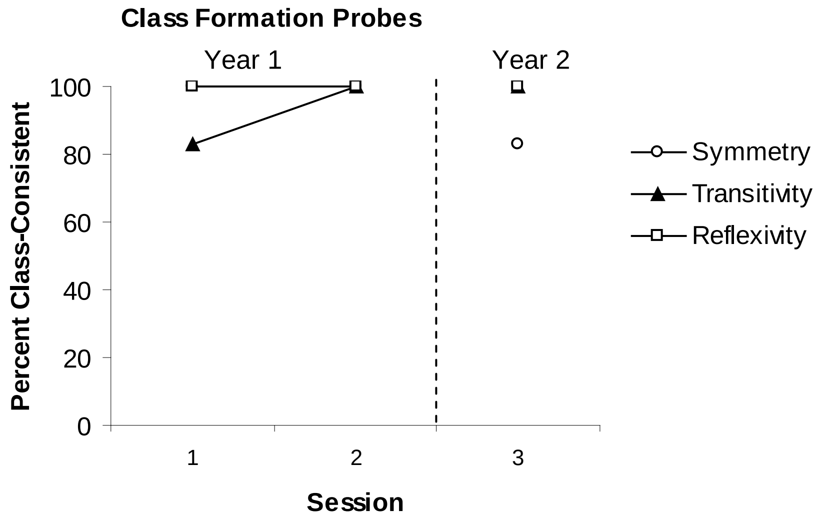


Figure 12. Participant 7 Conditional Discrimination Training



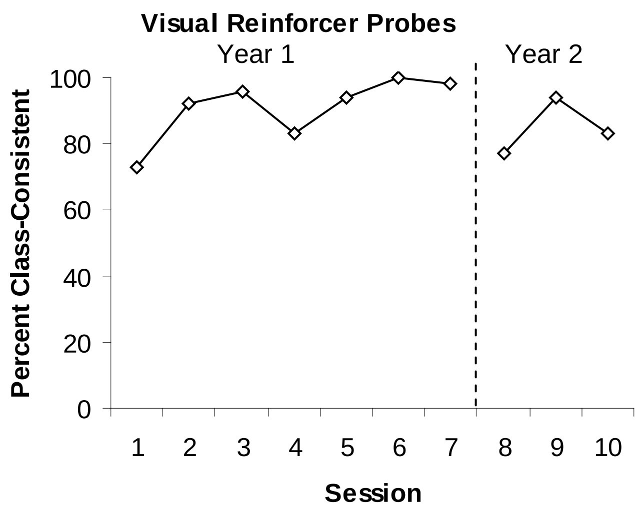


Figure 13. Participant 7 Conditional Discrimination Phase Probes

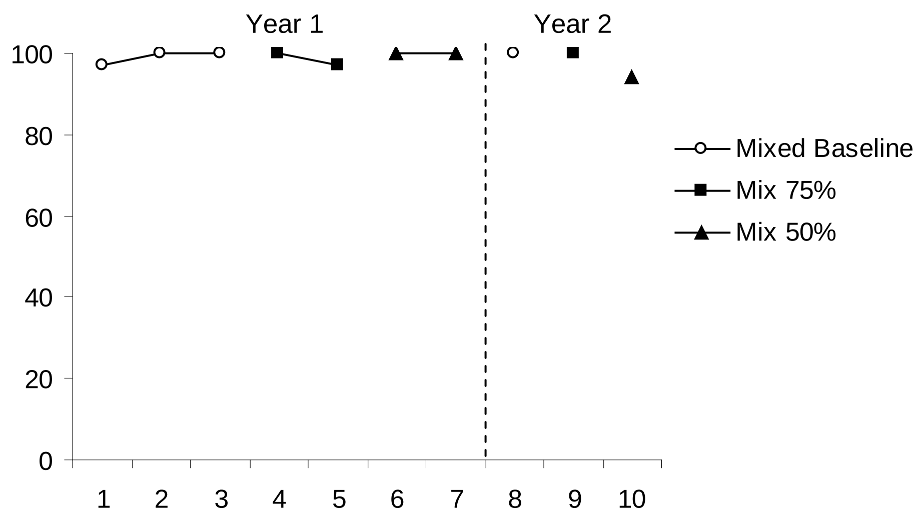
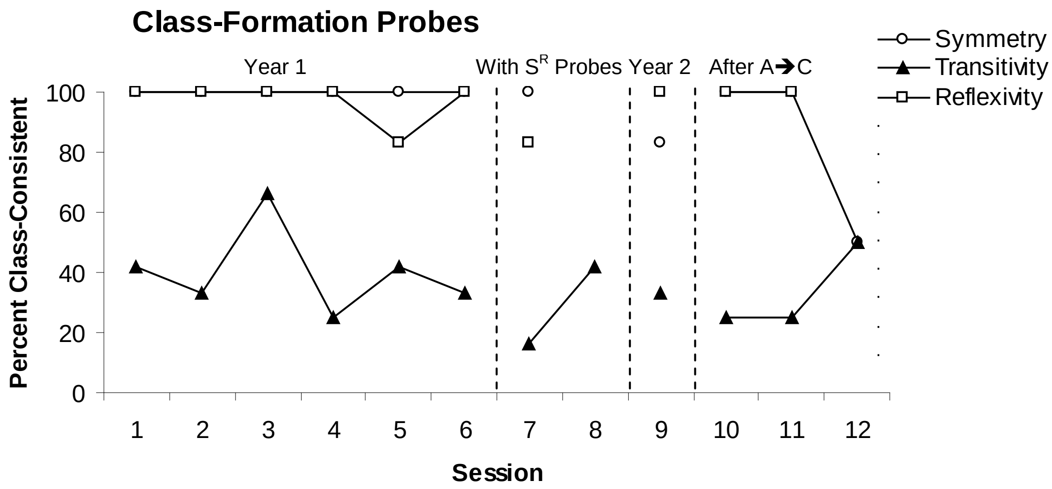


Figure 14. Participant 9 Conditional Discrimination Training



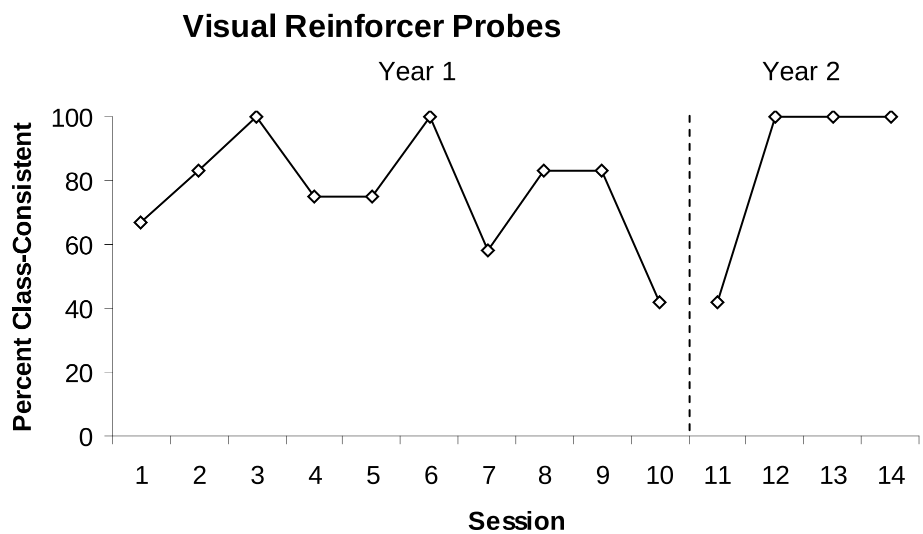


Figure 15. Participant 9 Conditional Discrimination Probes

never appeared together on a reinforced baseline trial and the participant was not given any reinforcement for marking the extra stimulus, yet he continued to do so accurately. Two blocks of reinforcer probes with visual stimuli were given in an attempt to bring about class-consistent responding on transitivity probes. Afterwards, sessions of symmetry, transitivity, and reflexivity probes were mixed in with sessions of reinforcer probes, but his performance on transitivity probes did not improve (see Figure 15, second top panel). Sessions 7-10 of the reinforcer probes in Figure 15, bottom panel, are those that were interspersed with class-expansion probes.

At this point, participant 9 stopped testing for the summer. He did not have any sessions from May 12 through August 27; however, when he completed a mixed baseline session on August 27th with both conditional discriminations, he chose the correct stimulus based on the sample on every trial. Because participant 9 had already re-established his conditional discrimination baseline at the start of the present study, and had achieved a perfect score on his first session after three months, he was required to complete only one session at the minimal 90% accuracy before progressing through the training (see Figure 14, right panel). Participant 9 completed one set of class-formation probe sessions and again showed that the transitive relations had not emerged (see Figure 15, third top panel). A round of reinforcer probes was completed next; his performance on the first session was somewhat class-consistent, but his performance on the second three sessions was errorless (see Figure 15, bottom right panel). Participant 9 then completed a session with symmetry probes and his baseline score fell to 88%, below the 90% accuracy requirement. As a result, the participant then completed sessions of mixed baseline trials at the 50% reinforcement density until reaching the mastery criterion of

90% correct on two sessions (note: baseline data for sessions with probes were not graphed). He was then returned to sessions with probe trials, without any improvement in transitivity probe performance. Participant 9 was then trained A→C relations, expanding his conditional discrimination baseline to A→B, A→C, and C→D. The procedure for this training followed that of the training with the original two conditional discriminations. Participant 9 met the mastery criterion with the A→C relations after four sessions, then completed sessions with his full baseline of A→B, A→C and C→D at decreasing reinforcement densities (see Figure 16). The participant then completed several rounds of symmetry, transitivity, and reflexivity probes; the scores reveled that transitive relations between the stimuli had still not emerged (see Figure 15, top right panel).

The remaining participants also began their training in the conditional discrimination phase. Participant 1 started with A→B training where one of three common objects (A stimuli) was presented with corresponding Italian names as comparison stimuli (B stimuli). There was concern that this participant could not discriminate between the words as a result of her young age and ability level. She was switched to training with C→D (abstract pictures→abstract pictures) after 10 sessions of training with A→B without any signs of acquisition. At first, she showed a slight trend toward acquisition, but her scores quickly decreased to chance levels (see Figure 17, top panel); "chance" scores are those that can be expected if a participant were to guess randomly on every trial. After 10 sessions of C→D training with almost all scores at the chance level, participant 1 was switched to Experiment 3 training with simple discriminations. Participant 3 showed similar results in the conditional discrimination

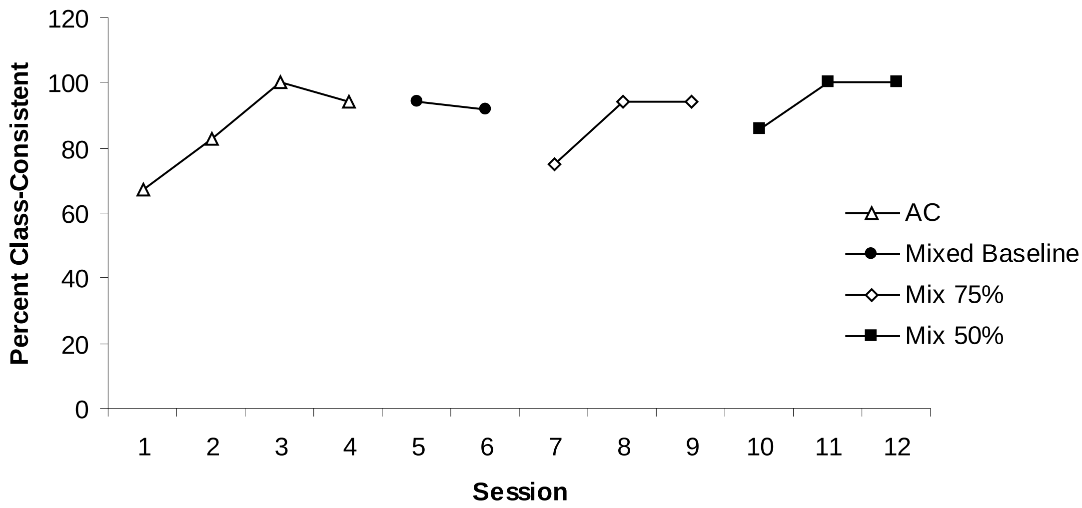


Figure 16. Participant 9 A→C Training

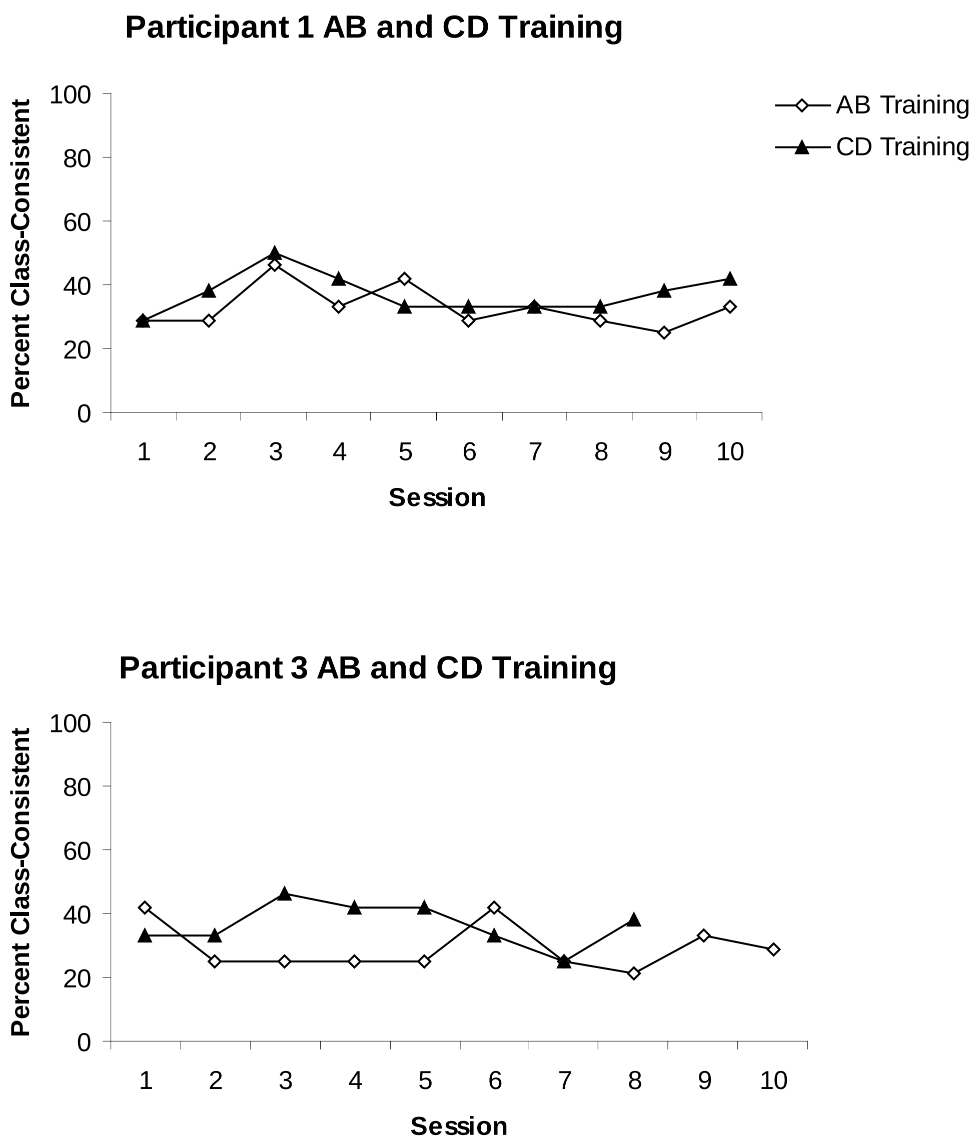


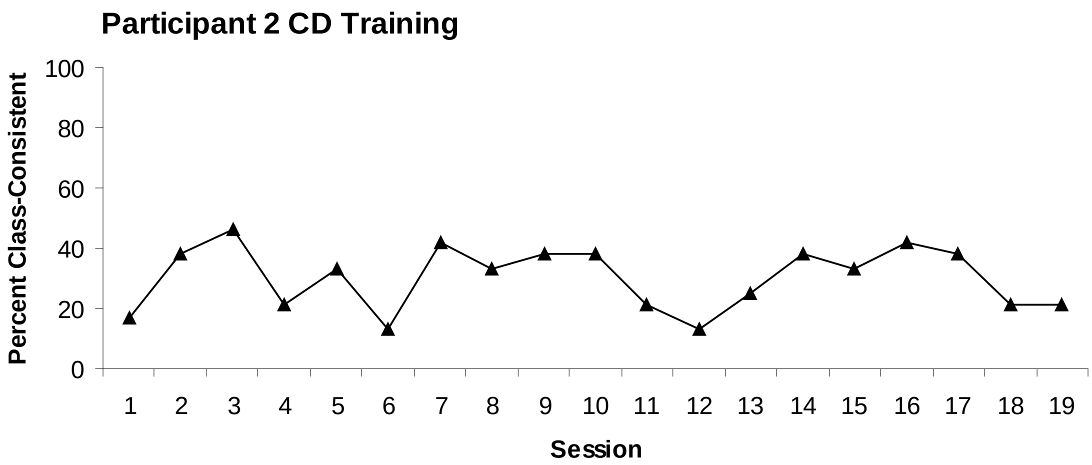
Figure 17. Participants 1 and 3 Conditional Discrimination Training

phase; he was also switched to Experiment 3 training after 10 sessions with A→B, followed by eight sessions of C→D training, without any trends toward acquisition (see Figure 17, bottom panel).

Participants 2 and 5 started training with C→D. After 10 sessions, all of participant 5's scores were at the chance level and he immediately began Experiment 3 training (see Figure 18, bottom panel). Participant 2 also started training with C→D. Because of the variability in his scores, he was given another nine sessions of training. The variability in his scores continued without any trends toward acquisition; therefore, this participant also started training for Experiment 3 (see Figure 18, top panel).

Discussion

For participants 6 and 7, the conditional discrimination baseline relations were rapidly re-established and probe performances demonstrated that three equivalence classes had emerged. The fluctuations in participant 7's baseline performance and, occasionally, probe scores were largely due to inattention or rushing; participant 7 was easily distracted by the activities of other students in the classroom. In addition, if participant 7 was scheduled to go to another class or activity shortly after his session, he responded rapidly and inaccurately, continually looking at the clock and making comments about not having enough time. It should be noted that the experimenter never began a session unless there was enough time for the participant to complete the session prior to their next scheduled activity. Participant 7's equivalence classes each contained six members, an A, B, and C stimulus and each of the three components of the compound class-specific reinforcer associated with that class. Participant 6's classes contained nine



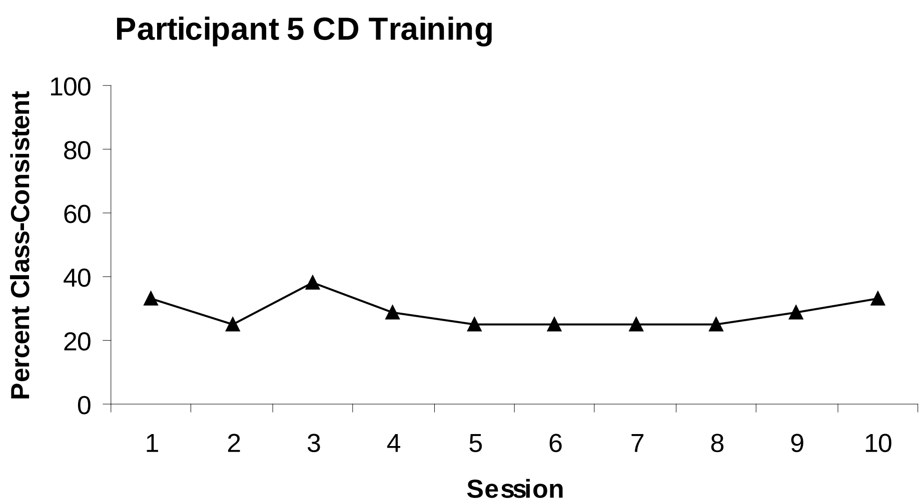


Figure 18. Participants 2 and 5 Conditional Discrimination Training

members each, including an A, B, C, D, E, and F stimulus, as well as the three components of each class's compound class-specific reinforcer.

The remaining seven participants failed to acquire the conditional discrimination baseline relations after at least 10 sessions of training. Their results provide evidence that conditional discriminations are often difficult for children with developmental disabilities, in this case autism to acquire.

Experiment 1

Method

Participants

Two participants, 6 and 7, met the acquisition criteria for the conditional discrimination training phase and began Experiment 1 training.

Apparatus and Setting

The apparatus and setting were identical to those of the conditional discrimination training phase, with the exception that both participants used only the baseline tally sheet (Figure 1).

Procedure

Simple discrimination overview

The purpose of Experiment 1 was to see if the equivalence classes that developed after the conditional discrimination training phase could be expanded. A set of three simple discriminations were trained with the same compound class-specific reinforcers used during conditional discrimination baseline training. If the stimuli trained with simple discriminations were to join the participant's existing classes, the only explanation would be that equivalence relations had developed between each G stimulus and the corresponding class members as a result of the compound class-specific reinforcers held in common.

Participants were trained with three, three-choice simple discriminations. The stimuli were Greek letters; the letters designated as correct were uppercase Phi (G_1), Pi (G_2), and Sigma (G_3), which corresponded via the compound class-specific reinforcers to the existing 1, 2, and 3 classes, respectively. The correct stimuli were assigned the alpha-numeric labels G_1, G_2, and G_3, because participant 6, the participant with the largest existing classes, had classes containing stimuli A-F. Each G stimulus was presented with two distracter stimuli, which were uppercase or lowercase Greek letters. These stimuli were labeled X_1-X_6; each G stimulus was presented with the same distracter stimuli on every trial (i.e., G_1 was always presented with X_1 and X_2, G_2 was always presented with X_3 and X_4, and G_3 was always presented with X_5 and X_6). The stimuli are presented in Figure 7. As during conditional discrimination training, stimulus presentation was balanced so that each stimulus appeared in all four corners of the screen on the same number of trials, and each of the four corners housed the correct stimulus on an equal number of trials. Table 4 lists the training session types in sequential order, and provides information on the types of trials and number of trials in each session.

Simple discrimination training with G stimuli

Each participant began training with the G_1 discrimination. Participants received training with one simple discrimination at a time, progressing to the next simple discrimination only after reaching the mastery criterion of at least 90% correct responding on two consecutive sessions.

G_1	G_2	G_3
Φ	Π	Σ
X_1	X_3	X_5
Θ	λ	Ω
X_2	X_4	X_6
ζ	δ	α

Figure 7. Experiment 1 G and X Stimuli

Table 4.

Experiment 1 Training Sequence

Session type	Stimuli	Number of trials
G_1 training	G_1	24
G_2 training	G_2	24
G_3 training	G_3	24
G mixed baseline	G_1, G_2, G_3	36
G mixed baseline 75% S^R	G_1, G_2, G_3	36; 9 unreinforced
G mixed baseline 50% S^R	G_1, G_2, G_3	36; 18 unreinforced
Complete mixed baseline	Conditional discrimination baseline stimuli and G_1, G_2, G_3	Varied by participant

During each of the 24 trials within a G_1 training session, stimuli G_1, X_1, and X_2 appeared in three of the four corners of the screen, and the participant was instructed to "Pick one." The participant was not given any instructions or explanation before beginning this new training phase. Because the participants had never before completed a three-term discrimination trial, the possibility that they might react with questions and comments was anticipated, and the experimenters were prepared to respond with comments such as "It's ok, just keep playing." If, on any trial within the session, the participant selected stimuli X_1 or X_2, the computer made a buzz sound and the screen went blank for the 1.5 second inter-trial interval. If the participant chose G_1, the compound class-specific reinforcer associated with the 1 class was given. The participant was prompted to mark on the baseline tally sheet (Figure 1) the visual reinforcer image that had appeared on the computer screen, and to mark on the columned sheet below the three cups the edible reinforcer that had been delivered. When the participants completed two sessions of training with G_1, selecting stimulus G_1 on at least 90% of the trials, they moved on to training with G_2, then G_3. Each G stimulus was presented with two unique distracter stimuli during baseline trials. The procedure for training each of the three simple discriminations was identical.

Mixed baseline training

Once all three simple discriminations were mastered separately, the three trial types were mixed together. When the participant met the mastery criterion of at least 90% accuracy on two consecutive sessions of mixed simple discrimination baseline trials with G stimuli, reinforcement density was reduced from 100% to 75%, then 50%. The participant had to meet the mastery criterion again each time the reinforcement density was reduced. Before proceeding to probe trials, the participants completed sessions of their complete mixed baseline, which included their conditional discrimination baseline trial types as well as simple discrimination trials with the G stimuli. The reinforcement density was 50% for these sessions. When the participant had completed two complete mixed baseline sessions with 90% correct responding, he or she started probe trials.

Class expansion probes

When participants successfully completed all phases of simple discrimination training with the G stimuli, class expansion probes determined whether the G stimuli had become members of the existing equivalence classes. Table 5 shows the different probe sessions each participant completed. Probe trials were interspersed with each participant's complete mixed baseline. Sessions remained at 50% reinforcement density. The distracter stimuli that had appeared with each G stimulus on baseline trials were never presented during probe trials; only the three G stimuli were used because the distracters were irrelevant to class formation. Table 5 presents the sequence in which probe types were presented in Experiment 1. The participants completed one of each session type listed, then repeated the sequence. Reflexivity probes were the first probe type presented; they determined the participants' ability to match each G stimulus with itself. The next type of probes determined whether the participants could match the G stimuli to existing class members. The G stimuli were presented as either samples or comparisons with each of the participant's existing class members (i.e., A-F for participant 6 and A-C for participant 7).

Table 5

Experiment 1 Probe Testing Sequence

Session type	Probe relations
Reflexivity probes	G⇢G
A and G probes	A⇢G, G⇢A
B and G probes	B⇢G, G⇢B
C and G probes	C⇢G, G⇢C
D and G probes*	D⇢G, G⇢D
Computerized visual S^R probes	Visual R⇢G, G⇢Visual R
Edible S^R probes	Edible R⇢G, G⇢Edible R
Sound S^R probes	Sound R⇢G, G⇢Sound R

Note. Trial number information was not included because it differed depending on the number of stimuli in each participant's baseline.

*A→B C→D baseline only.

Reinforcer probes

As in the conditional discrimination phase, probes were given to determine if each separate component of the class-specific reinforcers was also a class member. The first set of probes determined whether or not the visual components of the computerized display were class members. Images of the visual computer displays were presented as sample stimuli on some trials and comparison stimuli on other trials with the G stimuli. Reinforcer probes were also given to determine if images of the edible reinforcer and the sound elements of the compound class-specific reinforcers were class members. Participants completed one of each type of probe session listed in Table 5, in that order, and then repeated the sequence from the top until the scores were stable based on visual inspection of graphs of each participant's performance.

Results

Participant 6 asked questions during his first training session with G_1, such as, "Why can't I pick this one?" referring to one of the two X stimuli. Despite his reaction, participant 6 met the mastery criterion with G_1 in only five sessions, and reached the mastery criterion with G_2 and G_3 after only two training sessions with each simple discrimination (see Figure 19, top panel). During the mixed baseline phase, his scores only dropped below 100 one time (see Figure 19, left bottom panel). Participant 6's responses on class-expansion probes were highly class-consistent; he was able to match the G stimuli with their respective class members, although the only link between the existing classes and the G stimuli were the compound class-specific reinforcers (see Figure 20, top, left panel). Figure 20 (bottom left panel) also shows that his performance on reinforcer probes was also very class-consistent; high scores on each probe session

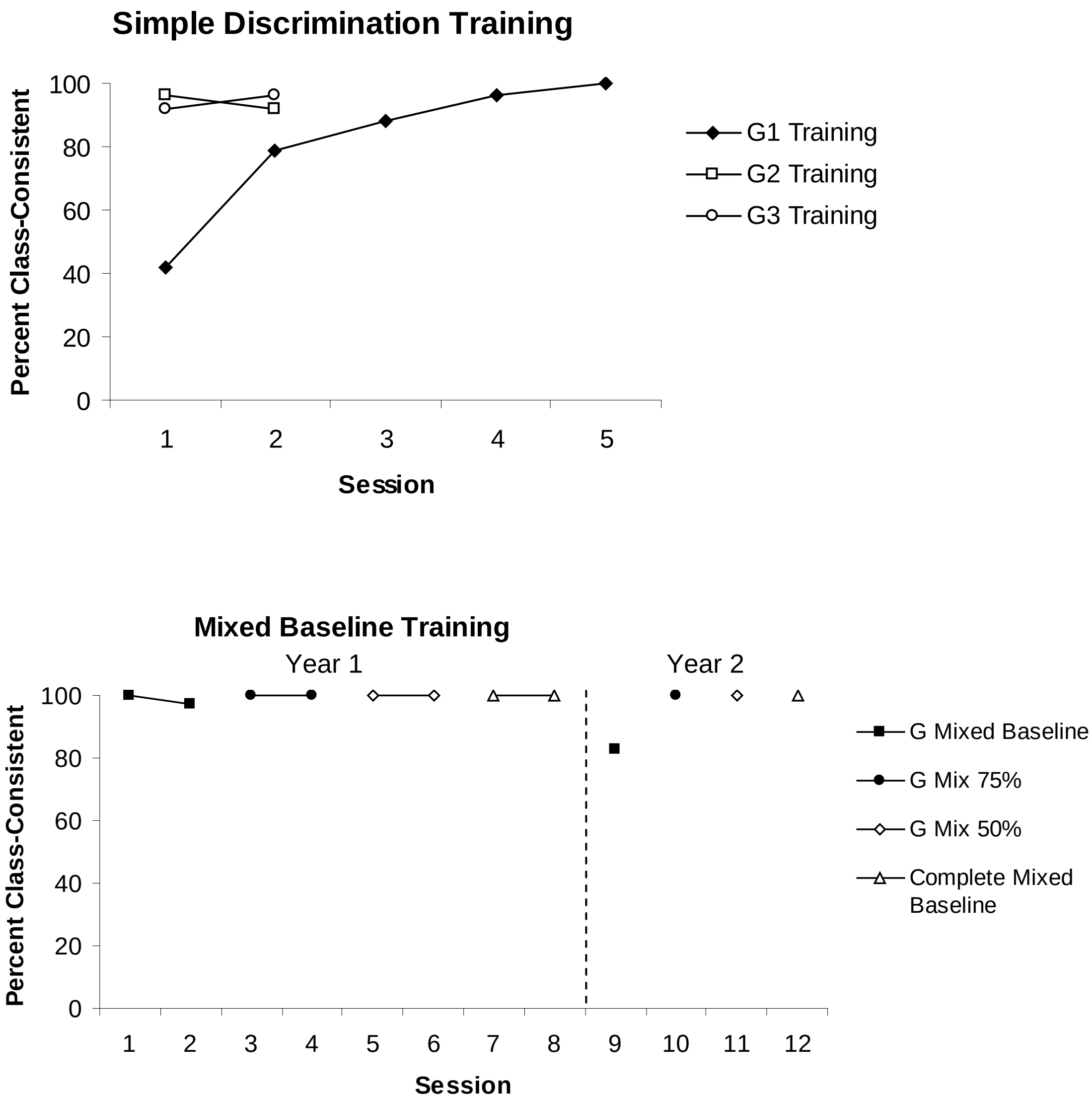
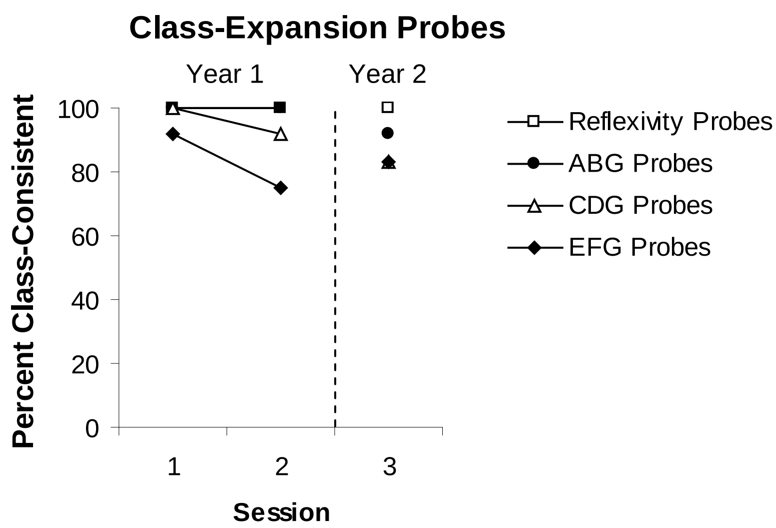


Figure 19. Participant 6 Experiment 1 Training



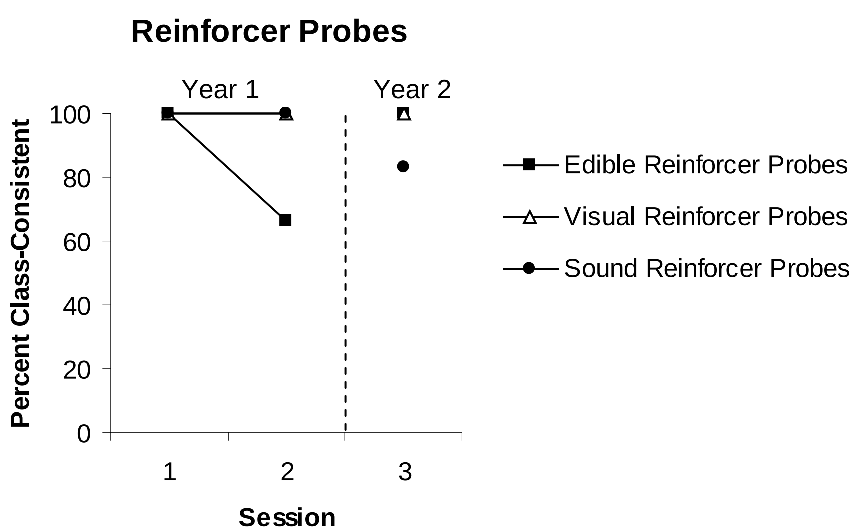


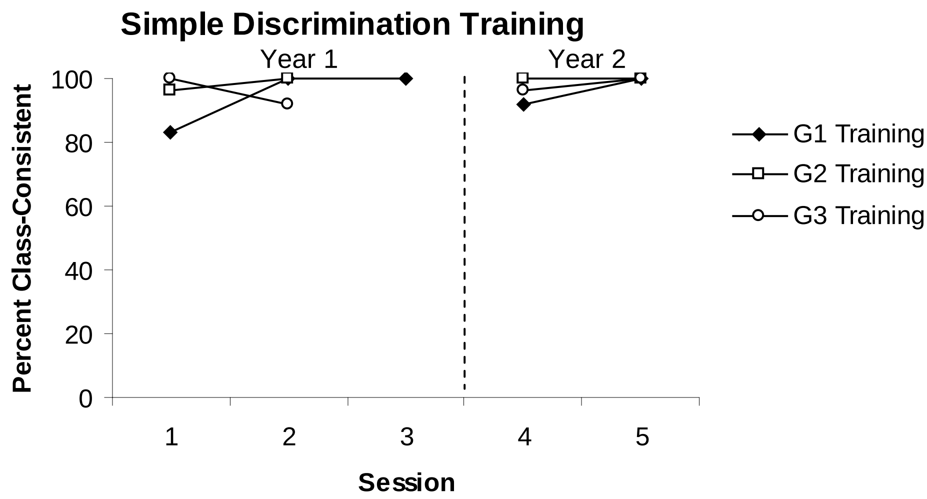
Figure 20. Participant 6 Experiment 1 Probes

showed that he had accurately matched each G stimulus with each of the three elements of the class-specific reinforcer.

Participant 6 completed Experiment 1 prior to the end of the school year. At the beginning of the following school year, he repeated Experiment 1 after his conditional discrimination baseline had been re-established. Because he had already completed the experiment, only one session of each probe type was presented, but his baseline scores were perfect after the first session and his probe scores were again predominantly class-consistent (see bottom right panels of Figures 19 and 20).

Participant 7 completed the simple discrimination training in Experiment 1 in the minimum number of sessions possible, with the exception of G_1 training, which he completed in three sessions (see Figure 21, top left panel). Because this participant completed Experiment 1 at the end of the school year and only completed one session per day, there was not enough time for all Experiment 1 probes to be completed before the school year ended. Instead, reflexivity probes and class-expansion probes were mixed into one long session completed on the last day of school. Although his performance on reflexivity probes was accurate, his performance on class-expansion probes, which tested the relations between the G stimuli and the A, B, and C stimuli, was not class-consistent (see Figure 22, top, left panel).

After the summer break, participant 7 completed the conditional discrimination training and testing phases and simple discrimination training for Experiment 1 again. This time, he completed all of Experiment 1 training in the minimum number of sessions possible, including G_1 training (see Figure 21, right panels). His reflexivity probe performances were again perfect; however, his performance on class-expansion probes



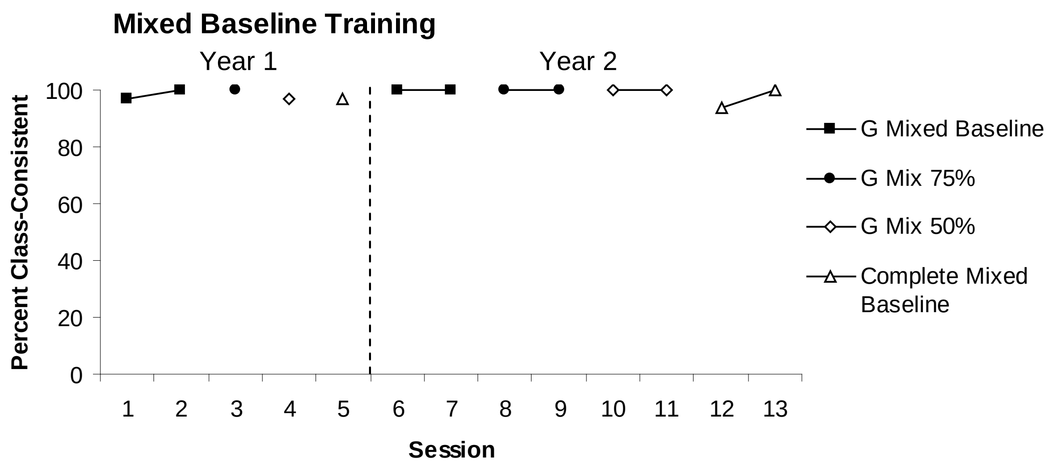
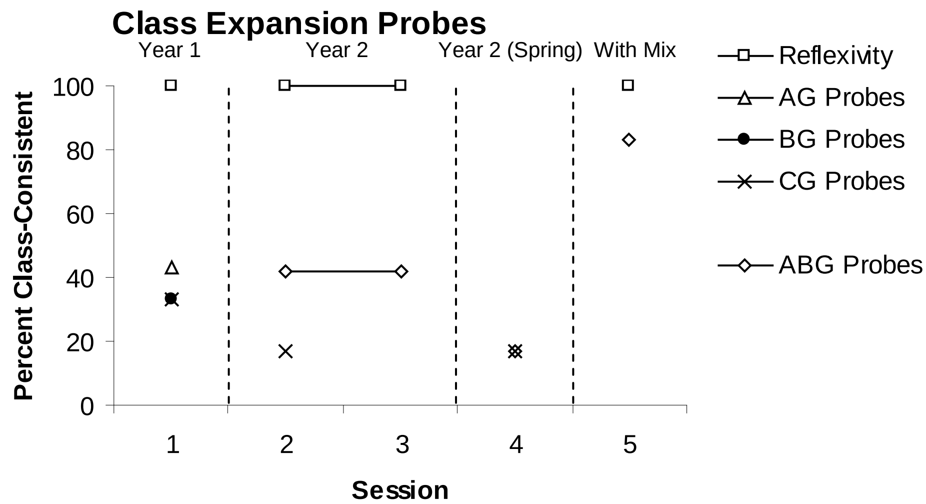


Figure 21. Participant 7 Experiment 1 Training



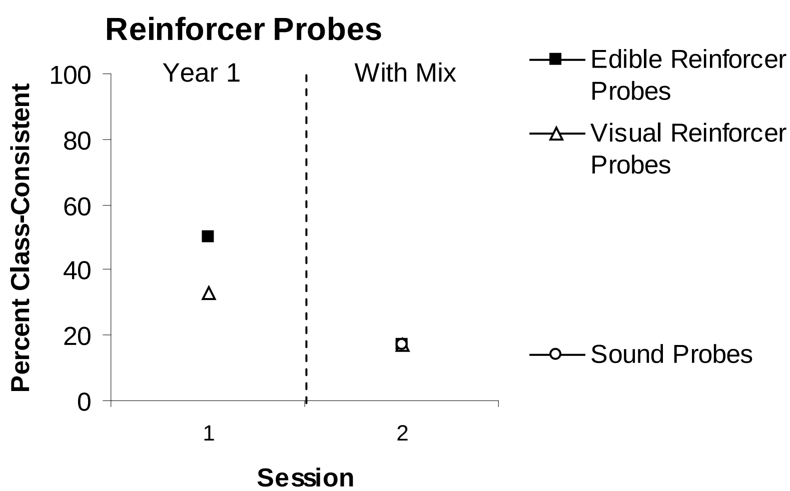


Figure 22. Participant 7 Experiment 1 Probes

between the G and the A, B, and C stimuli was still not class-consistent (see Figure 22, top second panel). He completed one session each of edible and visual reinforcer probes, which were also not class-consistent (see Figure 22, bottom panel). After several weeks off from school in December, participant 7 completed Experiment 1 training for the third time; his results were identical to those in Figure 21 (bottom right panel), with the exception that his scores on the complete mixed baseline sessions were reversed; the score was 100% in session one and 94% in session two. Class-expansion probes were still not class-consistent (see Figure 22, top, third panel)

Testing is ongoing with participant 7. At this point, sessions of mixed G simple discriminations and symmetry, transitivity, and reflexivity probes from the conditional discrimination phase are being alternated with Experiment 1 probe sessions to provide a stronger basis for the emergent relations. During his first session of A, B, and G probes to follow this alternation, his class-consistent score increased from 2/12 (16%) to 10/12 (83%) (see Figure 22, top fourth panel). Reinforcer probe scores are still not class-consistent (see Figure 22, bottom right panel).

Discussion

The question examined in Experiment 1 was whether the G stimuli would join each participant's existing classes via the compound class-specific reinforcers. Participant 6's class-consistent probe performances show that stimuli G_1, G_2, and G_3 had become members of the existing 1, 2, and 3 equivalence classes, respectively. The compound class-specific reinforcers were the only link between the G stimuli and the existing class members, but this was sufficient for class expansion to occur, leading to the conclusion that the class-specific reinforcers acted as nodal stimuli.

Participant 7 showed some evidence of class expansion after of mixed G simple discrimination baseline sessions and symmetry, transitivity, and reflexivity probe sessions were interspersed with the Experiment 1 probe sessions. It is not unusual for a participant's probe scores to improve over time, as opposed to emerging immediately (Sidman, 1994). Probe scores in this case may continue to demonstrate stronger evidence of class expansion, as the study is continued.

In order for the G stimuli to be considered class members, the relations between the G stimuli and the remaining class members must be characterized by the three mathematical properties of equivalence. Reflexivity (G⇢G) relations emerged immediately in the performances of both participants. The class-expansion probes in Experiment 1 required symmetric and transitive relations simultaneously. The "transitivity" probes in Experiment 1 did not meet the traditional mathematical definition, if A→B and B→C, then A⇢C. In this case, no conditional or discriminative stimulus relates the G stimuli with the remaining class members. Instead, the reinforcer, R, served as a node, creating the transitive relations; for example, if choosing G_1 produces R_1, or $G_1 \rightarrow R_1$, and selecting B_1 in the presence of A_1 yields R_1, or $A_1 \rightarrow B1 \rightarrow R_1$, then $G_1 \dashrightarrow A_1$ and $G_1 \dashrightarrow B_1$. Presenting the G stimuli as samples and comparisons required symmetry in addition to transitivity, for example, during a probe session targeting A and G stimuli, the participant was given probes that evaluated their ability to match both A⇢G and G⇢A.

Experiment 1 provided further evidence that three-term contingencies can produce equivalence relations. In addition, both participants acquired the simple discrimination relations rather quickly. During the Ashford (2003) study, when participant 7 completed A→B training for the first time, he completed 12 sessions before meeting the mastery criterion. In the present study, he did not meet the mastery criterion for mixed baseline training until the ninth session, though he had received training for both conditional discriminations in the past. In contrast, during his first exposure to simple discrimination training (G_1 training), he met the mastery criterion in only three sessions. His performance provides evidence that three-term contingencies may be learned more rapidly.

Experiment 2

Method

Participants

One participant, participant 6, successfully completed Experiment 1 and proceeded with Experiment 2.

Apparatus and Setting

The experimental setup was nearly identical to that in Experiment 1. The only difference was the tally sheet; the Experiment 2 tally sheet (Figure 3) included the images of the visual component of the compound class-specific reinforcers, as well as images of the three G stimuli, the purpose of which will be explained.

Procedure

Simple discrimination training

Experiment 2 was intended to further explore the functions of stimuli and reinforcers within a contingency, specifically, whether or not discriminative stimuli and reinforcers can share functions. The reinforcer components were shown to function as conditional and discriminative stimuli during reinforcer probe trials in both the conditional discrimination testing phase and Experiment 1. Experiment 2 sought to examine whether previous sample and comparison stimuli could function as reinforcers in a contingency. Another set of three simple discriminations was trained; the stimuli were abstract, nonsense shapes (Figure 8) measuring approximately 1 inch by 1 inch Three stimuli, labeled H_1, H_2, and H_3, were designated as the correct stimuli. Two distracter stimuli were assigned to each H stimulus. The same two distracter stimuli always appeared with a given H stimulus; X_7 and X_8 always appeared with H_1, X_9 and X_{10} always appeared with H_2, and X_{11} and X_{12} always appeared with H_3. The basic training procedures for Experiment 2 were identical to Experiment 1, with the exception of the class-specific reinforcers.

The compound class-specific reinforcers were not used during H simple discrimination training. Instead, the G stimuli were presented as visual consequences. When the participants made correct selections of H_1, H_2, or H_3, on a reinforced baseline trial, G_1, G_2, or G_3, respectively, appeared in the center of the computer screen on a gray background. When presented as a consequence, the size of each G stimulus was 1.5 inches by 1.5 inches. The purpose of enlarging the stimuli and changing the background color from white to gray was to distinguish the G stimuli presented as consequences from the G stimuli presented as conditional or discriminative stimuli. In addition, the G consequences were programmed so that the participant could not click on them; instead, the Experimenter clicked the “N” key to start the inter-trial interval. To prevent a decrease in accuracy due to the lack of edible reinforcers for H discrimination trials, all Experimenter 2 training sessions included all three types of G simple discrimination trials at 50% reinforcement. Table 6 shows the sequence of H simple discrimination training sessions. Half of the trials in each session were an equal number of each type of G

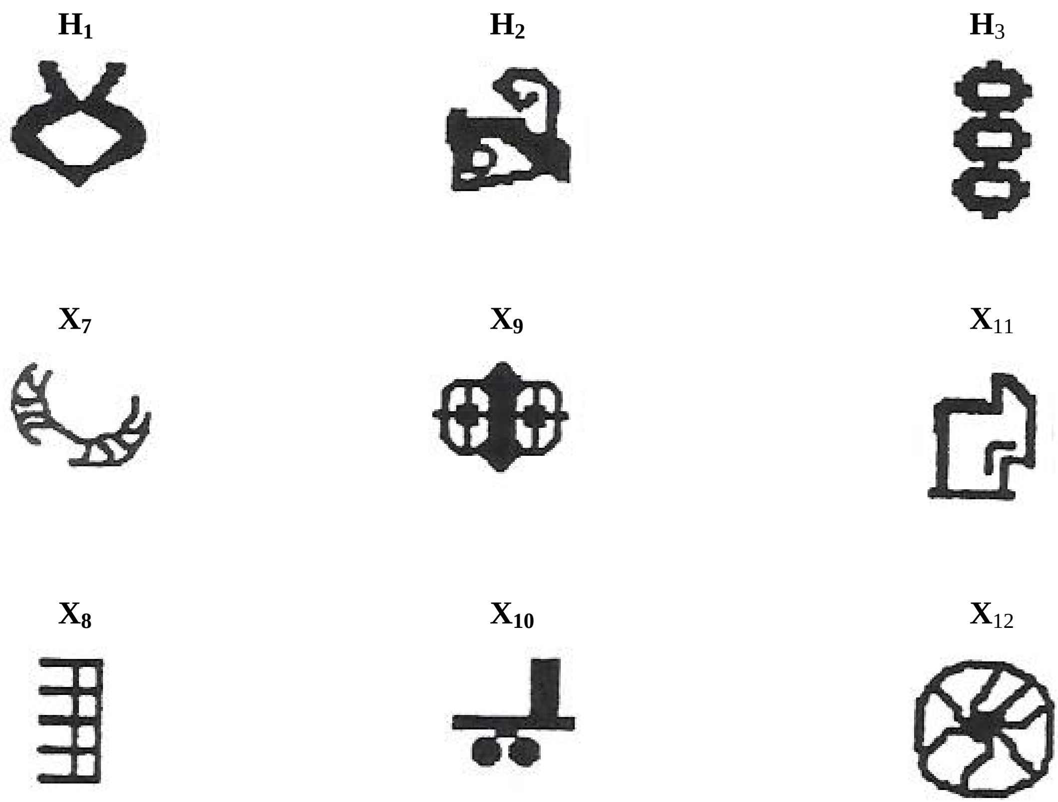


Figure 8. Experiment 2 H and X Stimuli

Table 6.

Experiment 2 Training Sequence

Session type	Stimuli	Number of trials
H_1 training	H_1, G_1, G_2, G_3	36; 18 H_1, 18 G_1, G_2, G_3
H_2 training	H_2, G_1, G_2, G_3	36; 18 H_2, 18 G_1, G_2, G_3
H_3 training	H_3, G_1, G_2, G_3	36; 18 H_3, 18 G_1, G_2, G_3
H mixed baseline	H_1, H_2, H_3, G_1, G_2, G_3	36; 6 of each type
H mixed baseline 75% S^R	H_1, H_2, H_3, G_1, G_2, G_3	36; 9 unreinforced
H mixed baseline 50% S^R	H_1, H_2, H_3, G_1, G_2, G_3	36; 18 unreinforced
Complete mixed baseline	Conditional discrimination baseline stimuli and G_1, G_2, G_3	Varied by participant

simple discrimination, and half of these trials were reinforced. The remaining half of the trials were H simple discriminations.

Training started with H_1; when an H_1 trial appeared on the computer screen (i.e., stimuli H_1, X_7, and X_8) the participant selected one of the stimuli, and one of two consequences occurred. As in Experiment 1, if either of the distracter stimuli were selected, the computer produced the sound of a buzzer and the stimuli disappeared, leaving the screen blank for a 1.5 second inter-trial interval. If the participant selected stimulus H_1, the computer screen turned gray and the enlarged image of stimulus G_1, appeared as a class-specific consequence. The experimenter left the G_1 consequence on the screen, gestured toward the Experiment 2 tally sheet, described earlier, and told the participant to "Mark what you saw."

Including the G stimuli on the tally sheet served two purposes. First, the participants had been and still were required to mark the visual elements of the reinforcers during reinforced conditional discrimination baseline trials, during Experiment 1 simple discrimination baseline trials with the G stimuli, and during reinforced simple discrimination trials with the G stimuli that were mixed in with H simple discrimination training trials. This step was required to ensure that the participants attended to the reinforcers and could distinguish between them. To ensure that the procedures were consistent and to increase the likelihood that participants were also attending to the G consequences on H simple discrimination trials, it was necessary to maintain this marking procedure. Second, although the G consequences were enlarged and on a gray background, they had previously served as sample and comparison stimuli.

Placing the G stimuli alongside the other visual reinforcers provided an additional context for their function as consequences in this experiment.

Once the participant had achieved the mastery criterion of 90% on H_1 training (the G and H simple discriminations were scored separately to ensure that the participant met the criterion on H_1 trials alone), H_2 training began, followed with H_3 training. Upon successfully completing training with all three H simple discriminations separately, mixed baseline training began. On these sessions, half of the trials were G simple discriminations which remained at 50% reinforcement regardless of the reinforcement density programmed for the H simple discrimination trials. The reinforcement density for H trials was decreased from 100% to 75%, then 50%, as the participant met the mastery criterion at each level with the mixed baseline.

<u>Class expansion probes</u>

The probe types and sequence are presented in Table 7. The reinforcer probes were particularly interesting because the H stimuli could only be related to the compound class-specific reinforcer components through the G consequences. One additional set of probes determined whether participants could match the appropriate H and G stimuli together.

<u>Results</u>

Participant 6 started training for Experiment 2 at the end of the school year, and, therefore, completed an abbreviated version of the experiment. This participant only received training with the H_1 simple discrimination due to the limited time remaining before the start of summer vacation. The mastery criterion of two consecutive sessions with 90% accuracy was reduced to one session; the participant did complete two sessions

Table 7.

Experiment 2 Probe Testing Sequence

Session type	Stimuli
Reflexivity probes	H, G, mixed baseline, H⇢H
A and H probes	A⇢H, H⇢A
B and H probes	B⇢H, H⇢B
C and H probes	C⇢H, GH⇢C
D and H probes*	D⇢H, H⇢D
Computerized visual S^R probes	Visual R⇢H, H⇢Visual R
Edible S^R probes	Edible R⇢H, H⇢Edible R
Sound S^R probes	Sound R⇢H, H⇢Sound R
G and H probes	G⇢H, H⇢G

with 90% accuracy but they were nonconsecutive (see Figure 23, top left panel). After eight sessions of H_1 training, participant 6 completed reflexivity and class-expansion probes (a mixed baseline session was not possible after training with only one simple discrimination). H_1 was presented as a sample stimulus on some trials and as a comparison stimulus on other trials with the A, B, C, D, E, F, and G stimuli as comparison stimuli or a sample stimulus. When H_1 was a comparison stimulus, it was presented with X_7 and X_8 because no training had been conducted with H_2 or H_3. Participant 6's reflexivity probe performances were errorless, and his performances on class-expansion probes ranged from 50-83% class-consistent, well above the chance level (see Figure 24, top left panel). Participant 6 received the full training for Experiment 2 the following school year after his conditional discrimination baseline had been re-established and Experiment 1 repeated. He reached the mastery criterion for H_1, H_2, H_3, and all parts of the mixed baseline training within the minimum number of sessions. He had no more than one incorrect trial with the H stimuli per session. Performances on complete mixed baseline sessions, which included A→B, C→D, E→E, F→F, G, and H stimuli, were errorless (see Figure 23, top right and bottom panels).

The results of participant 6's first set of all class-expansion probe types were class-consistent, ranging from 75-83%; however, the scores dropped significantly (see Figure 24, top middle panel). Next, the participant completed reinforcer probes. Again, the probe performances on the first set were partially or completely class-consistent, but dropped on the second set (see Figure 24, bottom panel). At this point, complete mixed baseline sessions at 50% reinforcement density for correct responses were alternated with

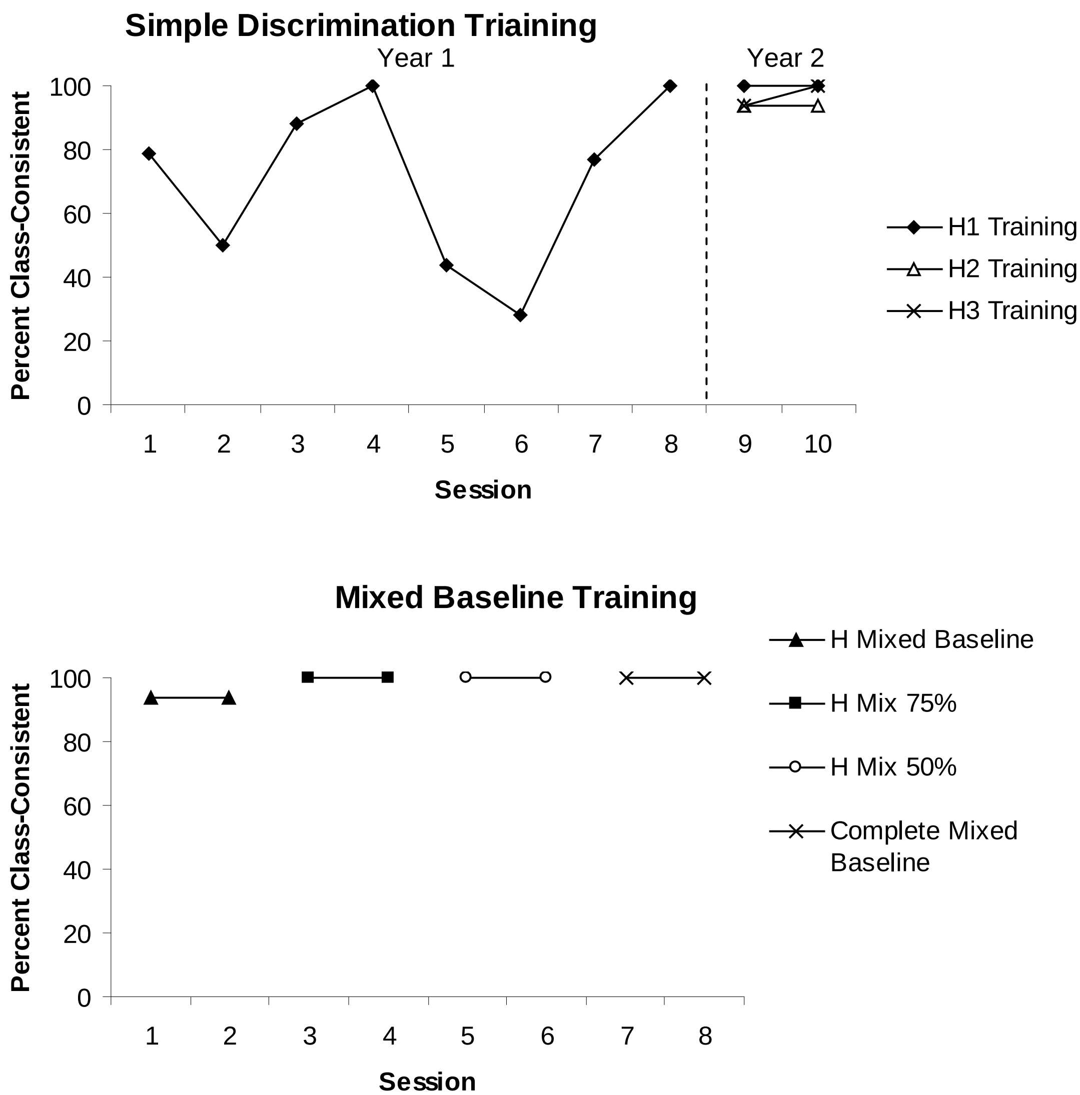
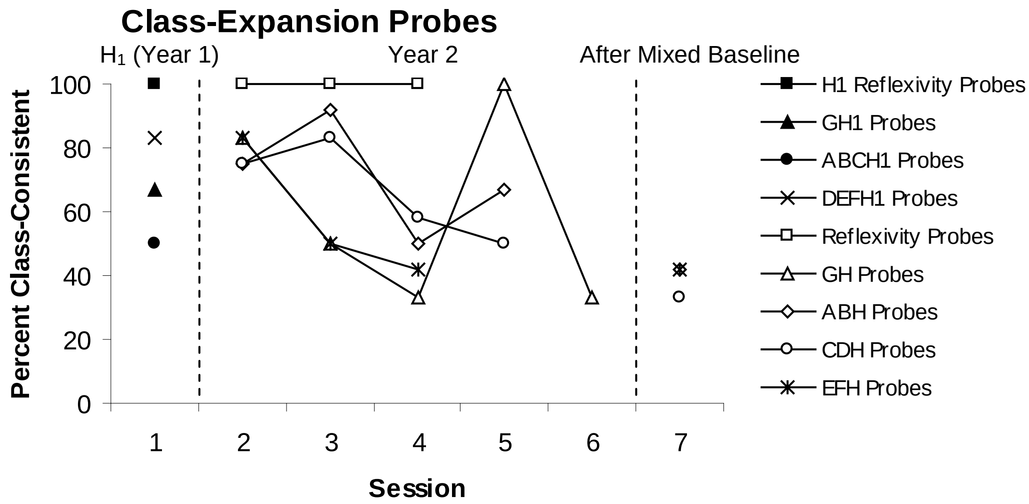


Figure 23. Participant 6 Experiment 2 Training



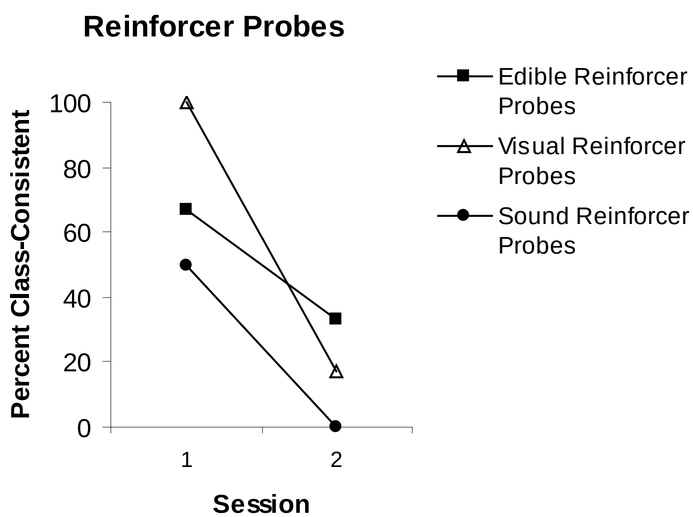


Figure 24. Participant 6 Experiment 2 Probes

class-expansion and reinforcer-probe sessions. As Figure 24 shows (top, right panel), no increase in class-consistent responses has been noted at this point.

Discussion

Participant 6's rapid acquisition of the H simple discriminations demonstrated that sample stimuli, comparison stimuli, and reinforcers can share functions within a contingency. G_1, G_2, and G_3 switched functions from sample and comparison stimuli to reinforcers for H simple discrimination baseline trials. The acquisition data indicate that presentation of the G stimuli as reinforcers was sufficient for the H_1, H_2, and H_3 simple discriminations to be learned.

The first set of class-expansion probes for participant 6 demonstrated that class expansion had occurred. The H stimuli were matched to the corresponding class members on over 70% of the probe trials, providing some evidence that they had joined the classes as a result of the G consequences used to train the discriminations. Participant 6's class-consistent responding during the first set of probes also provided strong evidence that conditional and discriminative stimuli and reinforcers can share functions within a contingency; the G_1, G_2, and G_3 stimuli trained originally as discriminative stimuli in Experiment 1 functioned as reinforcers in Experiment 2, following correct selections of H_1, H_2, and H_3, respectively.

Though all of the scores had dropped by the third block, it is highly unlikely that high performances on all of the probe trials in the first session were the result of chance guessing. In addition, the perfect class-consistent performance on session four of the G and H probes indicates that the G consequences were effective reinforcers, as the participant was able to match each H stimulus to the G stimulus from the corresponding equivalence class.

This experiment was more difficult than Experiment 1 because the H stimuli were not directly related to any of the original equivalence class members established during the conditional discrimination phase. Instead, they could only be related through the G consequences. In other words, the emergent H relations were dependent on the emergent G relations from Experiment 1, none of which were ever reinforced. The simple discriminations with G stimuli were also only related to the existing classes via the class-specific reinforcers; however, those reinforcers were identical to the reinforcers used during conditional discrimination training, so the relations between G stimuli and the remaining class members were more direct.

Another possible explanation for participant 6's fluctuating class-expansion probe scores is that participant 6 learned to discriminate between baseline and probe trials. Because responses on probe trials were not reinforced, he may not have attended as carefully on these trials, resulting in a drop in his initial class-consistent probe scores.

Experiment 3

Method

Participants

Four participants, 1, 2, 3, and 5, were included in Experiment 3. These participants did not acquire the conditional discrimination baseline relations. After a minimum of 10 sessions of training with one conditional discrimination, their scores did not approach the mastery criterion.

Apparatus and Setting

All aspects of the experimental setting were identical to the conditional discrimination phase, including use of the baseline tally sheet (Figure 1).

Procedure

The purpose of Experiment 3 was to determine whether training three-term contingencies could facilitate acquisition of conditional discriminations. Participants received training with the G and H simple discriminations from Experiment 1 and Experiment 2, with some changes, then received conditional discrimination training for G→H relations. Table 8 outlines all of the training sequence for Experiment 3.

Simple discrimination training

After conditional discrimination training was terminated for these participants, they began simple discrimination training with stimulus G_1, followed by G_2, and G_3. The procedures were identical to those of the training in Experiment 1. After meeting the mastery criterion for each simple discrimination separately, mixed baseline training occurred. The reinforcement density for correct responses started at 100% and was reduced to 75%, then 50%, as the participant met the mastery criterion at each level. When the participant reached the mastery criterion with the mixed baseline at a 50% reinforcement density, they began simple discrimination training with the H stimuli, starting with H_1. In Experiment 3, correct selections of the H stimuli were also reinforced with the compound class-specific reinforcers, as opposed to the Greek letter consequences utilized in Experiment 2. All three simple discriminations were trained separately, then combined during mixed baseline training, and the reinforcement density was reduced from 100% to 75%, then 50%, as the mastery criterion was reached for each

Table 8.

Experiment 3 Training Sequence

Session type	Stimuli	Number of trials
G_1 training	G_1	24
G_2 training	G_2	24
G_3 training	G_3	24
G mixed baseline	G_1, G_2, G_3	36
G mixed baseline 75% S^R	G_1, G_2, G_3	36; 9 unreinforced
G mixed baseline 50% S^R	G_1, G_2, G_3	36; 18 unreinforced
H_1 training	H_1	24
H_2 training	H_2	24
H_3 training	H_3	24
H mixed baseline	H_1, H_2, H_3	36
H mixed baseline 75% S^R	H_1, H_2, H_3	36; 9 unreinforced
H mixed baseline 50% S^R	H_1, H_2, H_3	36; 18 unreinforced
G and H baseline mix	G_1, G_2, G_3, H_1, H_2, H_3	36
G and H conditional discriminations	G⇢H	24
G and H conditional discriminations 75% S^R	G⇢H	24; 6 unreinforced
G and H conditional discriminations 50% S^R	G⇢H	24; 12 unreinforced

level. Once the participant reached the mastery criterion with the mixed baseline of all three H simple discriminations at the 50% reinforcement density, they completed sessions with all six simple discriminations, G_1, G_2, G_3, H_1, H_2, and H_3, also at a 50% reinforcement density. The mastery criterion remained in place for these sessions.

Conditional discrimination training

Because the compound, class-specific reinforcers were used to reinforce correct selections of the G and H stimuli during simple discrimination training, conditional discriminations between G and H stimuli were trained with the same class-specific reinforcers. During simple discrimination training, correct selections of H_1 and G_1 were reinforced with all components of R_1; correct selections of H_2 and G_2 were both reinforced with R_2, and correct selections of G_3 and H_3 were reinforced with R_3. Conditional discriminations were trained between the corresponding members from each stimulus set, and were reinforced with the compound class-specific reinforcer appropriate to those stimuli. Correct selections of H_1 in the presence of G_1 produced R_1, or $G_1 \rightarrow H_1 \rightarrow R_1$, $G_2 \rightarrow H_2 \rightarrow R_2$, and $G_3 \rightarrow H_3 \rightarrow R_3$. There were eight trials of each type within a session (see Table 8). On each trial, one of the three G stimuli was always the sample stimulus. The participant was instructed to click on the sample, and all three H stimuli appeared in three corners of the computer screen as comparison stimuli. The trials within a session were balanced for stimulus presentation according to the same standards explained in the conditional discrimination phase prior to Experiment 1. Selection of either of the two H stimuli that did not correspond with the sample, for example, selecting H_2 or H_3 in the presence of G_1, resulted in a buzzer and the 1.5 second inter-trial interval. Selection of, for example, H_1 in the presence of G_1, however, resulted in the compound class-specific reinforcer appropriate to those stimuli (i.e., the reinforcer with which each stimulus discrimination had been trained during simple discrimination training). Participants continued to mark the baseline tally sheet, as well as the columned sheet located below the reinforcer cups. The mastery criterion remained in place as the reinforcement density was gradually reduced.

Results

Participant 1 acquired the first simple discrimination (G_1) after nine sessions, but acquisition trends were evident early on, and she chose G_1 on 100% of the trials in session three. During one of the trials in that session, participant 1 pointed to each of the stimuli on the screen and repeated the phrase “pick one;” when she pointed to G_1, she said “just pick on that.” Figure 25 shows all of participant 1’s Experiment 3 training data. She also rapidly acquired the G_2 and G_3 simple discriminations. She completed the entire mixed baseline phase in the minimal number of sessions possible with perfect scores on all but one session, then began H training. She completed training for H_1 and H_2 in the minimum two sessions per each.

Figure 26 presents Experiment 3 training data for participant 2. He met the mastery criterion for G_1 training after 10 sessions, for G_2 after two sessions, and for G_3 after three sessions. He had perfect scores throughout all of the mixed baseline phase, completing it in the minimum number of sessions possible. Participant 2 moved on to simple discrimination training with H_1, completing H_1, H_2, and the first session of H_3 with perfect scores.

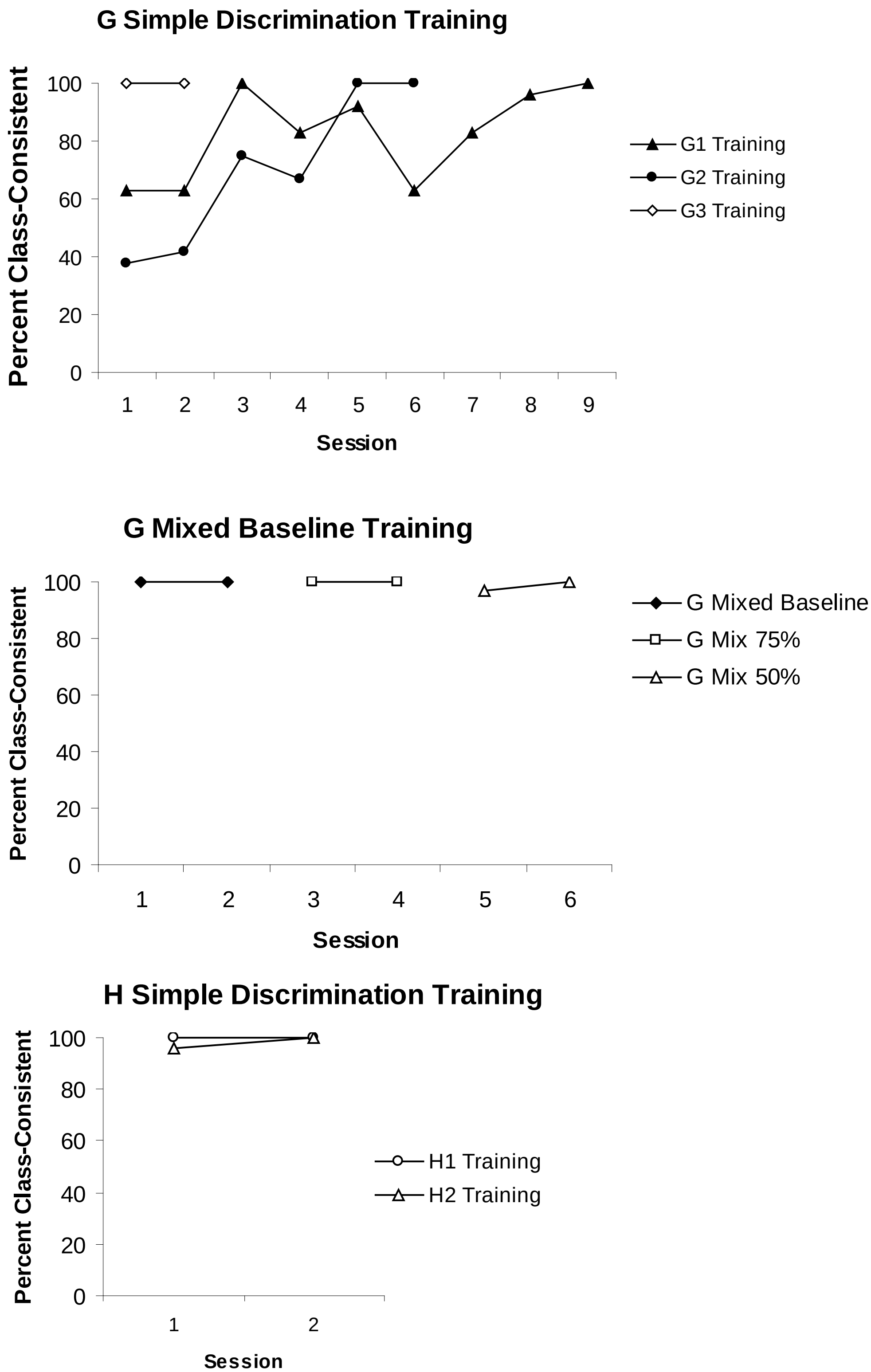
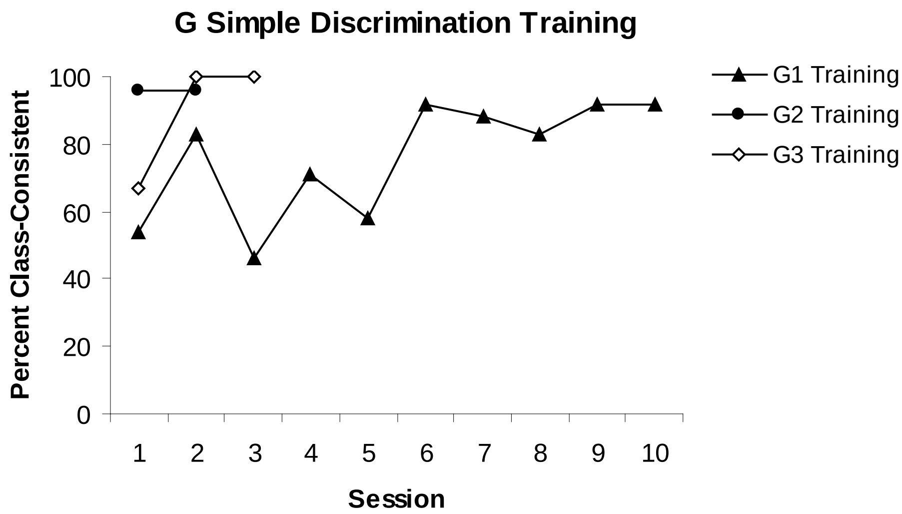
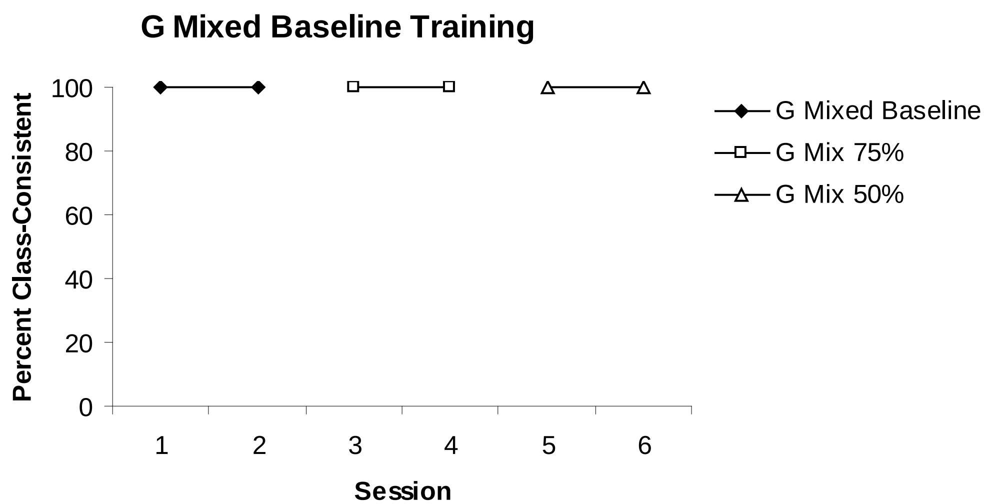


Figure 25. Participant 1 Experiment 3 Training





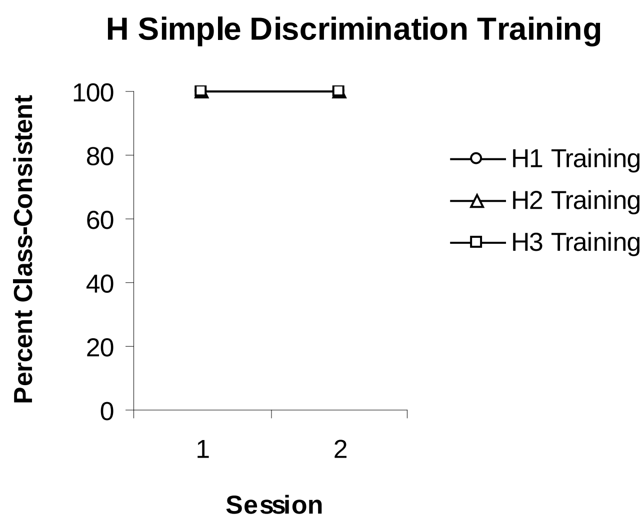


Figure 26. Participant 2 Experiment 3 Training

Participant 3 met the mastery criterion for G_1 in six sessions and met the criterion for G_2 in three sessions. His first session of G_3 was also above 90% (see Figure 27). Figure 28 presents participant 5's Experiment 3 training data. He met the mastery criterion for G_1, G_2, and G_3 in five, three, and three sessions, respectively. During his first few sessions with G_1 training, participant 5 pointed to the computerized visual reinforcers for classes 2 and 3 and asked why they were not showing up. During one session, he asked if the laptop was broken. After both questions, the experimenter told him to "just keep playing." His scores remained high throughout the mixed baseline phase and he moved on to H simple discrimination training, meeting the mastery criterion for H_1 after three sessions.

Discussion

Though all phases of Experiment 3 are not yet complete, the results of all four participants in the G and H simple discrimination phases provided overwhelming evidence that three-term contingencies are mastered more easily than four-term contingencies. After completing 20 sessions of conditional discrimination training, 10 with each discrimination, without any acquisition trends, participant 1 moved on to simple discrimination training with G_1 and demonstrated acquisition trends in the very first session. In fact, she had a perfect score as early as the third session. Participants 2 and 5 also acquired the G discriminations rapidly, particularly G_2 and G_3, after failing to show any acquisition trends during 20 sessions of conditional discrimination training. Participant 3 also acquired the G_1 and G_2 simple discriminations rapidly. After completing simple discrimination training with G stimuli, participants 1, 2, and 5 met the mastery criterion for H_1 and H_2 training even more rapidly. As this experiment

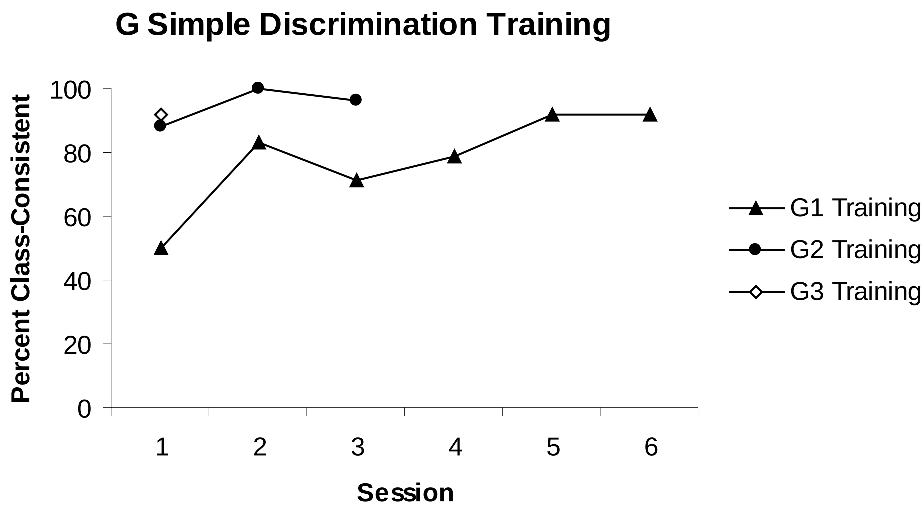


Figure 27. Participant 3 Experiment 3 Training

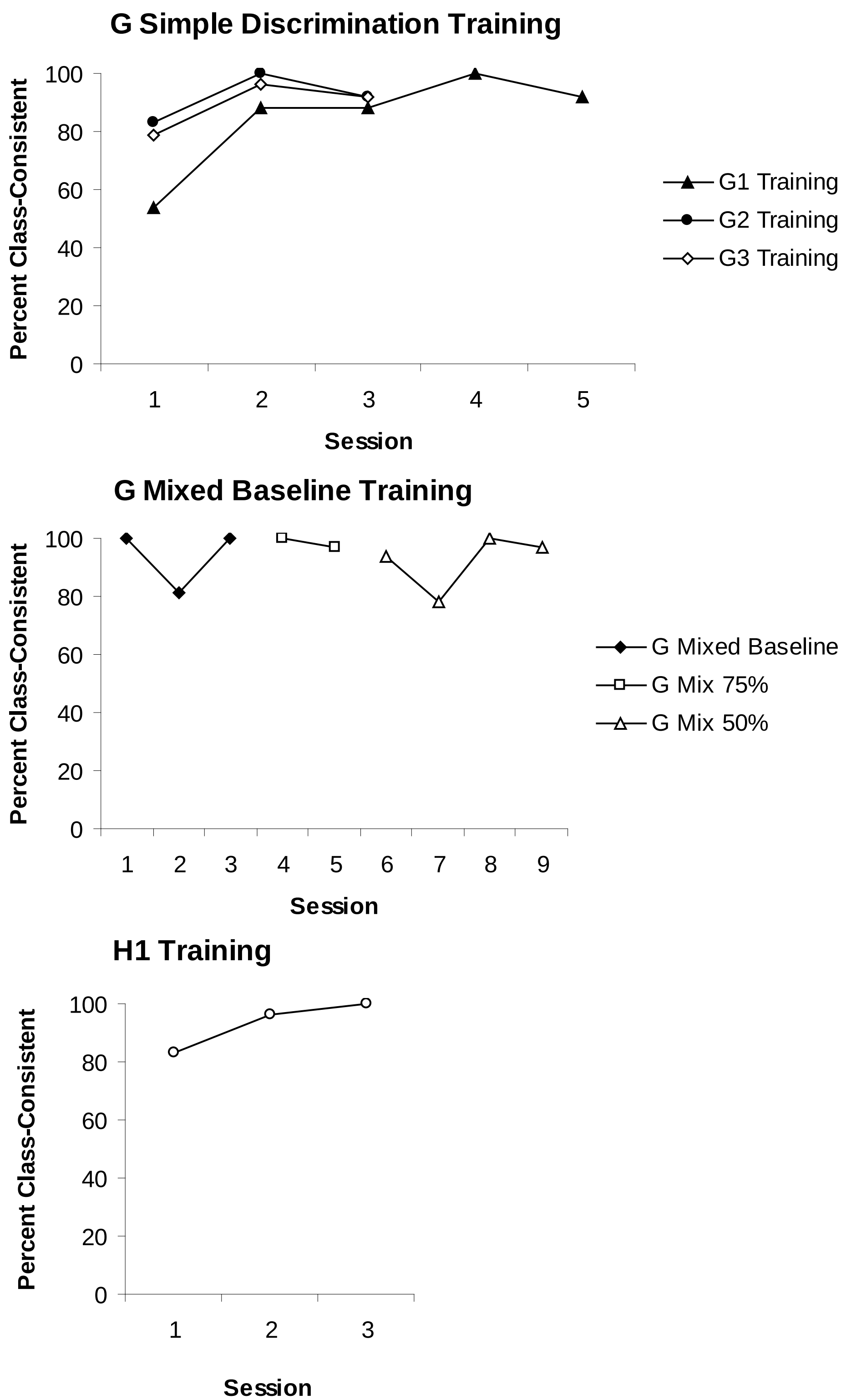


Figure 28. Participant 5 Experiment 3 Training

continues, it is expected that training the three-term contingencies for G and H will make conditional discriminations between G and H easier to learn.

General Discussion

The results of the present study have theoretical as well as practical implications. This study trained three-term relations with human participants, while much research on the formation of equivalence relations as a result of three-term contingency training has been completed with animal subjects (e.g. Kastak, Shusterman, & Kastak, 2001). Additionally, the study explored several aspects of Sidman’s reinforcer contingency theory. Experiment 1 was a direct test of whether three-term contingencies produce equivalence and whether reinforcers can become class-members, and Experiment 2 examined the functions of stimuli within a contingency.

The performance of participant 6 in Experiment 1 in particular adds to the accumulating evidence that three term-contingencies produce equivalence relations (see Sidman 2000). Kastak, Shusterman, and Kastak (2001), and Vaughan (1988) both studied equivalence as a result of three-term contingency training in animal subjects. Sidman, Wynne, Maguire, and Barnes (1989) did a study with young adults, but, at the time, Sidman argued against the theory that three-term contingencies produce equivalence. He later re-evaluated this view, asserting that the functional classes produced by three-term contingencies also imply equivalence (Sidman, 1994a).

Participant 6’s class-consistent responding on class-expansion probes clearly demonstrated that the G stimuli, trained with simple discriminations, had joined the existing classes via the class-specific reinforcers. An interesting theoretical question is whether the type of equivalence that existed between the G stimuli and the remaining class members was functional equivalence. During any reinforced baseline trial with, for example, a class 1 sample, the participants received the same compound class-specific reinforcer (i.e., the reinforcer elements were identical whether the trial was $A_1 \rightarrow B_1$, $A_1 \rightarrow C_1$, or $C_1 \rightarrow D_1$). During G_1 training, correct selections of stimulus G_1 (as opposed to X_1 or X_2) also resulted in delivery of the class 1 reinforcer elements. Participant 6 was able to correctly match G_1 with all other members of the 1 class as a result of their common relations to the compound class-specific reinforcer. It could be said that the G_1 stimulus is equivalent to all other class 1 stimuli because appropriately responding to a class 1 stimulus had the same function of producing the class 1 reinforcer elements. The same is true of stimuli G_2, G_3, and the remaining class 2 and class 3 stimuli, respectively.

The alternative explanation is that the relations between the G stimuli and existing class members were categorized by the three mathematical definitions of a standard equivalence relation. In other words, the relations between the G stimuli and the existing class members are characterized by the three mathematical properties of equivalence. Defining combined symmetric and transitive relations between the stimuli is possible because the reinforcers can be considered nodal stimuli. With the reinforcers as nodal stimuli, the transitive relations between G_1, A_1, and B_1, for example, are if $A_1 \rightarrow B_1 \rightarrow R_1$, and if $G_1 \rightarrow R_1$, then $A_1 \dashrightarrow G_1$ and $B_1 \dashrightarrow G_1$. Reversing the conditional and discriminative stimuli so that $G_1 \dashrightarrow A_1$ and $G_1 \dashrightarrow B_1$ evaluates both symmetric and transitive relations simultaneously, therefore, those probe types are equivalence probes.

Experiment 1 also provided further evidence that reinforcers can become class members (e.g., Dube, et al., 1987 and Dube, et al., 1989). The G stimuli had no relation to the existing classes except through the compound class-specific reinforcers, yet the G stimuli were matched to all existing equivalence class members. This shows that the reinforcer functioned as a nodal stimulus, and this was sufficient for class expansion to occur. These results also support Sidman's view (as opposed to naming, e.g., Horne and Lowe, 1996, or relational frame theory, e.g., Hayes, et. al, 2001) that equivalence relations emerge as a direct result of the reinforcement contingency and that all elements of a contingency can become class members. The reinforcer probe performance of participant 6 in Experiment 1 also revealed that each separate component of the three compound class-specific reinforcers were matched to the appropriate G stimuli, further indicating that each component was also a class member.

Experiment 2 evaluated the functions of stimuli and reinforcers within a contingency. Sidman (2000) asserts that all members of a contingency, including the response and reinforcer, can become equivalence-class members. Though participant 6's probe performances did not remain class-consistent after multiple sessions of each probe type, his initial performance demonstrated that conditional stimuli, discriminative stimuli, and reinforcers can share functions within a contingency. The G stimuli functioned as reinforcers to establish each H simple discrimination. Early in probe sessions, the G stimuli seemed also to function as nodes once again, resulting in probe performances with the H stimuli that were well above the chance level. Because stimuli and reinforcers appear to be able to change functions within a contingency, this is also evidence that reinforcers can function as nodes, the question examined in Experiment 1.

It is possible that participant 6's probe performances with H stimuli were unstable because the G consequences were not as distinct as the compound class-specific reinforcers; whereas the compound class-specific reinforcers were composed of three components which differed visually and audibly, the G consequences were not as elaborate, and it may have been more difficult to distinguish between them. In addition, the only relation between the H stimuli and existing class members from the conditional discrimination phase were the relations between the G stimuli and the existing class members. The participant was never given explicit feedback (i.e., reinforcers) that his responses on probe trials with G stimuli were class-consistent. Therefore, one possible explanation for participant 6's unstable performance on Experiment 2 class-expansion probes with H stimuli may be that the relations between the G stimuli and existing class member stimuli were never explicitly reinforced.

Though incomplete at the time the results were written, Experiment 3 was designed so that participants who did not acquire the conditional discrimination baseline could continue with the study. The results of all four participants indicated that three-term contingencies are easier to learn than four-term contingencies (see Sidman, 1986) which increases their utility as a teaching tool. These participants completed only one or two sessions each day. In a classroom, a teacher could repeat a training program numerous times each day, as they are short and easy to complete. In fact, because a reinforcer preference test had been conducted and the edible reinforcer components were preferred by each individual participant, they often asked to play extra sessions each day. If the four participants in Experiment 3, three of whom had never before participated in any type of research to the knowledge of the experimenters, much less equivalence research, learned simple discriminations in as few as two sessions, it is likely that students in some classrooms could acquire more than one discrimination per day.

As the present study was geared more toward theoretical rather than applied research, the power of stimulus equivalence as a teaching tool may not be immediately apparent. In an early elementary classroom, a teacher could use a match-to-sample teaching format to teach number recognition skills. For example, four-term contingencies could be arranged where the A stimuli are numbers (e.g., 1, 2, and 3), and the B stimuli are quantities of objects, (e.g., one star ★, two stars ★★, and three stars ★★★). When training A→B, the reinforcer might be a voice reading the numbers ("one," "two," and "three"). As there is significant evidence that the reinforcer and response become equivalence class members, using reinforcers relevant to the task increases the number of emergent relations. After completing A→B training in this sample procedure, the student could demonstrate three classes, each with a number, a quantity of objects, and the oral number name. Three-term contingencies might then be used to expand these classes. For example, three written words (e.g., *ONE*, *CAT*, and *DOG*) would be presented as discriminative stimuli, one of which belongs to one of the three classes that emerged after A→B training (*ONE*), and two distracters that do not fit in any of the classes (*CAT* and *DOG*). Selecting *ONE* on these trials would be reinforced with the class-specific reinforcer "one." After three-term contingency training for all three classes, and the appropriate probe sessions, the students might demonstrate classes with four members each; for example, the members of the one class would include 1, ★, "one" (spoken word) and *ONE* (written word). Further class expansion could be trained with the lowercase versions of the written words, and groups of different objects in different arrangements. If students were able to learn multiple discriminations within a week, conditional and simple discriminations for the numbers 1-10 and beyond could be learned rapidly.

There are multiple applications of this study to the field of education, including both regular and special education. In the area of special education, all nine participants were diagnosed with autism, a population that has not received much attention in equivalence literature to date (O'Donnell & Saunders, 2003). Schreibman (2000) noted that discrete trial training has been a successful teaching tool for students with autism; MTS is a form of discrete trial training, and, after Experiment 1, participant 6 had developed classes with 10 members each, including stimuli A-G and the three members of each compound class-specific reinforcer.

The utility of three-term contingencies in facilitating conditional discrimination acquisition is still being explored as this study continues. Experiment 3 is still in progress; after simple discriminations with all G and H stimuli are trained, G→H conditional discriminations will be trained. Training simple discriminations with G and H may facilitate acquisition of the conditional discriminations between those stimuli.

In each of the three experiments, procedures were adjusted for individual participants if the baseline relations were not acquired after at least ten sessions, or the relations tested in probe trials did not emerge. Experiment 3 was added as a procedural adjustment; there are innumerable procedural adjustments that can be made to an equivalence training and testing procedure. Sidman (1977) described the procedures that may be necessary for students with severe mental retardation before baseline relations are trained. The flexibility of equivalence procedures, as well as the variety of materials that can be used as stimuli makes them an invaluable teaching tool for students who fall into a continuum of ability levels.

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