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Relating Relations: The Impact of Equivalence-Equivalence Training on Analogical Reasoning

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Relating Relations:

The Impact of Equivalence-Equivalence Training on Analogical Reasoning

by

Anna R. Garcia

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts Department of Child and Family Studies College of Behavioral and Community Sciences University of South Florida

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Dedication

I dedicate this thesis to my Dad, my Mom, Sarita, Taty, Andres, Karina, Christian, and Salvador.

Thanks for all you help and support. I love you.
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Abstract

A well-researched line showing equivalence performances in a wide variety of areas has been conducted in the field of Behavior Analysis (BA). One area demonstrates that relating relations is a behavioral account of analogical thinking. Relating relations may have implications for the development of analogical training given that analogical reasoning is seen as the foundation of intelligence yet research in this area is limited. A protocol by Stewart, Barnes-Holmes, and Weil (2009) was developed to train children in analogical reasoning using equivalence-equivalence relations. The purpose of this study was to evaluate an equivalence-equivalence training protocol based on Stewart et al. (2009) and test whether the protocol was effective in training equivalence-equivalence responding to 7 and 8-year-old children. A secondary purpose was to test whether training in equivalence-equivalence responding increased performances on analogical tests. All five participants were dismissed throughout the study. Participant 1 was dismissed during the pre-assessments and all other participants were dismissed during intervention. Because none of the participants passed the equivalence-equivalence training, increases in performance in analogical tests were not analyzed. Individual performance data from training are examined and analyzed to provide an account of the failures to pass the equivalence-equivalence protocol.
**Introduction**

Relational Frame theory (RFT) is a behavioral account of language, it extends stimulus equivalence as a basic unit of language by including the numerous relationships found in daily interactions. These derived stimulus relations are an extension of the stimulus equivalence paradigm given that, unlike equivalence classes, where reflexivity, symmetry and transitivity sufficiently define the trained and derived relations involved, other terminology was necessary to delineate non-symmetrical relations. RFT uses the concepts of mutual entailment, combinatorial entailment, and transformation of function, as both process and outcome concepts to how these non-symmetrical relations are formed. Therefore, further exploration of these concepts is necessary to understand relating relations, and consequently human language.

**Mutual Entailment**

Mutual entailment is used in RFT because of its ability to describe non-symmetrical relations such as bigger than and less than (Hayes, Barnes-Holmes, & Roche, 2001). In non-symmetrical relations, such as stimulus A is bigger than stimulus B, the mutually entailed relation is stimulus B is smaller than stimulus A. Mutual entailment occurs when a relation is trained between stimulus A and stimulus B and a reciprocal relation is derived from stimulus B and stimulus A, such as when you train a child that an apple is bigger than an orange, and the child entails that an orange is smaller than an apple (see Figure 1). Training in a case like this starts as directly learned in both directions. Derived relational responding emerges as an overarching operant class from this direct experience. As a result, future relating results in emergent relations developing without direct training.
**Combinatorial Entailment**

Combinatorial entailment replaces the concepts of transitivity and equivalence because not all relations can be symmetrical (Hayes et al., 2001). In the example: A is opposite of B and A is opposite of C, symmetry cannot be shown because B is not equal to A and C is not equal to A. Another example that shows that not all relations can be symmetrical and cannot demonstrate the concept of equivalence is seen in the relation A is bigger than B and A is smaller than C. In this relation, transitivity can occur and the relations can be derived because we can decipher that B is greater than C; however, equivalence cannot be shown since the relations are not proportionate (B is bigger than C and C is smaller than B).

When combinatorial entailment takes place, a relation is derived between two trained relations. This can be seen when a child is taught that an apple is bigger than an orange and a lime is smaller than an apple, and the child entails that an orange is bigger than a lime and a lime is smaller than an orange (see Figure 1).

<table>
<thead>
<tr>
<th>Trained Relations</th>
<th>Mutual Entailment</th>
<th>Combinatorial Entailment</th>
</tr>
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Figure 1. Mutual Entailment and Combinatorial Entailment.
**Transformation of Stimulus Functions**

When mutual and combinatorial entailment occurs, the process of transformation of function also arises. In this process the function of a stimulus participating in the relation is transferred to other stimuli in the network as per the specific relational frames. In the previous example, if the context indicates that the function of orange is healthy, and this function transferred, through mutual and combinatorial entailment, to the apple, then in this context, the apple would be healthier than the orange because the apple is bigger than the orange, and the orange would be less healthier than the apple because it is smaller than the apple. A second example of transformation of function can be seen in the relation “a cat is a dog”. In this example, cat and dog are participating in an equivalence frame, which, means a cat and a dog are the same in a specific context. If the context indicates the function of a cat is being loveable and trustworthy; the function will transfer to a dog is now loveable and trustworthy when you encounter one.
Relating Relations: A Model for Analogical Reasoning

Just as relations are derived between two stimuli within a simple 3-term network, relations can also be derived within and between elaborate relational networks (Stewart, Barnes-Holmes, & Roche, 2009). When relating relational networks, the network is perceived as a single functional unit that is directly trained, under relational (contextual) control, with other networks/stimuli. Once this network is trained to match a second relational network or stimulus, derived responding will emerge and a resultant transformation of function occurs for all networks involved. This process is known as relating relations and has been used as a behavioral model for metaphors and analogies (Hayes et al., 2001). For the purpose of this study, we will focus on relating relations as a model for analogies because of its implications for executive function seen in humans.

The study of analogies is important because of their significance in aiding cognitive functions such as problem solving, decision-making, perception, memory, creativity, emotion, explanation, and communication (Hayes et al., 2001). People use analogies everyday in their lives because they help us understand abstract notions. For example, we “buy a fish because it is like our old one, or we use our friend’s advice because it was correct once before” (Sternberg, 1977). Analogies are also central to the identification and measurement of intelligence and our verbal ability. They are commonly used in standardized tests such as the IQ (intelligence quotients) to assess intelligence, and the GRE (Graduate Record Examination) to assess our verbal reasoning.

The word analogy is composed of two parts: the target, which is the domain to be
explained, and the analog, which is the domain that serves as a source of knowledge (Aubusson, 2006). When you attempt to solve an analogy, information is transferred from the analogue to the target. Take into account the analogy of “the driver is to a vehicle as photographer is to a camera”. You first decipher the relationship between “driver is to a vehicle”; you then use this relational structure and apply it to the second domain “photographer is to a camera” (see Figure 2). A relation is established between the two domains in order to understand that the relational structure is the same in both.

RFT uses relating relations as a behavior model of analogy to emulate this classic analogy of proportion A: B:: C: D. Deriving relations within and across relational networks is necessary to understand and solve these analogies (Stewart et al., 2009). In the analogy from the last example, a driver is to a car as a photographer is to a camera, you first identify that a driver uses a car to work (see Figure 2). You then apply this function to photographer and camera to understand that a photographer uses a camera to work. When you pair the two relational networks together, you derive a relation across both relational networks to understand that a driver uses a car to work is the same as a photographer uses a camera to work.

Figure 2. Example of analogies as relating relations.
Barnes, Hegarty, and Smeets (1997) were the first to test this behavioral model for analogical reasoning using equivalence-equivalence relations (two equivalence relations related to each other) in a series of three experiments. In the study, all participants received training on equivalence relations between arbitrary stimuli using matching to sample tasks, they were then exposed to tests that assessed whether they could derive relations of sameness between two separate equivalence relations and relations of distinction between two separate non-equivalence relations. The study tested whether passing an equivalence test was necessary to demonstrate equivalence-equivalence responding and examined whether contextual control could be shown in equivalence-equivalence relations. The results of the experiment revealed that participants could relate equivalence relations to other equivalence relations following training, or form relations of coordination between the two different networks stimuli without any explicit training. The study also showed that the participants were able to demonstrate equivalence-equivalence responding under contextual control even when the contextual stimuli were presented as sample stimuli and the sample stimuli were presented as the comparisons. The results of this study demonstrated that equivalence-equivalence provided a viable way of behaviorally modeling analogical reasoning, however; more studies were necessary to show that all the main characteristics of relational frame theory and analogical thinking were present in these relating relations.

Stewart, Barnes-Holmes, Roche, and Smeets (2001) extended Barnes et al. (1997) to further demonstrate that equivalence-equivalence relations can serve as a behavioral model for analogies by including arbitrary as well as non-arbitrary stimuli to show that both relations can be trained and derived. Additionally, they included five-member equivalence classes as opposed to three-member equivalence classes that result in a more ecologically valid preparation as it
relates closer to the complexity of our natural use of language. Stewart, Barnes-Holmes, Roche, and Smeets (2002) continued to explore relating relations as a model for analogical for analogical reasoning by examining the discrimination of formal similarity in equivalence-equivalence relations using various dimensions of shape and colors. They also demonstrated transformation of function in equivalence-equivalence relations with an increased number of stimuli presented in the relational networks. Finally, Carpentier, Smeets, Barnes-Holmes and Stewart (2004) modified the analogical procedure in which relating the relations could be attributed to matching functionally same relations and not just matching previously trained relations. Previous equivalence-equivalence tests required subjects to choose between a compound with two same-class elements and one with two different-class elements. This study attempted to adapt equivalence-equivalence tests more closely to the analogy by using only compounds with same-class elements. The study assessed whether these equivalence-equivalence performances and corresponding classical analogies could be based on equivalence-equivalence responding. These studies demonstrated that equivalence-equivalence relations could now be used as a behavioral model for analogical reasoning and that participants could be taught to respond to equivalent-equivalent relations. The next step was to show that young children could also be trained to respond to equivalence-equivalence relations.
Is Relating Relations a Matter of Age?

A line of investigation stemmed from Barnes et al. (1997), which attempted to accommodate research procedures for children under the age of 12 to pass equivalence-equivalence training. Teaching children to respond to equivalence-equivalence training has great implications given that developmental psychologist have traditionally believed that children under the age of 12 have difficulty solving analogy problems because they have not developed the formal operational thinking necessary to solve higher order analogies (Inhelder & Piaget, 1958). Barnes et al. (1997) demonstrated that two children, a 9-year-old and a 12-year-old could be taught equivalence-equivalence responding. Carpentier, Smeets, and Barnes-Holmes (2002) borrowed from Barnes et al.’ procedures to attempt to teach 5 and 9-year-old participants equivalence-equivalence responding. Carpentier et al. (2002) demonstrated that 4 out of 4 5-year-old participants could pass equivalence-equivalence testing when they were exposed to pre-training in easier tasks such as compound-compound training with previously learned relations. In these compound-compound training blocks participants were taught to match matched compounds to other matched compounds (e.g., A1B1-A2B2 and A1C1-A2C2) and unmatched compounds to other unmatched compounds (i.e., A1B2-A2B3 and A2C3-A1C2). Carpentier, Smeets, and Barnes-Holmes (2003) replicated Carpentier et al. (2002) to further test the compound-compound training that allowed 5-year-old children to pass equivalence-equivalence testing. The study partially replicated Carpentier et al.’s (2002) results. Only 2 out of 4 5 year-old children passed the equivalence-equivalence testing blocks even when they were exposed to compound-compound training. Carpentier et al. (2003) then tested whether familiar stimuli
could help participants pass this training in three studies. Two experiments used pictures of happy and sad faces to signal to participants whether compounds were matched and unmatched. When presented with a happy face, participants were required to point to a matched compound and when presented with a sad face the participant was required to point to an unmatched compound. A third experiment used familiar stimuli throughout the training (ex: bicycle, paint brush, tree) instead of arbitrary stimuli to teach equivalence-equivalence responding. These modifications demonstrated that the use of familiar stimuli did not help improve the percentage of participants that passed equivalence-equivalence tests; in fact the percentage of participants that passed the equivalence-equivalence responding was reduced to 25% (1 of 4 participants).

Despite unsuccessful attempts to replicate the results by Carpentier et al. (2002), these studies have demonstrated that some 5 year-old children were able to learn equivalence-equivalence responding and more research is warranted in this area. Because of the implication that relating relations may have on training of children in analogical reasoning, a protocol by Stewart et al. (2009) was devised that included successful modifications of previous studies such as the inclusion of baseline-baseline training (Carpentier et al. 2002, 2003) and equivalence testing prior to equivalence-equivalence testing (Carpentier et al., 2002). The protocol contains a series of 10 phases in which conditional discrimination, equivalence responding, and equivalence-equivalence responding are trained and tested. Phases 1-3 train and test A-B and A-C relations, phases 4-6 train and test compound-compound relations while Phases 7-10 test for the formation of symmetry, equivalence, derived matched/non-matched symmetry and equivalence-equivalence relations.

The reviewed literature has not only established equivalence-equivalence relations as a viable model for analogical reasoning, but it has also shown that 5-year-old children can be
taught to engage in equivalence-equivalence responding. A protocol (Stewart et al., 2009) was also devised for teachers to use to train children in analogical reasoning with the assumption that it would help analogical reasoning skills, but this assumption has not been evaluated. To date, studies have not shown that being exposed to equivalence-equivalence relations affects analogical reasoning skills. Showing that exposures to equivalence-equivalence relations will make equivalence-equivalence relations a more ecological behavioral model of analogies.

The purpose of this study was to empirically test an equivalence-equivalence training protocol based on Stewart et al., (2009) on whether it was effective in teaching 7 and 8 year-old children equivalence-equivalence responding. Seven and 8-year-old participants were chosen because it was believed they would be more likely to pass the protocol due to their age range; previous work by Carpentier et al. has shown that at least some components of the protocol were effective in teaching 5-year-olds. We felt this was a reasonable goal given that until now none of the phases have been included in a single teaching package. This study was also the first equivalence-equivalence study that used 7-8 year-children as participants. If participants do not pass the equivalence-equivalence protocol, future studies should test their ability to pass equivalence-equivalence relations using different methods. It should be noted that the failure to detect an effect using the methods proposed below does not support the conclusion that 7-8 year old children cannot derive equivalence-equivalence relations in general. Rather, participants’ inability to demonstrate equivalence-equivalence may be due to the protocol procedures.

Additionally, we will test whether training in equivalence-equivalence responding will improve performance on analogy tasks. This study will involve using a mobile device (laptop computer) to facilitate children’s learning. Testing the protocol in a computer tablet has great implications for dissemination and accessibility of trainings to educational settings, given that Mobile
technologies have shown to aid long distance learning (Fuegen, 2012) by helping learners focus for longer periods of times, provision of immediate feedback learners, and the portability of training protocols (Yousef, 2007).
Method

Participants

Five participants were recruited for this study. Four 8 year-olds and one 7-year-old were selected to take the pre-and post-assessments and the equivalence-equivalence training. All participants were typically developing children, spoke English as their primary language, had no prior knowledge or experience with RFT, did not engage in any problematic behavior that could disrupt the study sessions, and never failed a school grade. A pre-test was used to assess participant’s ability to answer analogy problems prior to being exposed to the analogical training program. All participants who scored 85% were excluded from the study.

Participants were recruited through announcements sent to friends, family, and University of South Florida faculty by email. Email addresses were gathered from the Principal Investigator’s (PI) contact list. The email message contained the flyer with the PI contact information. If the parent/guardian were interested in having their child participate in the study, parents/guardians were instructed, by the flyer, to contact the primary investigator to find out more about the study and its requirements. Upon contact by parents/guardians, Anna Garcia (PI) asked a set of questions to determine eligibility of the participant. If the participants met inclusion criteria and the parent/caregiver continued to be interested in having their child participate in the study, the PI set a meeting to review the consent form. At the initial meeting, the investigator explained the purpose of the study and all sections of the consent form were reviewed and parents had the opportunity to ask any questions. The research investigator explained to the caregivers that participation was optional and no repercussions would occur if
they did not participate. All parents were given one week after learning about the study to contact the PI to set an appointment to sign the consent form. The research investigator contacted the parents after the given time frame to confirm or deny their child’s participation. After the participant’s parents provided consent, each participant was presented with the verbal assent process in which the purpose, the methods, and the benefits of the study were described (see Appendix A). The participants were required to answer a "Yes" in order to participate in the study. If the participant refused to participate, he/she was thanked for letting us have the opportunity to speak to him and the research investigator left the room.

There were no anticipated risks in associated in this study. However, there was a small chance that children could become frustrated with the assessments or training protocol. The PI monitored for signs of agitation and/or frustration throughout the study. When signs of agitation/frustration occurred twice in any session, the session was discontinued and the next regular session was attempted. Breaks were provided at participant’s request and after phases were completed.

Participants were compensated for participating in the study independent of their performance on the pre- and post- assessments and equivalence-equivalence phases. They each received $1 for every analogy assessment and training phase they attempted regardless of the score they received or whether they completed the phase. Participants could earn up to $15 throughout the study because they were only paid for the first exposures to each phase and did not receive money for completing phases they previously passed.

**Materials**

**Stimuli.** The stimuli used in the protocol included 9 black arbitrary figures, which are identified alphanumerically (A1, A2, A3, B1, B2, B3, C1, C2, C3) throughout this document (see
Figure 3). The stimuli served as distractor stimuli in training and testing trials.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Shape A" /></td>
<td><img src="image2" alt="Shape B" /></td>
<td><img src="image3" alt="Shape C" /></td>
</tr>
<tr>
<td><img src="image4" alt="Shape A" /></td>
<td><img src="image5" alt="Shape B" /></td>
<td><img src="image6" alt="Shape C" /></td>
</tr>
<tr>
<td><img src="image7" alt="Shape A" /></td>
<td><img src="image8" alt="Shape B" /></td>
<td><img src="image9" alt="Shape C" /></td>
</tr>
</tbody>
</table>

Figure 3. Arbitrary stimuli used in equivalence-equivalence training.

**Laptop computer.** A MacBook Pro with a 13-inch screen was used to display stimuli in training and testing trials. The stimuli presentations were programmed using Livecode 5.5.1. The computer program, where the stimuli were presented, was validated by having two volunteers, a 9-year-old and 23 year-old, complete the program. Both volunteers passed the equivalence-equivalence protocol with no difficulties.

**Analogy tests.** Level 8 and Level 9 (for Participant 1) of the Cognitive Abilities Test (CogAT) Screening Form 7 was used to assess analogical reasoning in baseline and during the
post-instructional probes. The assessment is derived from the CogAT Form 7, which is designed to assess analogical ability. The level 8 assessment is composed of 54 questions and is divided into three sections; picture analogies, number analogies, and figure matrices. Each section contains 18 questions. The level 9 assessment is composed of 60 questions and is also divided into 3 sections; verbal analogies, number analogies, and figure matrices. Each section contains 22, 18, and 20 analogies, respectively.

**Design**

A non-concurrent multiple baseline across participants was used to assess the effect of equivalence-equivalence training protocol by Stewart et al. (2009) on improving participants’ analogical reasoning. The CogAT Screening Form 7 (described above) was used to assess participants’ abilities to answer analogy problems during baseline. The baseline assessment was administered between 1-5 times. The rationale for staggering implementation of the intervention across participants is to detect whether length of baseline (and other time-correlated extraneous variables) serves as a confounding variable. Following baseline, participants were exposed to the protocol using a laptop computer.

Every participant was presented with baseline assessments using the same CogAT Screening Form 7 during baseline, however; no participant passed the equivalence-equivalence training. Thus, we did not conduct post-intervention CogAT scores because it is unlikely any observed increases could have been reasonably attributable to the intervention.

**Procedure**

The study was conducted in up to 8 sessions, one to two sessions per day, with no more than 2 days in between two sessions. Participants that missed a session were re-exposed to Phases 1-3 to ensure previously trained relations were intact. Additional sessions took place on
the following day. Sessions were administered during the day in a time that was most convenient to the parents and the PI.

All sessions were administered to each participant individually, in a room that contained a table and a chair. When the participant entered the testing room, the PI instructed him/her to sit on the chair next to a table. At that point, the baseline assessments were administered. The PI administered the assessment via paper and pencil and followed the instructions from the CogAT Directions for Administration booklet, which was provided by the CogAT testing services.

After baseline assessments were administered the PI told the participants they could play a game on the computer.

Before beginning equivalence-equivalence training (described below) the PI trained the participant on how to respond to each trial by using printed snapshots of a single-stimulus trial layout. The layout consisted of one sample stimulus and three comparison stimuli. The sample stimulus was presented in the middle of the page with the three comparison stimuli, lined side by side, below the sample stimulus on the bottom of the screen. The PI provided instructions and modeled how to correctly touch the chosen answer; the participant then had two opportunities to practice. After the instructions, the PI told the participants to begin the protocol on the laptop computer.

**Equivalence-equivalence training.** The procedures used in this study were based largely on those described by Stewart’s et al. (2009). The protocol consists of 10 phases in which participants were trained and tested on A-B and A-C relations in Phases 1-3, matching single stimuli to compound stimuli in Phase 4, matching matched and un-matched compounds in Phase 5 and 6, testing relations of symmetry, equivalence, matched and non-matched symmetry and equivalence-equivalence relations in Phases 7-10 (See Appendix B for an overview of the
protocol). In addition, we included two additional phases (described below) when we did not observe the expected skill acquisition as a result of the other phases.

Feedback was presented in all training phases. When a trial was answered correctly a word in green colored font, such as, “Correct”, “Great Job”, “Excellent” or “Very Good”, was randomly shown in the center of the screen. The word “Wrong”, in red colored font, was presented if a trial was answered incorrectly. All training blocks were presented to participants until they receive a passing score, or until the PI determined that the participant was not improving at a reasonable rate. Participants had two opportunities to pass a testing block. If they did not receive a passing score on the second testing block, they were re-exposed to training blocks and given the opportunity to retake the testing block two more times. Participants who did not receive a passing score on the second testing block of the second training opportunity were dismissed from the study.

The next section describes procedures for teaching relations between three examples of stimuli (designated as A, B, or C) in each of three experimenter-defined classes (designated as 1, 2, or 3). Thus, in the text below, specific stimuli will be referred to by letter and number designations (e.g., A1, B3, etc.; see Figure 3). A hyphen between two stimuli indicates a relation (either trained or derived) between those stimuli (e.g., A1-B1 means that in the presence of A1, participants should select stimulus B1). We will also sometimes refer to relations between sets of stimuli from the same classes by omitting the class number. For example, A-B refers to all the relations between stimuli A and B: A1-B1, A2-B2, and A3-B3.

As described above, the protocol described by Stewart et al. (2009) consisted of 10 phases. The purpose of Phases 1, 2, and 3 was to train equivalence relations between stimuli in each of three experimenter-defined classes designated as 1, 2, and 3. A-B relations were to be
trained directly and tested in Phase 1. A-C relations were to be trained directly and tested in Phase 2. Phase 3 tested those trained relations in pseudo-random order.

In Phase 4, participants were trained to select compounds of stimuli given a sample consisting of the same two stimuli drawn apart. Compounds can consist of stimuli from either the same class (referred to as *matched*) or different classes (referred to as *unmatched*). In the text, such compounds themselves will be referred to using the stimulus designations without a hyphen, e.g., AB, AC, or BC.

The purpose of Phase 5 was to teach participants to select a matched compound in the presence of a sample consisting of a different matched compound. For example, in the presence of the compound A1B1, participants might be presented with two comparison compounds: A2B1 and A3B3, of which the second was considered the correct response.

The purpose of Phase 6 was to teach participants to select an unmatched compound in the presence of a sample consisting of a different unmatched compound. For example, in the presence of the compound A1B2, participants might be presented with two comparison compounds: A2B1 and A3B3, of which the first was considered the correct response.

The purpose of Phase 7 was to test whether the training experiences provided in Phases 1 and 2 (A-B and A-C) resulted in the participants also learning the corresponding symmetrical relations (B-A and C-A). For example, in the presence of the sample C1, and the following three comparison stimuli: A1, A2, and A3, the first (A1) was considered the correct response. Such symmetrical relations are often readily acquired in typically developing adults given analogous training experiences.

The purpose of Phase 8 was to test whether the training experiences provided in Phases 1 and 2 (A-B and A-C) resulted in the participants also learning the corresponding derived
equivalence relation (B-C) and its corresponding symmetrical relation (C-B). For example, in the presence of the sample B1, and the following three comparison stimuli: C1, C2, and C3, the first (C1) was considered the correct response. Such derived relations are often readily acquired in typically developing adults given analogous training experiences.

The purpose of Phase 9 was to test whether the training experiences provided in Phases 1, 2, 4, 5, and 6 resulted in the participants also learning the corresponding symmetrical matched and unmatched compound relations. For example, in the presence of the matched sample compound B1A1, participants might be presented with two comparison compounds: B2A2 and B3A1, of which the first would be considered correct. Similarly, in the presence of the unmatched sample compound B1A3, participants might be presented with two comparison compounds: B2A2 and B3A1, of which the second would be considered correct.

The purpose of Phase 10, the final phase, was to test whether the training experiences provided in Phases 1, 2, 4, 5, and 6 resulted in the participants also learning the corresponding derived and symmetrical matched and unmatched compound relations. For example, in the presence of the matched sample B1C1, participants might be presented with two comparison compounds: B2C2 and B3C1, of which the first would be considered correct. Similarly, in the presence of the unmatched sample compound B1C3, participants might be presented with two comparison compounds: B2C2 and B3C1, of which the second would be considered correct.

Phase 1: A-B training and testing. In Phase 1, A-B relations (A1-B1, A2-B2, A3-B3) were trained in a matching-to-sample style. A1-B1 training and testing were presented followed by A2-B2 training and testing and A3-B3 testing and training, respectively.

Each trial consisted of one sample stimulus and three comparison stimuli. The sample stimulus was presented in the middle of the screen with the three comparison stimuli, arranged
side-by-side, below the sample stimulus on the bottom of the screen (see Figure 4). The participant was required to click on the comparison stimulus that matched the sample stimulus. The location of the correct comparison stimulus was quasi-randomly selected from one of the three positions (left, center, or right). Distractor (incorrect comparison) stimuli were always selected from the same letter group as the correct comparison stimulus, for example; when A1-B1 relations are presented, B2 and B3 stimuli were shown as distractor stimuli.

![Figure 4. A-B training and testing examples. The A stimuli on the top center are the sample stimuli and the three B stimuli on the bottom are the comparison stimuli. Participants were required to touch the comparison stimulus that matched the sample stimulus.](image)

Before beginning the training block, participants were presented with the following instructions:

1. *Point to the shape that goes with the top shape.*

2. *The computer will tell you if your response is Right or Wrong.*

3. *Mistakes are normal at the beginning.*

4. *Your task is to get as many Right as possible.*

5. *Press “START” when you are ready to begin.*

During the training blocks, trials were presented in 18-trial blocks; participants were required to answer all 18 trials correctly before continuing to the testing block.

After participants passed the A1-B1 training, a 12-trial testing block was administered to assure the relations were intact. Testing trials were presented in the same format as training
trials, however; no feedback was given for correct or incorrect responses until the end of the trial block. At the end of trial blocks, participants were shown their overall score and not provided feedback on their selections in any given trial. Participants were presented with the following instructions before beginning this phase:

*Continue to point to the shape that goes with the top shape.*

*The following tasks will not show whether you answered the task right or wrong.*

*Press the “START” button when you are ready to begin.*

Every participant was required to answer 10 out of 12 trials correctly to pass the testing block. If they did not pass it on the second try the participant was reintroduced to A1-B1 training and A1-B1 testing. If the participant did not pass the testing trial on the second exposure of the second training they were dismissed from the study.

Once all A-B relations were trained and tested, A-B mixed testing was conducted. A-B Mixed Testing consisted of a block of 36 trials in which A1-B1, A2-B2, and A3-B3 were assessed in random order, with two exposures to each relation. As mentioned previously, no feedback was given for correct or incorrect responses until the end of the block. Prior to beginning the testing phase participants were presented with the following instructions:

*Continue to point to the shape that goes with the top shape.*

*The following tasks will not show whether you answered the task right or wrong.*

*Press the “START” button when you are ready to begin.*

Mastery criterion for this block was defined as responding correctly on 34 out of 36 trials. If the participant did not pass the mixed testing block on the second exposure they were reintroduced to training on all A-B relations. If the participant did not pass mixed testing on the second exposure of the second training they were dismissed from the study.
**Phase 2: A-C training and testing.** In Phase 2, A-C training and testing was conducted in the same manner as Phase 1. Participants were presented with training, testing and mixed testing blocks as described in the A-B relations (see Figure 5), with the exception that A-C relations (A1-C1, A2-C2, A3-C3) were used.

![Figure 5](image)

Figure 5. A-C training and testing examples. The A stimuli on the top center are the sample stimuli and the three C stimuli on the bottom are comparison stimuli. Participants were required to touch the comparison stimulus that matched the sample stimulus.

**Phase 3: Mixed A-B and A-C testing.** Mixed A-B and A-C testing blocks (see Figure 6) were presented in Phase 3 to assure that the relations are intact. This phase was conducted in the same format as the mixed testing blocks in the previous two phases. The test presented A-B and A-C relations in quasi-random order across blocks of 18 trials each. Three presentations of each of the six trial-types (A1-B1, A2-B2, A3-B3, A1-C1, A2-C2, A3-C3) were included in the mixed blocks. The participants were required to answer 34 out of 36 trials correctly to continue to the next phase. If they did not receive a passing score on the testing block they were re-trained on the relations they had the most errors on. For example; if they made the most errors on the A-B relations they were re-exposed to Phase 1 and if they made the most errors on A-C relations they were re-exposed to Phase 2. Just as the in the previous phases, if participants did not pass the second testing blocks of the second exposure to training they were dismissed from the study.

By the end of Phase 3, participants were assumed to have sufficient experience to learn that stimuli from the same class were equivalent.
**Phase 4: Matched (A-B—AB and A-C—AC) compound training and testing.** In Phase 4, participants were presented with compound training and testing. They were taught to match compound stimuli that were functionally equivalent to corresponding sample stimuli: A-B stimuli is equal to AB compounds and A-C stimuli is equal AC compounds. Carpentier et al. (2002) found that when 5 year-old participants where taught to match compounds using relations that were already trained, they were more likely to pass equivalence-equivalence testing. The A stimulus was presented, as a sample stimulus, in the middle of the screen and three B stimuli were quasi-randomly presented at the bottom of the screen. One B stimuli was positioned in the bottom left corner, one in the bottom center of the screen, and one in the bottom right corner. Three AB compounds were presented immediately above the sample stimuli, side by side (see Figure 7). The first stimulus of the compound stimulus was always the same as the sample stimulus in the middle of the screen to reduce correct responding due to process of elimination of distinct stimuli. Participants were required to touch the compound stimulus that was functionally
equivalent to the A and B stimulus. The participants were presented with the following instructions before beginning the session.

1. *Point to the top shape that matches.*
2. *The computer will tell you if your response is Right or Wrong.*
3. *Mistakes are normal at the beginning.*
4. *Your task is to get as many Right as possible.*
5. *Press “START” when you are ready to begin.*

The compounds trained in this phase were A-1—B1, A-2—B2, A-3—B3. A block containing 18-trials was presented with six exposures to each of the relations. A score of 100% was required to continue to the next section. Participants continued to receive training blocks until they received a passing score.

The compound-testing phase was presented in the same format as the training phase; however, blocks contained 12 trials each. The participants were given the following instructions prior to beginning the section:

*Continue to point to the shape that matches.*

*The following tasks will not show whether you answered the task right or wrong.*

*Press “Start” when you are ready to begin.*

Participants were required to answer 10 out of 12 trials correct to continue to the AC matched compound training phase.

A-C—AC training and testing was conducted in the same manner as A-B—AB testing and training with the only difference that AC compounds (A-1—C1, A-2—C2, A-3—C3) were taught.
Mixed testing was presented in the same format as matched compound training and testing. Testing blocks contained randomized A-B—AB and A-C—AC matched compound trials, in sets of 36 trials. Participants must answer 34 out of 36 trials correctly to continue to the next phase.

![Matched compound trial examples](figure7.png)

Figure 7. Matched AB (top row) and AC (bottom row) compound trial examples. In an AB training trial, an A stimulus was presented in the middle of the screen and three B stimuli were presented at the bottom of the screen, as a sample stimuli. Three AB compounds were presented immediately above the A stimulus, as comparison stimuli. Participants were required to touch the comparison stimulus that was functionally equivalent to the sample stimulus. AC compounds are presented similarly with the exception that C stimuli were presented in place of the B stimuli.

**Phase 5: Matched compound-compound training and testing.** In Phase 5, participants were trained to match compound stimuli to other compound stimuli (A1B1 = A3B3). They were presented with one compound configuration as the sample stimulus (presented in center of the screen) and two other compound configurations as comparison stimuli (presented in the top right and top left of the screen)(see Figure 8). For example, when compound A1B1 was presented, as the sample stimuli, participants should choose A3B3 as the correct comparison stimuli. Participants were trained that a relation of coordination exists between the two matched
compound stimuli. The participant must choose the comparison stimulus that enters in a relation of coordination with the sample stimuli. The location of the correct comparison stimuli was quasi-randomized throughout the training.

Figure 8. AB (top row) and AC (bottom row) Matched compound-compound trial examples. A compound configuration was presented in the center of the screen, as the sample stimulus, and two other compound configurations were presented in the top right and top left of the screen, as comparison stimuli. Participants were required to touch the comparison stimulus that was equivalent to the sample stimulus.

The participants were given the following instructions prior to beginning the blocks.

Point to the top shape that matches bottom shapes.

The computer will tell you if your response is Right or Wrong.

Mistakes are normal at the beginning.

Your task is to get as many Right as possible.

Press “START” when you are ready to begin.”

Matched AB compound-compound training was presented in blocks of 18 trials. The relations trained were A1B1-A2B2, A1B1-A3B3, A2B2-A1B1, A2B2-A3B3, A3B3-A1B1,
and A3B3-A2B2. Three exposures to each of the six trial types were included in each block.

Matched compound-compound testing was conducted using 12-trial blocks, which included two exposures to each of the 6 trial types. All participants were required to correctly answer 10 out of 12 trials to continue to the AC-AC matched compound-compound training and testing.

AC compound-compound training and testing were conducted in the same manner as AB-AB matched compound-compound training and testing.

_A2C2 Mass Trials_. A separate training block was conducted to teach Participant 1 to relate A2C2 relations to other matched compound stimuli (A1C1 and A3C3) after she failed to respond correctly to training trials that contained A2C2 trials as sample or comparison stimuli during Phase 5 AC-AC matched compound-compound training. This trial block is not based on Stewart et al. (2009) and it was not presented using the laptop computer as the other phases. Each trial in the block was presented using 2 x 2 index cards. During the trials, the A2C2 compound stimulus was presented as a sample stimulus, an AC matched compound comparison stimulus (A1C1 or A3C3) was presented as a comparison stimulus and an unmatched stimulus (ex. A1C3) was presented as a second comparison stimulus. The trials were presented until the participant pointed to the correct comparison stimulus for a minimum of 3 consecutive trials. The A2C2 stimulus was then presented as a comparison stimulus and an AC matched compound stimulus was presented as a sample compound stimulus until she responded correctly for a minimum of 3 consecutive times. The A2C2 stimulus was then alternated as sample stimulus and as a comparison stimulus until she chose the correct sample stimulus for a minimum of 3 consecutive trials. When Participant 5 met the requirements, she was re-exposed to Phase 5 AC-AC match compound training.
A mixed test that included 36-trials blocks of randomized test trials containing all AB—AB compounds and AC—AC were presented to participants. All participants were required to score 34 out of 36 correct in order to pass to the next phase. Participants were given two opportunities to receive a passing score; if they did not receive a passing score on the second try they were reintroduced to matched compound training and testing in Phase 4.

**Phase 6: Non-matched compound-compound training and testing.** Phase 6 attempted to teach participants to match non-matched compound-compound stimuli to other non-matched compound stimuli. The participants should learn that two relations of difference could be matched like two relations of coordination. For example, when stimulus A2B3 is presented participants should select an unmatched compound such as A1B2 opposed to A1B1 (see Figure 9). Phase 6 was conducted in the same format as Phase 5 with the exception that the sample stimuli were non-matched stimuli and the correct comparison stimuli were non-matched compound.

![Figure 9. AB (top row) and AC (bottom row) Non-matched training and testing examples. A compound configuration was presented in the center of the screen, as the sample stimulus, and two other compound configurations were presented in the top right and top left of the screen, as comparison stimuli. Participants were required to touch the comparison stimulus that was equivalent to the sample stimulus.](image-url)
Phase 7: Symmetry testing. Phase 7 tested for symmetry relations that should emerge within A-B and A-C relations. The format for this phase was similar to Phase 1, with the exception that the relations tested included: B1-A1, B2-A2, B3-A3, C1-A1, C2-A2, and C3-A3 (see Figure 10). All trials were presented in mixed 36 trial-blocks containing six exposures to each relation. No feedback was given for correct or incorrect responses. Participants must correctly answer 34 trials out of 36 to pass the phase. If they do not receive a passing score on the second attempt, they were retrained on A-B and A-C relations (Phase 1 and 2). The participants had two more opportunities to pass the test. If they did not receive a passing score on the test they were dismissed from the study.

![Figure 10](image)

Figure 10. B-A (top row) and C-A (bottom row) symmetry testing examples. The stimulus on the top center is the sample stimulus and the three stimuli on the bottom are the comparison stimuli. Participants were required to touch the comparison stimulus that matched the sample stimulus.

Phase 8: Equivalence testing. Phase 8 tested for the emergence of combinatorially entailed relations between B and C stimuli. The format for this phase was similar to Phase 1 testing; with the only difference that the relations tested were be B1-C1, B2-C2, B3-C3, C1-B1, C2-B2, and C3-B3 (see Figure 11).
The trials were presented in blocks of 36 trials containing 6 exposures to each relation. Participants were required to correctly answer 34 out of 36 trials to continue to Phase 9. If they did not receive a passing score on the second attempt, they were retrained on A-B and A-C relations (Phase 1 and 2). They had two more opportunities to pass the test. If they did not receive a passing score on the test they were dismissed from the study.

**Phase 9: Derived Matched and Non-matched Symmetry Testing.** Phase 9 will test for mutually entailed relations between matched and non-matched compounds. Derived matched testing will be presented first, followed by derived non-matched and mixed-testing. The trials were presented in a similar fashion as Phases 5 and 6. A compound stimulus was presented in the center as a sample stimulus and two compound stimuli were placed on the top of the screen: one on the top right corner and one on the top left corner (see Figure 12). Derived matched symmetry testing included three exposures of each matched compound-compound relation (B1A1-B2A2, B1A1-B3A3, B2A2-B1A1, B2A2-B3A3, B3A3-B1A1, B3A3-B2A2, C1A1-C2A2, C1A1-C3A3, C2A2-C1A1, C2A2-C3A3, C3A3-C1A1, C3A3-C2A2). Each
combination was quasi-randomly presented throughout the testing block. All participants were required to answer 34 out of 36 trials correctly to continue to derived non-matched testing. If a participant did not pass on the second attempt they were retrained on Phases 7 and 8.

During the derived non-matched symmetry testing, participants were exposed to 36 possible unmatched compound combinations (B1A2, B1A3, B2A1, B2A3, B3A1, B3A2, C1A2, C1A3, C2A1, C2A3, C3A1, C3A2). All participants were required to answer 34 out of 36 trials correctly to continue to Phase 10. If a participant did pass on the second attempt they were retrained on Phases 7 and 8. Mixed testing was administered by presenting 18 derived matched and 18 derived non-matched trials in one block. All participants were required to answer 34 out of 36 trials correctly to continue to Phase 10. If a participant did not pass on the second attempt they were retrained on Phases 7 and 8.

**Mixed Matched and Unmatched Training and Testing.** A separate training and testing block was presented to Participant 5 after he received a score of 100% on matched symmetry compound testing and 0% on unmatched symmetry compound testing. It was hypothesized that Participant 5 did not learn how to discriminate between matched and non-matched compound trials, therefore; the PI conducted a mixed training and testing block where matched and unmatched training trials were mixed to teach him to discriminate between the trials. The blocks contained 18 matched and 18 unmatched of AB-AB and AC-AC matched and unmatched trials. The trials were presented in the same format as in Phase 5 and 6, with the exception that AB-AB and AC-AC trials were mixed. Feedback was provided during the training block. The same trials were then presented in the testing blocks and no feedback was provided. The participant was required to answer 34 trials correctly of 36 in both training and testing blocks to pass each block. Once Participant 5 passed the blocks he was re-exposed to Phase 9. The Mixed Matched and
Unmatched Training and Testing trials were presented using 2x2 index card, and like the A2C2 Mass trials this block was not based on Stewart et al. (2009) protocol.

Figure 12. BA (top row) and CA (second row) matched and, BA (third row) unmatched (bottom row) compound symmetry testing examples. The two compound stimuli on the top center are the comparison stimuli and the compound stimulus on the bottom center is the sample stimulus. Participants were required to touch the comparison stimulus that matched the sample stimulus.

**Phase 10: Equivalence-equivalence testing.** In phase 10, participants were assessed on the derivation of combinatorial entailed relations between matched compound and unmatched compounds. The phase was conducted similar to Phase 5, where one compound configuration is presented as the sample stimuli and two other compound configurations as comparison stimuli
(see Figure 13). Matched compound testing was administered, followed by non-matched compound testing, and mixed matched and non-matched compound testing, respectively.

In matched compound testing the relations assessed were B1C1-B2C2, B1C1-B3C3, B2C2-B1C1, B2C2-B3C3, B3C3-B1C1, B3C3-B2C2, C1B1-C2B2, C1B1-C3B3, C2B2-C1B1, C2B2-C3B3, C3B3-C1B1, and C3B3-C1B1. The relations were presented in blocks of 36 trials; each relation was shown three times. Participants were required to answer 34 out of 36 trials correctly to pass the testing phase.

Unmatched compound relations were tested in the same format as matched compound relations, with the exception that the sample stimuli were a non-matched compound. Participants were required to choose the non-matched compound stimulus as the correct stimulus. There were a total of 12 non-matched compound combinations (C1B2, C1B3, C2B1, C2B3, C3B1, C3B2, B1C2, B1C3, B2C1, B2C3, B3C1, B3C2); each compound combination was quasi-randomly presented as a comparison stimuli to assure there was sufficient exposure to all possible non-matched compound combinations.

If participants did not pass any of the blocks in this phase, they were re-exposed to Phase 8 to check whether the equivalence relations were intact. They then had two more opportunities to pass equivalence-equivalence testing.

Mixed testing was administered by presenting 18 derived matched and 18 derived non-matched trials in one block. All participants were required to answer 34 out of 36 trials correctly to pass the phase. If a participant did not pass on the second attempt they were retrained on Phase 8. The study was submitted for review to the Institutional Review Board (IRB). The IRB number is Pro00015432 (see Appendix C).
Figure 13. BC (top row) and CB (second row) matched equivalence-equivalence testing examples, and BC (third row) and CB (bottom row) unmatched equivalence-equivalence examples. The compound stimulus on the bottom center is the sample stimulus and the two compound stimuli on the top are the comparison stimuli. Participants were required to touch the comparison stimulus that matched the sample stimulus.
Results

Baseline Assessments

All participants were exposed to the CogAT baseline assessment. Overall screening totals (percentage correct) for each administration of the baseline assessments and the percentage correct for each analogy section of the assessment (i.e. Verbal Analogy, Number Analogy, Figure Matrices) were calculated and are shown in Table 1 and the left-hand column of Figure 14. Participant 2 was exposed to 4 assessments and scored an average of 48.1%. Participant 3 was exposed to 6 assessments and scored an average of 65.87%. Participant 4 was exposed to 4 assessments and scored an average of 61.08%. Participant 5 was only exposed to 1 assessment and he received a score of 50%. With the exception of Participant 3, baseline scores were suitable for moving on to the training phase. Participant 3’s scores show an upward trend throughout her six baseline assessments. This upward trend occurred without any feedback being provided for her performance. Her first assessment score was 51.8% and her last score was 76.9%. Participant 3 was dismissed from the study because of her improvements in the baseline assessment scores observed during baseline might make it difficult to attribute any observed increase in post-training CogAT scores to the independent variable.

Equivalence-Equivalence Training

All 4 participants were exposed to a total of 347 blocks and 10,302 trials during the equivalence-equivalence-protocol (Table 2). The table does not include the number of trials for the mixed matched and unmatched training and testing and the A2C2 mass trials, these blocks were not conducted on a laptop computer so the number of trials were not recorded. As stated
earlier, zero participants completely passed the training protocol during the study. Participant 1 and Participant 5 were dismissed in Phase 9 (Compound Symmetry Testing), Participant 2 was dismissed in Phase 5 (Matched AB-AB training), and Participant 3 was dismissed in Phase 6 (Unmatched AB-AB Training).

Table 1

Baseline Assessment Scores (CogAT)

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<tr>
<th>Test #</th>
<th>Picture Analogy</th>
<th>Number Analogy</th>
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<th>Screening Total (Overall Percent Correct)</th>
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Scores displayed above represent the percentage of items answered correctly out of the total number of items attempted overall (Screening Total) and for each subsection. Note: Screening Totals are not merely an average of scores obtained in each subsection because the number of items in each subsection varied. Instead, it is the total percent correct calculated as the number correct divided by the total number of assessment items.
Figure 14. The left-hand column shown baseline screening scores from Participants 1-5. The right-hand column shows the proportion of exposures to each equivalence training and testing phases passed for Participants 1-5 (excluding Participant 3 who did not participate in training due to her upward trend in baseline). The lower right-hand column shows the average proportion of exposures to each phase passed for all participants.
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</tr>
<tr>
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<td>A-B--AB</td>
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<td>2 (36)</td>
<td>1 (18)</td>
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</tr>
<tr>
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<td>1 (12)</td>
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Figures 15-18 summarize each participant’s progress through each phase of equivalence-equivalence training and testing. Phases and data are plotted in chronological order and show each participant’s training, testing, and mixed testing scores for each phase and any retrainings required throughout the protocol. Summary data are also plotted in the right-hand column of Figure 14 which shows the proportion of exposures to each phase passed.

Participant 1 passed Phases 1-4 and started Phase 5. She reported that she was tired and requested to end the session for the day. The session was stopped and an appointment was set for the following day. She missed the following appointment and upon her return (2 days later) she was re-exposed to Phases 1-3 (per the Methods above) to assure that the previously trained, A-B and A-C relations were intact. Re-exposure to Phases 1-3 confirmed the A-B and A-C relations were intact, thus she was returned to Phase 5. Participant 1 required 16 blocks to pass AC-AC matched compound training. Although her scores demonstrated an increasing trend, the PI noticed that she never selected the correct comparison compound stimulus on trials involving the compound sample stimulus A2C2. To resolve this deficiency, the PI implemented Mixed Matched and Unmatched Training and Testing block to teach her these relations (described in the methods section). Following the training block, she passed AC-AC matched compound training.
within 3 attempts and went on to pass Phases 5, 6, and 7. After failing Phase 8, which tests for the emergence of derived B-C relations (which should emerge following training on A-C and A-B relations during Phases 1 and 2), Participant 1 also re-exposed to Phases 1-3. Following re-exposure to phases 1-3, she was re-exposed to and demonstrated proficiency during Phase 8. In Phase 9, Participant 1 passed derived matched symmetry testing but failed to pass derived unmatched symmetry testing after two attempts. She was re-exposed to Phases 5 (matched compound training and testing) and 6 (unmatched Compound training and testing) to retrain her on matching compound stimuli. She was re-exposed to Phase 9. She did not receive a passing score on her second attempt to derived unmatched symmetry testing and was dismissed from the study. Note, that she responded considerably worse than chance; possibly suggesting she was not attending to the sample compound stimulus. This point will be elaborated on further in the discussion.

Participant 2 passed Phases 1-4 after the second attempt (she required re-training on Phases 1-3 after she failed to pass Phase 3 on the first attempt). Unlike previous phases, accuracy was only slightly above chance during Phase 5 (where participants are first trained to select and respond to unmatched compound of stimuli as opposed to matched compound stimuli for which they received training on in Phase 4). As a result, she was re-exposed to Phase 4 (matched compound training and testing) to assure that she learned that single stimuli (ex: A1-B1) were functionally equivalent to compound stimuli (ex: A1B1). Subsequent re-exposure to Phase 5 resulted in a subtle increase in accuracy. However, after six blocks, the participant expressed signs of frustration and stated she did not know how to answer the questions. At this time the study protocol was followed and the participant was dismissed.
Participant 4 passed Phases 1-5 on the first attempt. During Phase 6 (AB-AB unmatched compound training), Participant 4’s accuracy was variable but averaged at only chance levels after 18 trial blocks, therefore; the participant was dismissed.

Participant 5 passed Phases 1-8 on the first attempt. In Phase 9, Participant 5 failed to pass symmetry unmatched compound testing (Phase 9 is similar to Phase 6, except the order of stimuli presented in a compound are reversed) after two attempts. At this point, he was presented with the mixed matched and unmatched AB-AB and AC-AC training and testing blocks to expose him to matched and unmatched trials together and teach him to discriminate between the two types of trials. He passed both blocks with a 94%. He was re-exposed to Phase 9 and failed to pass symmetry unmatched compound testing after two more attempts. He was dismissed from the study.

The right-hand column of Figure 14 shows the proportion of exposures to each equivalence training and testing phase passed for Participants 1-5 (excluding Participant 3 who did not participate in training due to her upward trend in baseline). Participant 5 passed all exposures to the phases he was exposed to but he did not pass any exposures to Phase 9. Participant 1 only passed 50% of the exposures to Phase 5. Participant 4 passed all exposures to Phases 1-5 and failed to pass any exposure to Phase 6. Participant 2 passed 50% of the exposures to Phase 3 and did not pass any exposures to Phase 5.

The bottom right graph of Figure 14 shows the average proportion of exposures to each phase passed for all participants. The graphs show that Phase 9 was passed 0 times throughout the study, Phase 5 was passed 50% of the attempts, and Phase 6 was passed 75% of the attempts. Phases 1, 2, and 7 were passed 100% of the attempts. Data from the graphs show that phases 5 and 9 were the most difficult for the participants that experienced those phases.
Post-Instructional Probes

Because all participants were dismissed from the study prior to completing the equivalence-equivalence training protocol, post-instructional probes were not conducted and we were unable to assess a change in CogAT scores.
Figure 15. The graph shows the scores for training, testing, and mixed testing blocks, calculated in percentage. The scores are split into two graphs. Sessions 180 are demonstrated in the top graph and sessions 81-160 are demonstrated in the bottom graph.

Figure 16. The graph shows the scores for training, testing, and mixed testing blocks, calculated in percentage.

Figure 17. The graph shows the scores for training, testing, and mixed testing blocks, calculated in percentage.

Figure 18. The graph shows the scores for training, testing, and mixed testing blocks, calculated in percentage.
Discussion

The current study evaluated a protocol for teaching equivalence-equivalence relations in 7 and 8-year old children based closely on a description provided by Stewart et al. (2009). Ostensibly, the purpose was to see if experience with the training protocol could produce improvements in analogical reasoning as assessed using a standardized measure, the CogAT Screen Form 7. Five participants were exposed to the CogAT baseline assessments in a multiple-baseline design format. One of the five began to show improvements in CogAT scores without feedback and was dismissed from the study. The remaining four began training using the equivalence-equivalence protocol, however; none of the participants were able to complete the training. This finding was unexpected. Thus, this discussion will reflect upon the training protocol, data and patterns of responding observed during the training protocol that might help to identify possible reasons for its failure, and ultimately a reconsideration of the original research question. Hopefully this endeavor will lead to the identification of refinements that may benefit future researchers in this area.

Two kinds of phases were included in the protocol. One kind included both training and testing trial blocks; the latter of which was used to evaluate the direct effects of training provided in that phase. These included Phases 1, 2, 4, 5, and 6. The other kind included only testing blocks and was used to evaluate the proficiency of some skill expected to be acquired in either a previous phase or a combination of previous phases.

Of primary interest are the phases and subject performances that led to their dismissal from the study and ultimately a failure in the training protocol. Participant 3 was dismissed during the pre-assessment phase after her scores continuously increased after six exposures to the
CogAT assessments. The increase in scores occurred without any feedback on the pre-assessments or exposure to equivalence-equivalence training. Such a result could be interpreted to suggest that there are other types of procedures that might be used to teach analogical reasoning, such as continuous exposures to analogy tests, and exposure to relational training in new contexts, such equivalence-equivalence training, may not be necessary.

Participants 1 and 5 progressed furthest in the training protocol. Both were dismissed in Phase 9 only after they failed to pass the unmatched symmetry testing blocks. These blocks tested whether participants could match the symmetry compounds derived from the trained compound relations in Phases 5 and 6. Both participants received high scores (above 90%) in the matched symmetry compound block of Phase 9 and low scores (below 40%) in the unmatched symmetry test of Phase 9. One possible explanation for the differences in scores may be that participants could not discriminate between matched and unmatched blocks. In an attempt to ameliorate this difference, Participant 1 was re-exposed to Phase 5 (matched compound training) and Phase 6 (unmatched compound training) to teach her to relate matched compounds to other matched compounds and relate unmatched compounds to other unmatched compounds. After passing Phases 5 and 6, Participant 1 was re-exposed to Phase 9, but her scores were similar to her first attempt of Phase 9: She scored a passing score on the matched symmetry test and a low score on the unmatched symmetry tests. As a result, she was dismissed from the study. Re-exposure to and proficiency in Phases 5 and 6 was not sufficient to teach her to discriminate between matched and unmatched compound trials.

Like Participant 1, Participant 5 also failed the unmatched compound blocks in Phase 9. Because of the possibility that Participant 1’s failure was due to an inability to discriminate between matched and unmatched compounds, we implemented Mixed Matched and Unmatched
Compound Training trials (described above in the Methods; in addition to Phases 5 and 6) with Participant 5 following his first failure in Phase 9. He passed both training and testing blocks during the mixed matched and unmatched training and testing block. This was apparently not sufficient training, as he also still did not pass the unmatched symmetry compound block during the second exposure to Phase 9. At that point Participant 5 was dismissed from the study. The mixed matched and unmatched training and testing blocks was not sufficient to allow the participant to show mastery of the unmatched compounds in Phase 9.

One possible interpretation of Participant 1 and 5’s results are that choices were not under the control of the sample compounds. Indeed, our protocol (which was based closely on the one described by Stewart et al. (2009)) involved relatively few training or testing blocks that necessitated control by the sample stimuli (i.e., only the mixed blocks). Loosely speaking, our procedures may have permitted participants to choose the comparison stimuli without paying attention to the sample stimuli. With respect to performance in Phase 9, matched and unmatched training and testing blocks were presented separately and sequentially. In the first part of Phase 9, participants were expected to choose the matched compound when they were presented with a matched compound stimulus as a sample. Participants were only presented with two options to choose a correct answer from. The options were a matched stimulus and an unmatched stimulus. The trials were correct when they pointed to the matched compounds and were incorrect when they pointed to the unmatched compounds. Rather than attend to the sample, participants might have learned to simply choose either matched or unmatched comparison stimuli in any given sequence of blocks based on the feedback from the previous block. An analogous scenario occurred in Phase 6, participants were required to point to the unmatched stimulus to pass all of the trials in the phase. Because there was no mixed testing, the matched and unmatched
compound trials were never presented together and participants were not required discriminate between the two types of trials.

Future research should study modifications to the protocol that would require participants to pay attention the sample stimulus and enhance control by the sample stimulus over participant choices. One modification that could be tested is the addition of mixed matched and unmatched compound training and testing blocks to teach participants to discriminate between both types of trials. Mixed blocks might prevent participants from passing blocks by choosing all matched or all unmatched trials and passing the block, as was observed in the study. The mixed testing presented to Participant 5 in this study demonstrated that under such conditions she was able to discriminate between matched and unmatched trials. A second modification that could be studied is the order in which stimuli are presented that would allow participant to consider the sample stimulus prior to choosing a comparison stimuli, such requiring an observing response. In some matching to sample procedures, participants are required to touch or approach the sample stimulus prior to the presentation of the comparison stimuli and has been shown to enhance stimulus control. In fact, Barnes et al. (1997) used a similar procedure when he exposed 9 year-old and 12 year-old participants to equivalence-equivalence training.

Participants 2 and 4 were dismissed much earlier in the training protocol. Although both showed acquisition of the trained A-B and A-C relations (Phases 1 and 2), and relating elements to compounds with those elements (Phase 4), both showed difficulty learning to relate compounds containing matched elements (e.g., A1B1 or A2B2) to other compounds containing matched elements (e.g., A1C1 or A2C2). Those difficulties lead to Participant 2’s dismissal. During a second exposure to Phase 5, Participant 2 exhibited signs of frustration when she continued to answer trials incorrectly in the matched compound training blocks. Because
Participant 2 did not pass the training blocks in Phase 5, she was re-exposed to Phase 4 (relating elements to compounds). Participant 2 passed Phase 4 and was re-exposed to Phase 5, however; she did not receive a passing score and was dismissed from the study. At the time of dismissal, Participant 2 had been exposed to a total 65 blocks (1290) of which 15 blocks (90 trials) were from Phase 5. Just before the dismissal, she began asking the PI for help in answering trials and stating she did not know how to choose the correct “picture”. She also stated she did not want to work on the program anymore so she was dismissed immediately. These statements ultimately led to her dismissal.

Unlike Participant 2, Participant 4 eventually acquired the matched compound relations in Phase 5. However, the subsequent performance in Phase 6 was quite variable and never consistently maintained above chance-levels. After exposures to 18 trial blocks (324 trials) Participant 4 did not learn to match the unmatched compound relations and was dismissed from the study. The variability in responding in Phase 6 should have allowed Participant 4 to contact reinforcement and to acquire unmatched compound relations. However, persistent chance-levels of responding might suggest that the training program’s feedback following correct responses was not sufficiently reinforcing. In addition, Stewart et al.’s (2009) protocol does not specify what should be done if acquisition fails to occur during a training phase. This point will be elaborated on further in the next section.

In general, all of the participants made comments with respect to the difficulty of the task in at least one of the phases. For example, they asked for help in answering the trials or clues to choose the correct shapes. They stated that they thought blocks were too long and they showed signs of disappointment when they missed trials, which resulted in retaking blocks. Session 1 of Participant 1 was also stopped when she reported she wanted to stop the session for the day and
continue it the next day. These statements may suggest that some phases of the protocol produced extinction or ratio-strain-like effects became aversive to them during the study, therefore; the PI modified the original protocol to reduce the aversiveness experienced by participants.

In an attempt to address this potential problem, verbal praise and words of encouragement provided after each block. Originally the PI was not required to sit next the participant and provide praise, however; the PI noticed participants were getting discouraged when they were not receiving passing scores throughout the blocks so the PI sat next to the participants and provided verbal praise and words of encouragement at the end of the training and testing blocks such as “You’re doing awesome!”, “You only missed 3 trials lets try one more time!”, or “Yes! 15 trials correct, that was 5 more correct than the last try!” to continue motivating participants throughout the phases.

However, such statements were not implemented systematically nor supported by the addition of tangible reinforcers. Thus, it continued to prove difficult to keep participants motivated especially in instances where the study protocol necessitated repeating phases. For example, participants were required to complete phases they had difficult with, such as Phase 5, 6, and 9, with minimal feedback or assistance on the phases. The participants asked the PI, multiple times, for more instructions on answering the trials, however; the PI could only repeat the original instructions provided in the beginning of each block. Participants were also required to complete an entire block once they started the block despite the multiple errors they made already. For example, if a participant started Phase 8 and answered the first 5 trials incorrectly they were required to complete the block to receive the score. This exposed them to many trial they did not know the answers to which could have made the blocks aversive to them.
Throughout the study, participants also learned that they could only miss two trials per block, otherwise; they would be required to retake the block. When participants missed more than 2 trials they were observed to click on the trials quickly to complete the block so they could restart it.

All 4 participants were exposed to a total of 10,302 trials during the equivalence-equivalence-protocol. This number is much higher than the number of trials participants were exposed to in other studies, including studies where participants did not pass equivalence-equivalence training, such as Experiment 3 of Carpentier et al. (2002) who were exposed to 2,917 trials. Likewise, participants who passed equivalence-equivalence-equivalence training were only exposed to 2,306 trials (Carpentier et al., 2002). Inability to discriminate between matched and unmatched trials, constant re-exposures to training trials without any feedback, and the participants’ lack of motivation to pass trials could have contributed to this high number of exposures. Future replications of this study may include requirements to end testing blocks after the maximum number of allowed incorrect answers has been met to reduce exposure to trials that participants are not passing. Future studies should also study procedures for to conduct if participants are unable to pass training blocks. This would also help reduce the number of trials participants are exposed to and help prevent trial blocks becoming aversive.

The unfamiliarity of the stimuli used in this study may have also played a role in participant’s ability to demonstrate equivalence-equivalence responding. In this study, participants were trained to relate arbitrary stimuli to assure that already existing relations between non-arbitrary stimuli did not interfere with the formation of derived relations during the protocol. The use of arbitrary stimuli may have made it difficult for participants to learn and derive relations between stimuli they have never experienced before. It may be that use of
familiar stimuli may facilitate equivalence-equivalence responding. The three studies that have tested whether the use of the familiar stimuli could facilitate equivalence-equivalence responding (described in the introduction) have shown that using familiar stimuli, such as happy faces, sad faces, glasses, and bicycles, were not able to detect improvements in acquisition (Carpentier et al., 2003), however; future research should replicate these studies and test whether the familiar stimuli did not help or whether the failure to pass equivalence-equivalence test was due to the training protocol procedures failure to effectively teach equivalence-equivalence responding.

According to the protocol described by Steward et al. (2009), two conditions might suggest a necessity to revisit previously mastered training or testing phases: extended calendar time since the last training session (e.g., due to a missed appointment) or failure to meet mastery criteria during training or testing blocks (defined as responding incorrectly on more than two trials in a testing block). Only the latter occurred in the present study, but those occurrences may provide an opportunity to evaluate the role of exposure to early phases on performance during latter phases.

A total of six phase re-exposures were performed in three of the four participants (one participant did not experience any). Four out of the six re-exposures were associated with increased accuracy that allowed the participants to meet the mastery criterion for that phase. Of these, re-exposure to previous training phases seemed to lead to improved performance in Phases 3 and 8, for participants 2 and 1, respectively. In both cases, re-exposure to the training provided in Phases 1 and 2 served as the remediation. The purpose of Phases 1 and 2 is to establish class membership (e.g., that A1 is equivalent to B1, and A1 is equivalent to C1, etc.), which is tested in Phase 3. The purpose of Phase 8 is to determine if participants have acquired the emergent relation between B and C (e.g., that B1 is equivalent to C1). Thus, it is reasonable that re-
exposure to Phases 1 and 2 would lead to improved accuracy in Phases 3 and 8. In fact, this is a common finding in RFT research (Sidman, 1971, 2001). Of potential interest to future researchers is whether performance during the testing blocks at the end of Phases 1 and 2 predicted success in Phases 3 and 8. Figure 19 shows performance during the mix-testing blocks of Phases 1 and 2, and performance during Phases 3 (top panel) and 8 (bottom panel). No obvious pattern of responding in the former test blocks appears predictive of performance in later phases, except for Participant 2 in the top panel and Participant 1 in the bottom panel for whom more stringent criteria might have been applied. Although, counter examples can also be found where high-accuracy during Phases 1 and 2 was not predictive for passable performances later (e.g., Participant 5 in both the top and bottom panels). Future researchers may wish to evaluate future researchers may wish to evaluate indicators of mastery during the acquisition of A-B and A-C relations that predict emergence of B-C and C-B relations.
Figure 19. The graph shows the performance during the mix-testing blocks of Phases 1 and 2, and performance during Phases 3 (top panel) and 8 (bottom panel).
References


Appendices

Appendix A: Child Accent Process

Hi (child's name)

We are doing a research study about analogies. A research study is a way to learn more about people. If you decide that you want to be part of this study, you will be asked to take 2 tests on analogies and complete a program on the laptop that will try to teach you to answer analogies.

There are some things about this study you should know. The program has 10 phases and it will take about 3 days to finish. Every time you complete a phase you will earn a prize. We will meet every day for about 3 days.

Not everyone who takes part in this study will benefit. A benefit means that something good happens to you. We think these benefits might be learning how to answer analogies.

When we are finished with this study we will write a report about what was learned. This report will not include your name or that you were in the study.

You can ask questions about this study at any time. You do not have to be in this study if you do not want to be. If you decide to stop after we begin, that’s okay too. Your parents know about the study too.

If you decide you want to be in this study say “yes” if you do not want to be in the study say “No”.

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## Appendix B: Equivalence-Equivalence Protocol

### Intervention: Equivalence-Equivalence Protocol

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Appendix C: IRB Letter of Approval

7/8/2014

Anna Garcia
USF ABA-Applied Behavior Analysis
4202 E. Fowler Ave.
Tampa, FL 33620

RE: Expedited Approval for Initial Review
IRB#: Pro00015432
Title: Relating Relations: The Impact of Equivalence-Equivalence Training on Analogical Reasoning

Study Approval Period: 7/8/2014 to 7/8/2015

Dear Ms. Garcia:

On 7/8/2014, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents outlined below.

Approved Item(s):
Protocol Document(s):
Relating Relations Thesis Proposal Manuscript

Consent/Assent Document(s)*:
Relating Relations Thesis Consent Form.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent document(s) are only valid during the approval period indicated at the top of the form(s).

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45 CFR 46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:
(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

This study involving data pertaining to children falls under 45 CFR 46.404 – Research not involving greater than minimal risk.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Kristen Salomon, Ph.D., Vice Chairperson
USF Institutional Review Board