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Relational Frame Theory and Analogical Reasoning: Empirical Investigations

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Abstract

Much RFT-based research has concentrated on using derived relational responding to model particular aspects of language and higher cognition. One by now particularly successful example of this research is that which has modelled analogical language in terms of the relating of derived relations. The current article describes the progress of research in this area. Initial RFT-based models of analogy have successfully demonstrated several important aspects of this phenomenon, including the presence of non-arbitrary relations, the transformation of behavioral functions and the generativity of analogical language in the naturalistic environment. More recent studies have provided an important extension of this research by examining developmental trends in analogical responding. Perhaps the most notable and unexpected outcome of this latter work is the revelation that the behavioral tradition represented by RFT may by now have provided a precise definition of analogical reasoning in the apparent absence of a similarly precise definition from the cognitive/developmental tradition

Key words: Analogical Reasoning, Relational Frame Theory, Equivalence-Equivalence, Development.

Resumen

Gran parte de la investigación basada en la RFT se ha centrado en la utilización del comportamiento relacional derivado para modelar (proponer modelos de) aspectos particulares del lenguaje y los procesos cognitivos superiores. Un ejemplo particularmente exitoso hasta el momento de este tipo de investigación lo constituyen los modelos del lenguaje analógico en términos de relaciones entre relaciones derivadas. El presente artículo describe el progreso de la investigación en esta área. Los modelos iniciales de la analogía basados en la RFT han demostrado con éxito varios aspectos importantes de este fenómeno, incluyendo la presencia de relaciones no arbitrarias, la transformación de funciones conductuales y la generación del lenguaje analógico en el ambiente natural. Estudios más recientes han ampliado de manera importante esta línea de investigación al examinar las tendencias en el desarrollo del comportamiento analógico. Quizás el resultado más notable e inesperado de esta línea de trabajo sea la revelación de que la tradición conductual representada por la RFT puede haber aportado una definición precisa del razonamiento analógico, ante la aparente ausencia de una definición igualmente precisa por parte de las tradiciones cognitiva y evolutiva.

Palabras clave: Razonamiento analógico, relaciones entre relaciones, RFT, relaciones no arbitrarias, generatividad.

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A central assumption of Relational Frame Theory (RFT; Hayes, Barnes-Holmes & Roche, 2002) is that language and cognition may be explained in terms of derived relational responding. Furthermore, RFT research has by now modelled a number of arguably important areas of linguistic-cognitive functioning based on controlled laboratory demonstrations of this phenomenon. The main purpose of the present article is to consider one particular strand of RFT-based research that has focused on providing a derived relations–based model of analogical language.

Relational Frame Theory, Derived Relations and Language

There is now an appreciable quantity of evidence to suggest that verbal/cognitive and derived relational phenomena are closely linked. Relational Frame Theory explains this link by arguing that the former are in fact examples of the latter. The theory explains all derived relational phenomena as generalized contextually controlled relational responding which, in RFT terminology, is referred to as arbitrarily applicable relational responding. Naming is perhaps the simplest example. When a child is taught to name, he or she is taught explicitly, using numerous exemplars, that if a name is a certain object (A is B) then the object is also the name (B is A). Eventually, aspects of the context in which this bi-directional relationship is learned, such as the word 'is' for example, come to control the application of the relation. Hence, when the child learns that a wholly novel name X 'is' a wholly novel object Y, he or she will derive that the object Y is also the name X. This particular example of derived relational responding constitutes what linguists refer to as reference (name = object; object = name) and what behavioural researchers refer to as symmetry (A = B; B = A). RFT sees this type of derived or arbitrarily applicable relational responding as the initial and most basic form. Continued exposure to human socio-verbal interactions produces many more complex patterns than this, including, for example, responding in accordance with relations of equivalence, opposition, difference and comparison.

Despite the variety of forms of derived relational responding, RFT argues that all forms involve the following three core properties:

(i) *Mutual entailment* describes the relations between two stimuli or events. For example, if an experimental participant is trained that A goes with B then s/he will derive the mutually entailed relation of B goes with A. This is the symmetrical relation demonstrated in equivalence research. If the relation between A and B is not one of sameness or equality, however, then the mutually entailed relation may differ from the trained relation, in which case the relational pattern is non-symmetrical. For example, if a participant is taught that A is greater than B then they will derive that B is less than or samaller than A.

(ii) *Combinatorial entailment* refers to a derived relation in which two or more stimulus relations combine. For example, if a participant is trained that A is the same as B and B is the same as C then s/he will derive the combinatorially entailed relations of A same as C and C same as A. In this case, the trained relations are of sameness, and thus the resulting combinatorially entailed relations are those of transitivity and equivalence, respectively. However, if training involves non-sameness relations then a different derived relational pattern may emerge. For example, if the participant is taught that A is opposite to B and B is opposite to C then the resulting combinatorial relational pattern of A same as C and C same as A is non-transitive and non-equivalent (i.e., two opposite relations combine to produce *same*, not *opposite*).

(iii) *Transformation of function* is perhaps the most important of the three properties from an applied psychological perspective. For example, if a participant is trained such that s/he derives the mutually entailed relation A less than B, and a punishing function is trained to A, then the previously neutral function of B may be transformed such that B now acquires a more aversive function than that directly trained to A. This transformation of function occurs as a result of the derived comparative relation between A and B. This phenomenon, which has been empirically demonstrated, is particularly important from an RFT perspective in that it suggests how language may readily change the psychological functions of events.

There is a wealth of empirical research demonstrating the variety of multiple derived stimulus relations referred to above and their core properties as described by RFT (e.g., Barnes, Hegarty & Smeets, 1997; Barnes & Keenan, 1993; Dymond & Barnes, 1995, 1996; O'Hora, Roche, Barnes-Holmes & Smeets, 2002; Roche & Barnes, 1996; 1997; Roche, Barnes-Holmes, Smeets, Barnes-Holmes & McGeady, 2000; Steele & Hayes, 1991; Stewart, Barnes-Holmes, Roche & Smeets, 2001, 2002). From an RFT perspective, these different forms of derived relational responding provide the basis for socio-verbal and higher cognitive performances that are unique to human beings. This contention is supported by a considerable weight of empirical evidence indicative of the connection between derived or arbitrarily applicable relations and human language and cognition. Particularly important examples of this evidence include the following.

(1) Whereas a wide variety of normal human participants has shown derived relational responding, the phenomenon is arguably absent or at least very difficult to produce in non-human populations (Dugdale & Lowe, 2000; Hayes & Hayes, 1992; Sidman, Rauzin, Lazar, Cunningham, Tailby & Carrigan, 1982; but see also Shusterman & Kastak, 1993).

(2) Research has demonstrated the emergence of derived relations in infancy and has tracked the development of this behaviour. Lipkens, Hayes and Hayes (1993) reported the emergence of mutually and combinatorially entailed relational responding at age 17 and 23 months, respectively, in a normally developing infant and provided a record of the gradual development of derived transitive responding over the course of a year.

(3) Development of derived relations correlates with the development of verbal and cognitive abilities (Devany, Hayes & Nelson, 1986; Barnes, McCullagh & Keenan, 1990; Pelez-Nouregas, O'Hora, & Barnes-Holmes, in press). Devany et al. (1986) reported that learning disabled children who lacked receptive naming skills performed poorly on tests of derived equivalence responding. Barnes et al. (1990) extended these findings by demonstrating similar effects with children who were cognitively normal but hearing impaired. Pelez-Nouregas et al. (in press) showed that levels of derived relational responding correlated with performance on the verbal sub-component of the Wechsler Adult Intelligence Scale.

(4) Derived relations produce priming effects similar to those found in studies of verbal semantic networks (Hayes & Bissett, 1998; Staunton, Barnes-Holmes, Whelan & Barnes-Holmes, 2002). Staunton et al. (2002), for example, reported faster reaction times to pairs of arbitrary nonsense words in derived relations than to pairs of unrelated nonsense words.

(5) Derived relational responding produces neural activation patterns similar to those produced by studies of verbal semantic networks (McIlvane et al., 1999; Dickens, Singh, Roberts, Burns, Downs, Jimmieson & Bentall, 2001; see also DiFore, Dube, Oross, Wilkinson, Deutsch & McIlvane, 2001). McIlvane et al. (1999) demonstrated differential Event Related Potentials (ERPs) measures for pairs of stimuli in derived relations as compared with unrelated stimuli. Dickens et al. (2001) used fMRI to show that brain activation patterns produced during the formation of equivalence relations resemble those produced during semantic processing underlying language.

Most of the foregoing work has been concerned with the investigation of the link between derived relational responding and basic semantic relations. However, much RFT-based research into language has concentrated on using derived relational responding to model particular aspects of language and higher cognition. One by now particularly successful example of this research is that which has focused on the provision of models of analogical language. The current article will now describe the progress of research in this area.

Analogy: Derived Relations Between Derived Relations

A study reported by Barnes, Hegarty and Smeets (1997) provided the first RFT model of analogical reasoning in terms of the derivation of equivalence relations between equivalence relations or ‘equivalence-equivalence’ responding. To understand the theoretical rationale for this work, consider the following question based on the classic proportion scheme (A : B : C : ?); “Apple is to orange as dog is to; (i) sheep, or (ii) book?”. “Apple” and “orange” may be conceptualized as participating in a relation of equivalence (or sameness) in the context *fruit* and “dog” and “sheep” conceptualized as participating in a relation of equivalence in the context *animals*. Hence, a language competent person might be expected to pick “sheep” as the correct answer. In effect, the response would be in accordance with a derived equivalence relation between two already established separate equivalence relations (see Figure 1, upper panel).

In the study reported by Barnes et al. (1997), participants were trained, using a standard matching-to-sample format, to make the following conditional discriminations: A1->B1, A2->B2, A1->C1, A2->C2, A3->B3, A3->C3, A4->B4, A4->C4. Four equivalence relations then emerged: B1<->C1, B2<->C2, B3<->C3, B4<->C4. Tests were then conducted to determine if equivalence relations between equivalence relations (e.g., B1C1<->B3C3) and equivalence relations between non-equivalence relations (e.g., B1C2<->B3C4) would be observed (see Figure 1, lower panel). Results showed that a range of participants, including two children, aged 9 and 12 years old, did indeed demonstrate this derived equivalence-equivalence responding.

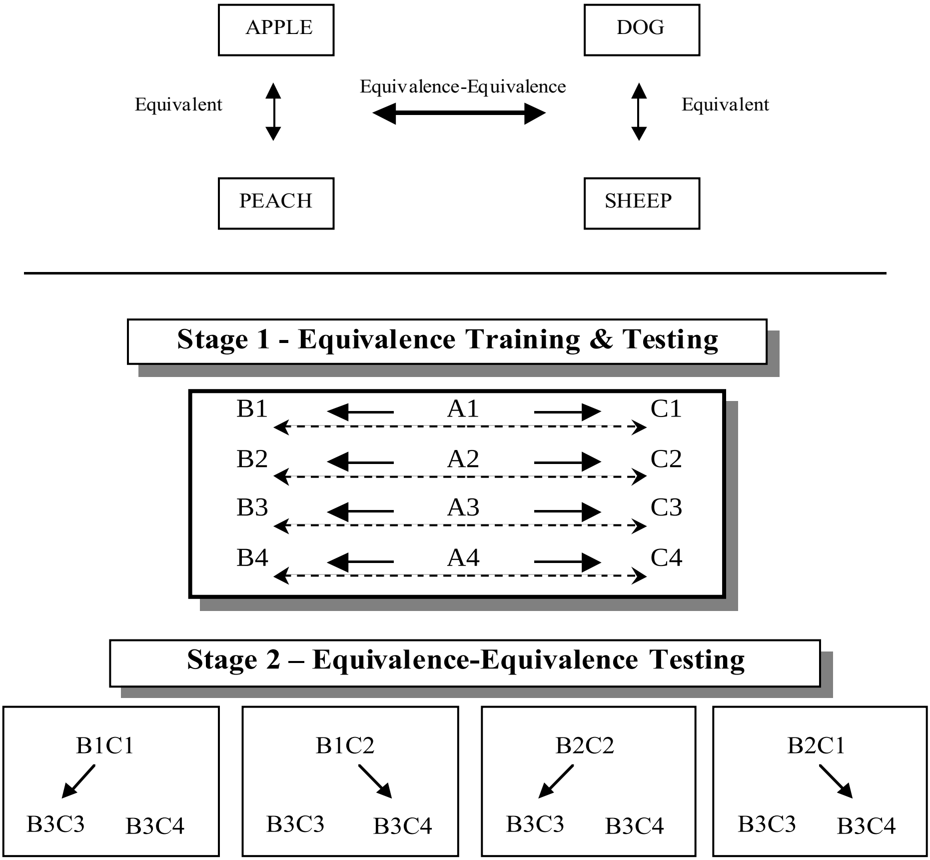

Figure 1. Upper Panel: Conceptualizing the analogy 'Apple is to Peach as Dog is to Sheep' in terms of the derivation of relations between derived relations. *Lower Panel:* Schematic representation of equivalence training and testing, and equivalence-equivalence testing in Barnes, Hegarty & Smeets (1997).

Incorporating non-arbitrary relations into the model

Stewart, Barnes-Holmes, Roche and Smeets (2001) extended this initial model. Specifically, these authors argued that, in addition to the arbitrary equivalence relations demonstrated by Barnes et al. (1997), analogy often involves the abstraction of common formal or physical properties. In the example given above, for instance, the arbitrary equivalence relation between the words "apple" and "orange" is based, to some degree, on the non-arbitrary or physical relation of similarity between actual apples and actual oranges (i.e., both are small, spherical, edible, sweet, etc.). Similarly, the arbitrary equivalence relation between the words "dog" and "sheep" is based on the non-arbitrary relation of similarity between actual dogs and actual sheep (i.e., in general, they are four legged, mobile, hairy, etc). Thus, the equivalence-equivalence or analogical relation between the equivalence relations 'apple-orange' and 'dog-sheep' may be traced back to the formal relations that obtain between particular objects in the environment. Stewart et al. (2001), therefore, attempted to include the role of formal properties in the Barnes et al. (1997) model.

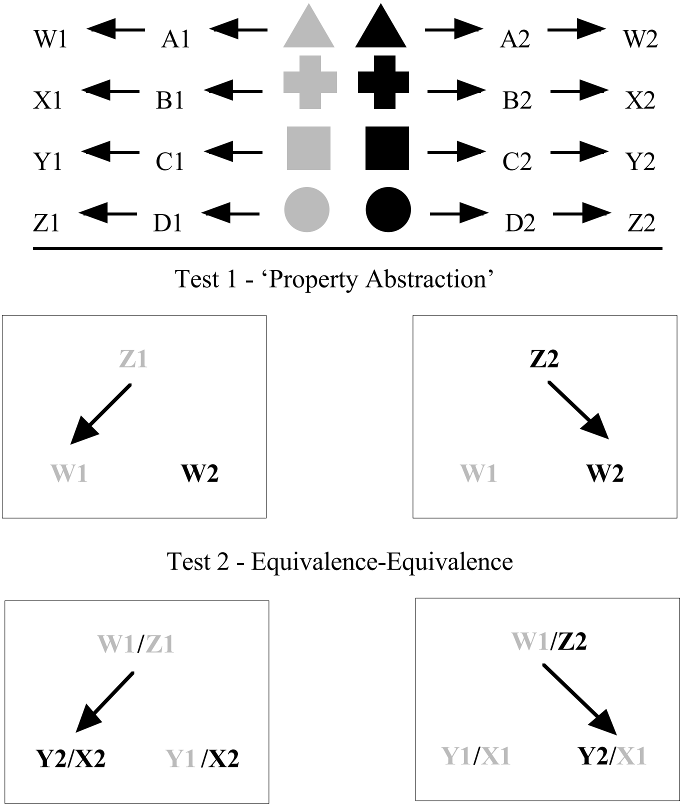

Figure 2. *Upper Panel*: Schematic representation of equivalence training in Stewart, Barnes-Holmes, Roche and Smeets (2001). Shapes appearing in a light shade were colored red and those in a dark shade were colored blue. *Lower Panel*: Representation of some of the equivalence and equivalence-equivalence testing tasks used in Stewart, Barnes, Roche and Smeets (2001). All nonsense syllables appearing in these tests were in black lettering. However, in this figure, for ease of communications, those nonsense syllables in equivalence relations with red shapes appear in a light shade, while those in equivalence relations with blue shapes appear in a dark shade.

Participants were taught, using a delayed matching-to-sample procedure, to choose a particular nonsense syllable in the presence of each of four blue and four red geometric shapes, and then to choose a further nonsense syllable in the presence of each of the first eight (see Figure 2, upper panel). In a subsequent test, participants demonstrated equivalence responding based on the abstraction of color by consistently matching nonsense syllables related to same-colored shapes to each other. Participants then showed equivalence-equivalence responding in which equivalence relations from the previous part of the experiment were related to other equivalence relations, and non-equivalence relations were related to other non-equivalence relations (see Figure 2, lower panel). Thus, these researchers provided a demonstration of equivalence-equivalence responding based on the abstraction of common formal properties, thereby extending the functional-analytic model of Barnes et al. (1997) to incorporate what appears to be an important feature of analogy.

Demonstrating a transformation of functions via analogy

In a recent study, Stewart, Barnes-Holmes, Roche and Smeets (2002) further extended the RFT model to capture another of the core properties of analogical reasoning. For illustrative purposes, consider the analogy ‘an atom is like the solar system’. In this example, the relation of the electrons to the nucleus is brought into an equivalence relation with the relation of the planets to the sun. In this case, a listener may relate a nucleus and its electrons in the same way that the listener relates the sun and the planets (i.e., hub to satellites). From this perspective, analogies are often used to help a listener discriminate a formal or non-arbitrary relation between two events (Stewart, Barnes-Holmes, Hayes & Lipkens, 2001). In the experimental protocol used by Stewart et al. (2001), however, participants were first required to discriminate the formal color relations to form the separate equivalence relations. Thus, when participants subsequently formed the complete equivalence-equivalence relational network, it did not give rise to the discrimination of a new formal relation. Thus, one of the purposes of the study reported by Stewart et al. (2002) was to model this type of discrimination, which apparently characterizes analogy.

A second purpose of the Stewart et al. (2002) study was to provide a model of the transformation of functions via analogical language. Transformation of functions is a core feature of the RFT account of verbal behavior because it is used to explain how language impacts generally upon human psychological processes. Consider the analogical phrase ‘Struggling with anxiety is like struggling in quicksand’, which might be used in the clinical treatment of anxiety. Contacting this particular analogy might cause a client to change his or her response to anxiety attacks. The client probably already knows, via the verbal community, that struggling in quicksand only makes drowning all the more likely. When the therapist suggests that struggling with anxiety is similar to struggling in quicksand, then the client may see that struggling with anxiety serves only to make the anxiety worse (i.e., trying really hard to escape feelings of anxiety can often increase those very feelings). Consequently, the client's behavior in the face of anxiety may change, such that he or she no longer attempts strongly to resist his or her

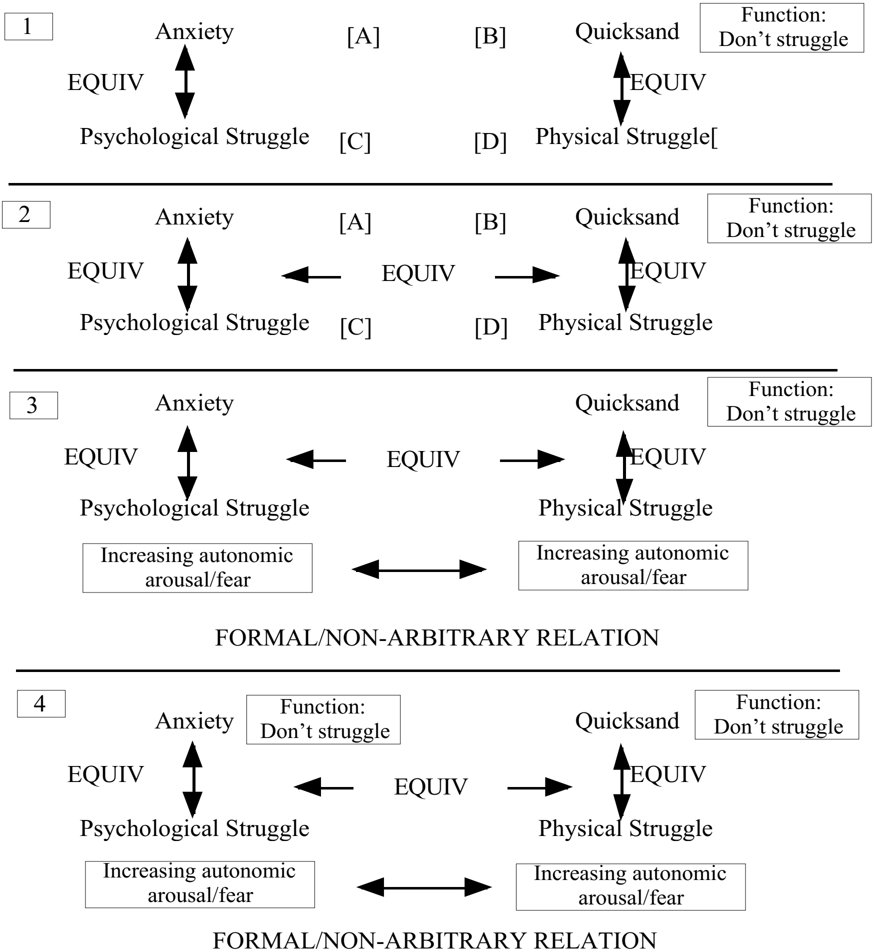

Figure 3. Four aspects of the process of the transformations of behavioral function via analogical language: [1] In the client's original relational network, "quicksand" has certain important response functions such as *Don't struggle*, for example, which "anxiety" does not. [2] The therapist changes the client's relational network by equating the relation "anxiety[A]/psychological struggle[B]" with the relation "quicksand[C]/physical struggle[D]" (i.e., "A is to B as C is to D"). [3] The newly changed relational network allows the client to discriminate a formal or non arbitrary relation of sameness between the relations "anxiety/struggle" and "quicksand/struggle" (i.e., both relations lead to increasing autonomic arousal accompanied by spiraling feelings of fear and panic). [4] The discrimination of a formal or non arbitrary relation between the relations "anxiety/struggle" and "quicksand/struggle" may lead to a transfer of the functions of "anxiety" such that "anxiety" now possesses some of the response functions of quicksand including, for example, *Don't struggle.*

anxiety, but instead accepts the anxious feelings as they arise, and thus prevents the downward cycle into full-blown panic.

This quicksand/anxiety analogy may be interpreted as a relational network that is functionally similar to the 'proportion scheme' analogy described earlier. In this case, however, "anxiety" [A] is to "psychological struggle" [B] as "quicksand" [C] is to "physical struggle" [D] (see Figure 3, Parts1 & 2). For current purposes, we will describe the relation between anxiety and psychological struggle, and the relation between quicksand and physical struggle, as two separate equivalence relations. From the RFT perspective, the relational network in this example of analogy may help the listener to discriminate a *formal* relation between two apparently very different events. This

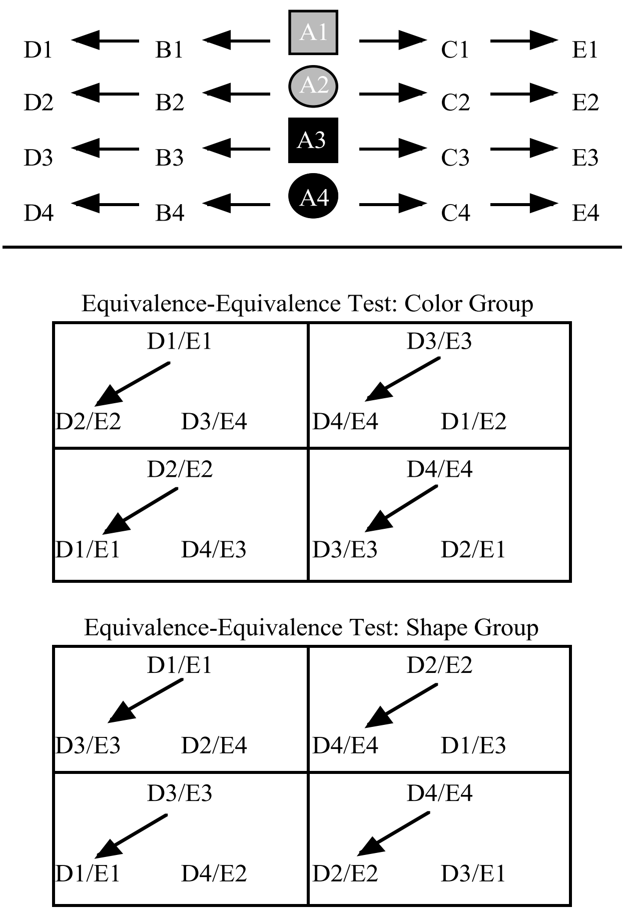

Figure 4. Upper Panel: Schematic representation of equivalence training in Stewart, Barnes-Holmes, Roche and Smeets (2002). Shapes appearing in a light shade were colored red and those in a dark shade were colored blue. *Lower Panel:* Schematic representation of the equivalence-equivalence tests provided to participants in the Color and Shape groups.

discrimination of formal similarity between the two events may make a transfer of function from one to the other more likely. In this particular analogy, deriving a relation between anxiety/psychological struggle and quicksand/physical struggle could help the listener to discriminate that struggling in either case leads to *structurally or formally similar* physiological and psychological effects (i.e., massively increased autonomic arousal, and a sense of fear and panic; see Figure 3, Part 3). Consequently, some of the functions of "quicksand" might now be more likely to transfer to "anxiety". For example, a clinically anxious person might derive certain important cause/effect relations including the following; "struggling with anxiety will only make my situation worse" and "by ceasing to struggle I can begin to overcome my anxiety" (see Figure 3, Part 4). Thus the original problem may come to be 'recast' in view of the derived analogical relational network. More generally, this type of pattern of transfer of functions throughout a relational network generates, from the RFT perspective, the often experienced richness and complexity of analogical language, as well as the emotional 'insight' which such language can often confer upon the listener.

In the Stewart et al. (2002) study, four adult participants first received a block sorting task in which they could sort colored wooden blocks in accordance with color, shape or both dimensions. They were then exposed to the model of analogical language. They were first trained and tested for the formation of four five member equivalence relations: A1-B1-C1-D1-E1; A2-B2-C2-D2-E2; A3-B3-C3-D2-E2; and A4-B4-C4-D4-E4 (see Figure 4, upper panel). The B, C, D and E stimuli were three-letter nonsense syllables, and the A stimulus was a colored shape. Participants were then successfully tested for equivalence-equivalence responding (e.g., matching D1E1 to D2E2 rather than D3E4; Figure 4, lower panel). These tasks were designed such that equivalence-equivalence responding might allow participants to discriminate a physical similarity between the relations involved. For example, in one of these tasks the correct (equivalence-equivalence) response is to match D1E1 to D2E2 rather than D3E4; note from Figure 5 (upper panel) that D1 and E1 are both in an equivalence relation with a red object, D2 and E2 are also in an equivalence relation with a red object, but D3 and E4 are in *separate* equivalence relations with blue objects. A participant who responds correctly on this and similar tasks may eventually come to discriminate this non-arbitrary color relation. Some participants (color participants) received only equivalence-equivalence tasks in which they might discriminate a color relation whereas others (shape participants) were given tasks in which they might discriminate a shape relation (see Figure 4, lower panel). The upper panel of Figure 5 presents an explanatory illustration of a task used with the color participants. In a subsequent test for the discrimination of formal similarity (see Figure 5, lower panel), color participants matched according to color, whereas shape participants matched according to shape. On re-exposure to the block sorting task, color participants matched according to color while shape participants matched according to shape, irrespective of how they had sorted on their first exposure to the block sorting task. Subsequently, all participants were exposed to the model of analogy again, except that this time color participants received equivalence-equivalence testing in which they could discriminate a formal similarity in terms of shape and shape participants received equivalence-equivalence testing in which they could discriminate

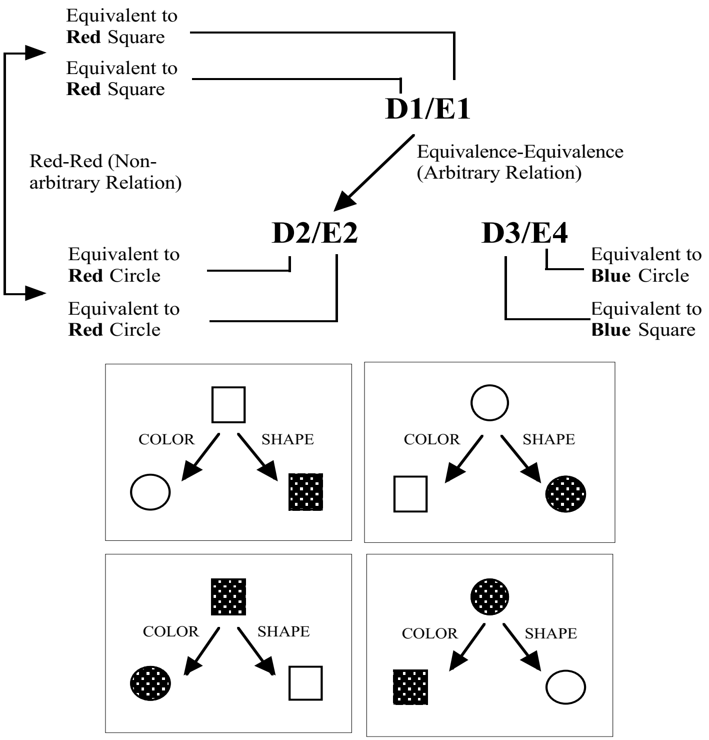

Figure 5. Upper Panel: A schematic representation of the important relations, both arbitrary and non-arbitrary, involved in equivalence-equivalence responding as tested in Stewart, Barnes-Holmes, Roche and Smeets (2002). *Lower Panel:* A representation of the four trial types used in the test for discrimination of formal similarity in Stewart, Barnes-Holmes, Roche and Smeets (2002).

a formal similarity in terms of color. Upon re-exposure to the block sorting task, participants sorted according to the new formal dimension to which they had been exposed. In two further exposures to the model of analogy and subsequent block-sorting task, participants demonstrated two further reversals of the transformation of function effect.

Providing a generative model of analogy

The studies reviewed so far have involved the empirical demonstration of limited numbers of simple analogies, and the matching-to-sample methodology, which is common to each of these studies, has proven adequate with regard to the demonstration of analogical reasoning. However, one possible criticism of this procedure is that the extensive training and testing involved results in the demonstration of a limited number of analogies (i.e., only those that are possible based on the trained and tested equivalence relations). Thus, given the need to model the potential generativity and complexity of analogical language in naturalistic settings, RFT researchers have begun to turn to novel empirical protocols. One such methodology is the Relational Evaluation Procedure (REP; see Hayes & Barnes, 1997; Cullinan, Barnes & Smeets, 1998; Cullinan, Barnes-Holmes & Smeets, 2000).

The core feature of the REP is that it allows participants to evaluate, or report on, the stimulus relation or relations that are presented on a given trial. In the typical approach, participants may confirm or deny the applicability of particular stimulus relations to other sets of stimulus relations. For example, a participant might be presented with a contextual cue for DIFFERENT and two arbitrary stimuli that are specified within that trial as participating in a difference relation. The participant is then required to choose between two arbitrary shapes for which the response functions of TRUE and FALSE have previously been established. In this case, the participant should choose TRUE, because the DIFFERENT cue co-ordinates with the arbitrary stimulus relation. If the cue had been SAME or the stimulus relation had been one of sameness, the appropriate choice would have been FALSE. In pilot studies using this methodology,

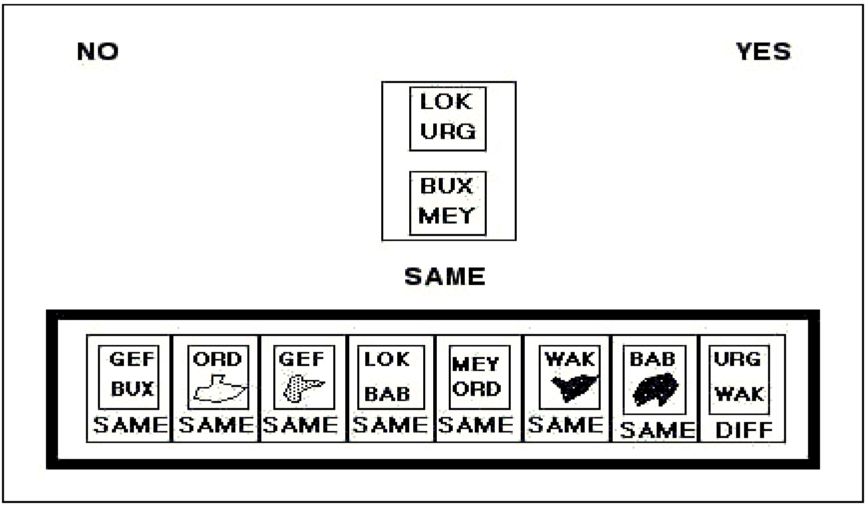

Figure 6. A trial-type from the final stage of Stewart, Barnes-Holmes & Roche (in press) which involved using the Relational Evaluation Procedure to train and test participants in order to model analogical language. Participants were first trained and tested to respond in accordance with particular relations (YES, NO, SAME, DIFFERENT) in the presence of particular contextual cues (represented in this diagram by English words for ease of communication) and were then presented with a series of increasingly complex tests involving the relation of non-arbitrary relations in accordance with networks of mutually and combinatorially entailed relations. In the final stage, participants each readily demonstrated 24 completely novel instances of responding in accordance with analogical relations as conceptualized by RFT, that is, the relating of (non-arbitrary color) relations based on arbitrary relations of combinatorial entailment.

it has been found that once a number of appropriate contextual cues have been established, a potentially infinite number of relational responses may be observed. The critical point is that the number of relational responses that may be observed is not constrained by the prior training and testing of a specific set of derived relations.

Given the apparent power of this methodology to generate unconstrained numbers of derived stimulus relations, it is now being adopted by researchers exploring a number of disparate areas. Stewart, Barnes-Holmes and Roche (in press) have used the REP to provide an empirical demonstration of analogy. The experiment involved nine stages in which five adult male participants were exposed to a complex series of REP training and testing protocols. Participants' behavior was first brought under the control of cues for responding in accordance with SAME and DIFFERENT, and TRUE and FALSE relations. Following exposure to a number of intervening training stages, a final test was presented that was designed to examine the relating of combinatorially entailed relations based on non-arbitrary relations (see Figure 6). The task presented in Figure 6 requires that the participant examine the nonsense syllables contained in the boxes in the center of the screen, and then determine if the relations found therein coordinate with the stimuli found in the boxes presented in the lower section of the screen. In this case, LOK and BAB and BAB and a black shape are specified as the *same* (in the lower boxes). Similarly, URG and WAK, and WAK and a black shape are specified as the *same*. In this case, therefore, LOK and URG may be defined as participating in a *same* relation because they are both combinatorially related to black shapes. If similar relational responses occur for BUX and MEY, however, the participant will determine that they are each combinatorially related to differently colored shapes. Consequently, the relation between the LOK-URG and BUX-MEY relations is one of *difference*, not *same*. On this particular task, therefore, the correct response is FALSE, not TRUE. During the final stage of the experiment, participants were presented with 24 novel variations of this task, and they each responded as predicted across all of the tasks. The results of Stewart et al. (in press) thus complemented the previous findings on analogical reasoning, as derived relations between derived relations, by providing a truly generative model of the processes involved.

Examining analogical responding in children

The studies described thus far constitute a progressive empirical research program that has used the concept of relations between derived relations to model analogical language in adults. If this model of analogy has some validity, however, then tests of equivalence-equivalence should produce outcomes similar to those observed with traditional tests of analogical reasoning. A more recent series of RFT-based studies has provided some interesting data in this regard by seeking to determine if the emergence of equivalence-equivalence responding follows the same developmental trend as that of analogical reasoning.

A number of mainstream developmental studies have reported that analogical competence is rarely found before the age of twelve and that children under nine have difficulties solving even the simplest analogies (e.g., Levinson & Carpenter, 1974;

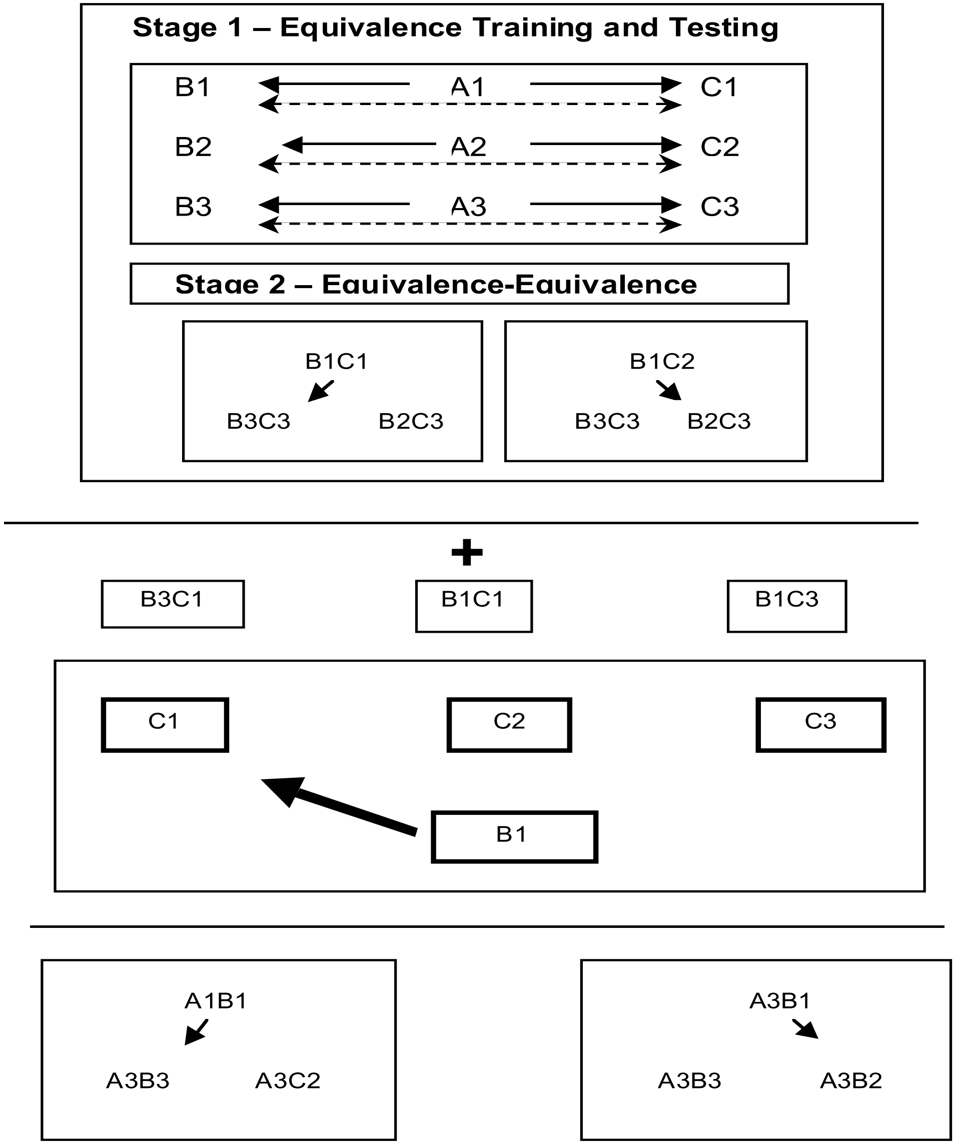

Figure 7. *Upper panel:* A schematic representation of the equivalence training and testing, and examples of the equivalence-equivalence testing, to which participants were exposed during Experiment 1 of Carpentier, Smeets & Barnes-Holmes (2002). *Center panel:* An example of the sample-comparison (compound) remediation training to which participants were exposed during Experiments 2 and 3 of Carpentier, Smeets & Barnes-Holmes (2002). *Lower panel:* An example of the compound-compound matching tasks with trained relations between compound elements to which participants were exposed during Experiment 4 of Carpentier, Smeets & Barnes-Holmes (2002).

Lunzer, 1965; Piaget, Montangero & Billeter, 1977; Sternberg & Rifkin, 1979). Carpentier, Smeets, and Barnes-Holmes (2002) reported a study that sought to establish if the emergence of equivalence-equivalence follows a similar developmental trend. In Experiment 1, adults, nine-, and five-year-olds were trained and tested for equivalence and equivalence-equivalence responding (Figure 7, upper panel). Whereas most of the adults and nine-year-olds successfully showed equivalence-equivalence, none of the five-year-olds did so.

In Experiment 2, a novel group of adults, nine-, and five-year-olds received similar training and testing to that employed in the first experiment. However, this time, those who failed the equivalence-equivalence test received sample-comparison-(compound) training as remediation. That is, participants were presented with a stimulus compound (e.g., B1C1) and were required to emit a separate matching response that coordinated with the compound (i.e., matching C1 to B1) (see Figure 7, centre panel). Again, whereas adults and nine-year-olds demonstrated successful equivalence-equivalence responding, all of the five-year-olds failed to do so. Experiment 3 employed sample-comparison-(compound) training before exposure to the equivalence-equivalence test using a new group of four five-year-olds. However, none of the participants was successful.

Experiment 4, again using a new group of five year olds, exposed participants to compound-compound matching tasks with trained relations between compound elements (e.g., A1B1-A3B3, A1B2-A1B3; Figure 7, lower panel). In effect, the children were required to match the directly trained relations to each other (e.g., A1B1 to A3B3) prior to the equivalence-equivalence test. Finally, in this experiment, all four children successfully showed equivalence-equivalence responding. The finding that five-year-olds only demonstrated this performance after very specific additional training procedures had been included in the experiment suggested a developmental divide similar to that reported in the earlier cognitive/developmental research on analogical reasoning.

This conclusion received further support from the findings of Carpentier, Smeets & Barnes-Holmes (2003), who investigated the extent to which prior training and testing arrangements, such as those provided in Carpentier et al. (2002) might also allow five-year-olds to pass equivalence-equivalence tests before first passing an equivalence test. Previous experiments (e.g., Barnes, Hegarty & Smeets, 1997) had shown that adults would readily pass the former before the latter. However, Carpentier et al. (2003) reported that even after exposure to a considerable number of training and testing arrangements designed to facilitate correct responding, only 2/18 five-year-olds showed equivalence-equivalence before equivalence.

Thus, the findings from the Carpentier et al. (2002, 2003) studies are broadly consistent with previous research on analogical reasoning in children and adults. In effect, the adults and older children demonstrated equivalence-equivalence responding with relative ease, whereas younger (four- to five-year-old) children did not. At the same time, however, five-year-olds in the Carpentier et al. studies did demonstrate equivalence-equivalence responding under certain circumstances following a successful equivalence test, whereas they almost always failed to demonstrate such responding under any circumstances preceding such a test. This finding may well have some bearing on a long-lasting debate that has been ongoing in the cognitive developmental literature on analogical reasoning.

Some researchers have argued that when a young child solves an analogy, the solution is 'primarily though not exclusively associative' (Sternberg & Nigro, 1980, p.36; see also Gentner, 1989). In contrast, others have argued that genuine analogical reasoning "is an important building block from an early age" (Goswami & Brown, 1990, p.207). The extent to which the current data support one of these two positions depends primarily on the definition of *associative*. If the term is taken to imply that direct teaching, reinforcement, or explicit instruction of stimulus pairings is a necessary prerequisite for an analogy-like performance then the current data refute the former position -five-year-old participants clearly demonstrated equivalence-equivalence responding based on untaught or *derived* equivalence relations. If, however, the term *associative* implies that the analogy-like performance is based on stimulus pairings that occur either via direct reinforcement *or derivation* then the data appear to support the former position rather than the latter. That is, almost all of the five-year-olds required an equivalence test during which the derived *associations* could occur, before successfully passing the equivalence-equivalence test..

At this point, therefore, RFT seems to have provided a relatively precise definition of analogical reasoning, whereas traditional cognitive/developmental psychology has not. As a result, some of the findings from RFT research may help to resolve a debate within mainstream psychology on the development of analogical reasoning itself. Furthermore, the definition of analogical reasoning in terms of equivalence-equivalence relations continues to facilitate more focused analyses of this aspect of cognition, and it is to this issue that we now turn.

Differentiating analogy from associative responding

A recent study by Carpentier, Smeets, Barnes-Holmes and Stewart (in press) attempted to develop a closer model of traditional analogical reasoning tasks than had hitherto been provided. Previous equivalence-equivalence tests required the subjects to choose between a compound with two same-class elements and one with two different class elements (e.g., B1C1-B3C3/B2C3). This feature is also present in the analogy task described earlier, in which subjects have to choose between sheep-dog (equivalent in the context *animals*) and sheep-book (non-equivalent in most contexts). In most well-designed classical analogy tasks, however, all d-term options are in some way or another related to, hence 'go with' the c-term (e.g., automobile : gas :: sailboat :: *travel* / *wind sails* / *rudder* [Gallagher & Wright, 1977]; spider : web :: bee : *hive* / *honey* / *ant* / *fly* [Goswami & Brown, 1990]). Unlike the equivalence-equivalence tests, these analogy tasks require the subjects to identify which pre-established c-d relation (e.g., bee-hive, bee-honey, bee-ant, bee-fly) is functionally the same as that between the a- and b-terms (spider-web).

Carpentier et al. (in press) attempted to model the equivalence-equivalence tests more closely on the classical analogy tasks by using only compounds with related stimuli. In Experiment 1 (Figure 8, upper panel), adult participants were trained to relate X and Y stimuli to a same color (X1 => Red <= Y1; X2 => Green <= Y2; X3

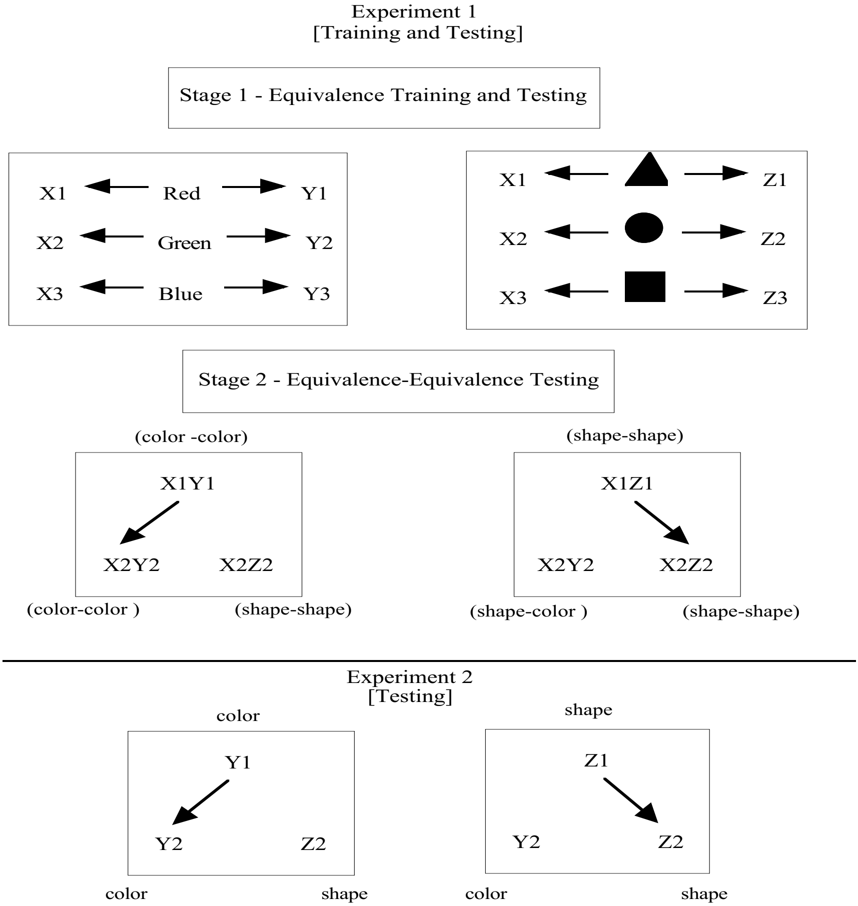

Figure 8. Upper panel: A schematic representation of the equivalence training and testing, and examples of the equivalence-equivalence testing, to which participants were exposed during Experiment 1 of Carpentier, Smeets, Barnes-Holmes & Stewart (in press). *Lower panel:* An example of tasks that tested for the matching of dimension related stimuli during Experiment 2 of Carpentier, Smeets, Barnes-Holmes & Stewart (in press).

=> Blue <= Y3) and to relate the X and Z stimuli to a same shape (X1 => Triangle <= Z1; X2 => Circle <= Z2; X3 => Square <= Z3). After assessing equivalence, equivalence-equivalence was tested. These tests involved three compounds, a sample with two color-related elements (e.g., X1Y1) or two shape-related elements (e.g., X1Z1) of one equivalence relation and two comparisons with elements of another equivalence relation, one with color-related elements (X2Y2) and one with shape-related elements (X2Z2). These tasks were deliberately designed to closely parallel analogy tasks in which all d-terms are associated or 'go with' the c-term. All participants passed the equivalence-

Analogy Tasks
Goswami and Brown (1990)

	Tasks a: b: c:	**d1**	**d2**	**d3**	**d4**
•	spider : web :: bee :	hive	honey	ant	fly
•	dog : dog basket :: baby :	crib	bottle	kitten	doll
•	dress : hanger :: coat :	hook	hat	sweater	coat

Experiment 3 Tasks
Carpentier, Smeets, Barnes-Holmes & Stewart (in press)

- **X** is to **web** as **Y** is to **hive, honey, fly, or ant**
- **X** is to **dog basket** as **Y** is to **kitten, bottle, doll, or crib**
- **X** is to **hanger** as **Y** is to **sweater, hat, hook, or coat**

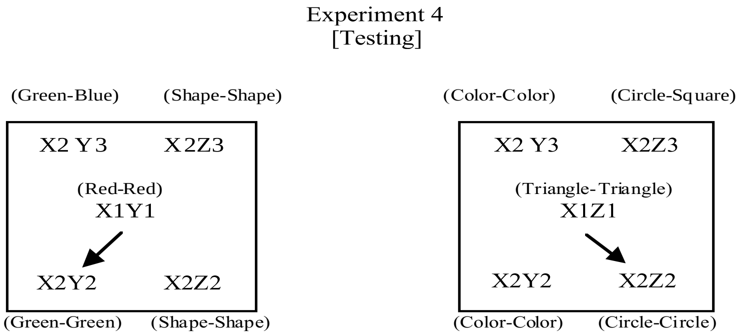

Figure 9. Upper panel: Above, a sample of the 'analogy' tasks employed by Goswami and Brown (1990) and, underneath, three corresponding tasks, in which the a- and c-terms have been removed. In Experiment 3 of Carpentier, Smeets, Barnes-Holmes & Stewart (in press), most participants presented with the Goswami & Brown tasks in the absence of the a- and c-terms, successfully solved all ten tasks. *Lower panel:* An example of the modified tasks that permitted differentiation of equivalence-equivalence from simple equivalence responding that were employed in Experiment 4 of Carpentier, Smeets, Barnes-Holmes & Stewart (in press).

equivalence test. However, Experiment 2 subsequently demonstrated, with a new group of adult participants, that these performances may not have been based on matching dimension-related equivalence relations (e.g., X1Y1-Color, X2Y2-Color, hence X1Y1-X2Y2) but on matching dimension related stimuli (Y1-Color, Y2-Color, hence Y1-Y2). Figure 8 (lower panel) provides an example of the testing tasks that replaced equivalence-equivalence tests in Experiment 2 and that all participants successfully passed.

Somewhat surprisingly, Experiment 3 demonstrated that this problem is also present in the 4-term analogy tasks that have been used in key studies in the cognitive developmental literature (see Figure 9, upper panel). When the a and c terms are removed from the tasks employed by Goswami and Brown (1990), for example, the participant may still produce the correct answer by simply matching the b and d terms because they participate in a single class (e.g., web and hive are in the class "animal homes"). In fact, when the Goswami and Brown tasks were presented to adult participants in Experiment 3, *with the a- and c-terms removed*, almost without exception all 10 participants selected the same d term that would have been correct had the a and c terms been present! Thus, contrary to what had been assumed, these analogy tasks can be solved "associatively" on the basis of the b-term alone (b-d equivalence).

In Experiment 4, therefore, a modified test was used that permitted differentiation of equivalence-equivalence from simple equivalence responding. For illustrative purposes, consider the task presented on the left of Figure 9 (lower panel). The critical feature to note is that if participants were simply matching the Y stimuli (the functional equivalent of matching the b and d terms), then either the X2Y2 or the X2Y3 compounds may be matched to X1Y1 (i.e., all three Y stimuli are related to colors). If, however, participants are relating derived relations, then only the X2Y2 compound is correct because, like the sample compound, both elements are related to the *same* color (i.e., X1Y1 both to red and X2Y2 both to green; in contrast, the elements of the X2Y3 compound are related to *different* colors). In fact, all five adult participants who were exposed to a series of tasks like those presented in the lower panel of Figure 9 readily matched same-dimension equivalence relations (e.g., X1Y1-X2Y2, X1Z1-X2Z2). In effect, this experimental model demonstrated unambiguous analogical reasoning, as defined by RFT.

By providing an RFT model of classical analogy tasks, such as those used in Goswami and Brown (1990), Carpentier et al. showed that it is possible to solve such analogies associatively (i.e., based on simple derived relations) rather than through analogical reasoning (based on derived relations *between* relations). Modeling the processes involved also allowed the researchers to provide exemplars of equivalence-equivalence tasks in which the only possible way to respond consistently is on the basis of the derivation of relations between relations (i.e., true analogical responding).

Based on the evidence provided by Carpentier et al. (in press) it appears that mainstream cognitive/developmental research does not currently have a precise behavioral definition of analogical reasoning. Furthermore, some of the key cognitive/developmental studies that have claimed to be investigating analogical reasoning may in fact have been studying simple matching responses instead. In contrast, behavioral psychologists, working under the rubric of RFT, now have a precise definition of analogical reasoning, and can generate this phenomenon under laboratory conditions, and can also provide appropriate remediation under conditions in which analogical reasoning is found to be deficient.

Conclusion

Relational Frame Theory researchers have modeled a number of important linguistic-cognitive processes in terms of derived or arbitrarily applicable relational responding. The modeling of analogical language is one example of this overarching program of research. In conceptualizing analogy in term of the derivation of relations between derived relations, RFT experimenters have generated a growing body of empirical research into aspects of analogical reasoning in both children and adults. Perhaps the most notable and unexpected outcome of this work is the provision of a precise definition of analogical reasoning in the apparent absence of a similarly precise definition from the cognitive/developmental tradition. Nevertheless, much more work remains to be done on the relating of derived relations as a model of analogical reasoning, and this research program is continuing across our two laboratories.

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