



## Review

## The formation of equivalence classes in individuals with autism spectrum disorder: A review of the literature

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## ABSTRACT

Articles that empirically investigated the emergence of untaught equivalence relations among individuals with autism are presented in this review. Systematic searches of academic databases, journals and ancestry searches identified nine studies that met inclusion criteria. These studies were evaluated according to: (a) participants, (b) developmental assessments conducted and reported, (c) experimental design, (d) stimulus content, (e) setting, (f) teaching procedure variables, (g) independent variables, (h) emergent skills tested, (i) main findings, (j) retention testing, and (k) reliability measures. The results of this synthesis demonstrate that while most individuals with ASD are able to form equivalence classes, the findings are variable. There are several examples in the literature in which untaught equivalence relations only emerged for some of the participants, or under modified teaching and testing conditions. In view of the limited research in this area, the lack of replication of findings, and the lack of investigation into variables that may affect the formation of equivalence classes, several recommendations are made for further research.

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## 1. Introduction

There have been several reviews of the research on general teaching strategies for children with Autism Spectrum Disorder (ASD) (Mudford et al., 2009; Virues-Ortega, 2010; Vismara & Rogers, 2010). The general conclusion is that intervention based on behavioral principles can be effective in improving communication and language, social functioning, daily living skills, cognitive functioning, and managing behavioral concerns in children with ASD. Outcomes are deemed to be most favorable when interventions begin at an early age, are sufficiently intensive, and address the core symptoms of Autism (National Research Council, 2001).

While there is extensive empirical support for the efficacy of behavioral approaches, critics of these strategies, and particularly the use of Discrete Trial Teaching (DTT) argue that the structured nature of this type of teaching can inhibit generalization (Daniel, 2004; Vismara & Rogers, 2010). Mudford et al. (2009) reviewed the literature to evaluate the effectiveness of intervention based on Applied Behavior Analysis (ABA) for individuals with ASD. They reported generalization outcomes for 169 of the 463 identified studies. Of the 169 studies, 45 assessed generalization of main effects. Twenty eight of the 45 studies demonstrated strong evidence of generalized main effects across behavior, academic skills, communication skills, interpersonal skills, and personal responsibility. However, in three studies, there was no evidence of a generalized main effect and in 14 of the 45 studies the evidence for a generalized main effect was limited. It was also concluded that there was no single intervention strategy that enhanced the likelihood of generalization across a broad range of target behaviors (Mudford et al., 2009). One of the key implications of this review is that generalization and maintenance are areas that need to be planned for with individuals with ASD due to generalization not necessarily being automatically attained with this group of learners.

The majority of the early research in the area of generalization which involves children with ASD has focused on two areas; setting and stimulus generalization, and the generalization of language responses. Setting or stimulus generalization research has generated studies that have examined whether the acquisition or performance of skills in a structured setting generalizes to novel settings (Betz, Higbee, & Pollard, 2010; Handleman, 1979, 1981; Jones, Feeley, & Takacs, 2007; Koegel, Camarata, Valdez-Menchaca, & Koegel, 1998; McGee, Krantz, Mason, & McClannahan, 1983; Rincovey & Koegel, 1975), novel examples or novel presentation methods (Betz et al., 2010; Craighead, O'Leary, & Allen, 1973; Koegel et al., 1998; Pellechia & Hineline, 2007; Secan, Egel, & Tilley, 1989) or generalization from teachers to parents, peers, or siblings (Craighead et al., 1973; Jones et al., 2007; Koegel et al., 1998).

Research into the generalization of language responses has typically investigated one of two areas. The first is stimulus generalization, that is, generalization of verbal responses across stimulus classes. In this example, generalization is demonstrated when the child applies the correct label to various representations of a concept (e.g., a child applies the verbal label "three" not only to various forms of the written numeral "3" but also to various representations of the quantity "three"). The second type of language generalization is generalization across response classes. This is a type of response generalization. For example, there are several different language responses which can be used interchangeably because they each have the same meaning (e.g., a child can greet somebody by saying "hi" or "hello" or "good morning" as each of these phrases has the same meaning).

Much of the research that has examined the generalization of language responses has focused on the effects of teaching method on the generalization of language responses across stimulus classes or response classes (Egel, Shafer, & Neef, 1984; Young, Krantz, McClannahan, & Poulson, 1994). Some of these studies used spontaneous language use or spontaneous responding as their measure of response generalization. Other studies examined the degree of spontaneous language use which occurred during structured and unstructured teaching sessions (Kok, Kong, & Bernard-Opitz, 2002; Miranda-Linne & Melin, 1992). While one study investigated the effect of a verbal discriminative stimulus on the frequency of spontaneous responding (Williams, Carnerero, & Perez-Gonzalez, 2006).

What we can conclude from the research is that while many children with ASD demonstrate generalization across novel stimuli, settings, people and response topographies without additional programming (Jones et al., 2007; Koegel et al., 1998) there is an equally substantial body of evidence that suggests that children with ASD have difficulty generalizing responses

that have been learned, and that transfer of stimulus control may not occur across the members of a stimulus class without direct teaching (Betz et al., 2010; Pellechia & Hineline, 2007; Williams et al., 2006; Young, Krantz, McClanahan, & Poulson, 1994).

One unique area of generalization that does not fit within either of the above categories refers to the emergence of derived responses. Several theoretical accounts have conceptualized and measured the emergence of derived responding. Three of the most common of these are relational frame theory (Hayes, Barnes-Holmes, & Roche, 2001), naming theory (Horne & Lowe, 1996) and Sidman's theory of stimulus equivalence (Sidman, 1971, 1994).

### 1.1. Relational frame theory (RFT)

Relational frame theorists (Hayes et al., 2001) argue that for symmetry to be demonstrated, individuals require a history of being reinforced for bi-directional responding and it is an individual's prior learning history that accounts for the emergence of derived responding. RFT is not specifically focused on equivalence relations, but examines the principles behind relational responding in a more general sense. RFT suggests that it is an individual's history of multiple exemplar training which teaches individuals the relationships between the stimuli that are involved in the formation of equivalence responding. It is further suggested that derived responding is an example of generalization that has arisen from previously reinforced experience with arbitrary discriminated responses.

Extensive research has examined the emergence of derived relations in individuals with ASD using teaching based on the principles described by relational frame theorists. In the majority of these studies, derived relations emerged following the teaching of specific relational responses (Gorham, Barnes-Holmes, Barnes-Holmes, & Berens, 2009; Murphy, Barnes-Holmes, & Barnes-Holmes, 2005; Persicke, Tarbox, Ranick, & St Clair, 2012; Rehfeldt, Dillen, Ziomek, & Kowalchuk, 2007) however, as in the research into stimulus and response generalization, there is variability among children with ASD, and there are participants for whom multiple exemplar training is required (Murphy & Barnes-Holmes, 2010) or for whom antecedent conditions needed to be modified in order for derived relational responses to emerge (Egan & Barnes-Holmes, 2010).

Rehfeldt (2011) conducted a review of all articles that investigated the emergence of derived stimulus relations among all groups of learners, published in the Journal of Applied Behavior Analysis between 1992 and 2009. In this review Rehfeldt (2011) highlights a number of areas in need of further investigation. These included, examination of how programming for relational repertoires can be used to teach a range of academic concepts. Further research to enhance our understanding of procedures for facilitating the formation of frames of comparison, opposition, and deictic frames, and the recommendation that additional research be conducted that includes typically developing individuals, follow-up probes, and the application of these procedures within small group contexts. No English-language review has been published that has specifically examined the emergence of untaught equivalence relations in individuals with ASD, across all academic publications.

### 1.2. Naming theory

Horne and Lowe (1996) argue that language is a crucial mediating factor in the emergence of equivalence classes. They state that as "naming is evoked by, and itself evokes classes of events, it brings about new or emergent behavior such as that reported in studies of stimulus equivalence" (p. 185). The naming theory suggests further that the skill of naming incorporates two components that are symmetrically related. Firstly, specific stimuli control the verbal response that is produced and secondly, the alternative response (e.g., selection) is also controlled by that same stimulus. In this way, language involves both verbal responses and comprehension. Dugdale and Lowe (1990), Horne and Lowe (1996), and Clayton and Hayes (1999) argue that naming is a mediating factor in the emergence of untaught relations because assigning stimuli the same names and also assigning a common name to stimulus-response pairings develops an equivalence relation. Support for this theory comes from the finding that some children with minimal verbal repertoires do not always demonstrate the emergence of untaught equivalence relations (Devany, Hayes, & Nelson, 1986). Further support for this notion is provided in studies which have included nonhuman subjects in which stimulus equivalence has not been demonstrated (D'Amato, Salmon, Loukas, & Tomie, 1985; Lipkens, Kop, & Matthijs, 1988).

### 1.3. Sidman's theory of derived responding

Sidman's theory of derived responding described the emergence of equivalence relations as occurring as a direct outcome of reinforcement contingencies in which operant principles are applied (Jackson, Williams, & Biesbrouck, 2006). Sidman (2004) states that "a reinforcement contingency produces at least two types of outcome: analytic units and equivalence relations" (p. 128). Sidman's theory of derived responding differs to that proposed by Naming Theorists in that he argues that the formation of equivalence classes has an important role in the acquisition of language and that language is not a mediating factor in this process. Essentially, this means that language in and of itself does not play a pivotal role in the likelihood of derived responding, as proposed by Naming Theorists. Support for this view comes from research by Sidman, Willson-Morris, and Kirk (1986) in which participants demonstrated the emergence of untaught equivalence relations following teaching using auditory-visual and visual-visual relations. A review of the literature on equivalence relations and individuals with intellectual disabilities (O'Donnell & Saunders, 2003) also concluded that naming is not essential for the emergence of derived relations. Sidman's theory of derived responding differs from that of relational frame theorists in that

he argues that the emergence of untaught equivalence relations is a primary behavioral function (Sidman, 1994) and a history of reinforcement for bi-directional responding is not essential for the emergence of derived responses. While each of these theories differ in their account of derived responding all three theories view operant principles at work in the emergence of derived relations and one of the key theoretical underpinnings of both relational frame theory, and Sidman's theory of stimulus equivalence is that repertoires of derived responses consist of a number of complex human behaviors.

According to Sidman's account of stimulus equivalence (1971, 1994), language development involves the learning of multiple sets of stimulus-response correspondences. The sets of correspondences learned can be referred to as equivalence relations. For a stimulus-response relationship to be part of an equivalence class it must demonstrate what Sidman referred to as *reflexivity*, *symmetry* (or *reversibility*) and *transitivity*. Reflexivity is demonstrated when the child can perform generalized identity matching. Symmetry refers to the acquisition of a bi-directional relationship between two different stimuli such that if A is conditionally related to B, then B is conditionally related to A. Transitivity is demonstrated when, following acquisition of two of the three pairs of symmetrical responses, the learner is able to demonstrate that they have also acquired the third pair of symmetrical responses without requiring teaching in order to do so. As an illustration, the equivalence relations for the written word "cat" are given in Table 1.

Using the example provided in Table 1, reflexivity is demonstrated when a learner sees the written word "cat" and points to another example of the written word "cat" when presented with several written words, or when the child hears the word "cat" and says the word "cat" or when the child sees a picture of a cat and selects another example of a cat from a set of several different pictures. This is often referred to as "matching to sample".

Symmetry refers to the acquisition of a bi-directional relationship between two different stimuli such that if A is conditionally related to B, then B is conditionally related to A. In Table 1, discriminated responses 1 and 2, 3 and 4, and 5 and 6 constitute three symmetrical pairs of discriminated responses. A child who demonstrates that they have acquired both of the responses in a symmetrical pair (e.g., can demonstrate both comprehension of the oral word "cat" and the ability to name a picture of a cat is said to be demonstrating symmetry). Symmetry is often referred to as "reversibility". Symmetry is important because it has been found that once a child has acquired one of the responses in a symmetrical pair they will often be able to perform the other discriminated response in the pair without further instruction.

For transitivity to occur, a minimum of three pairs of symmetrical equivalence relations are required. Transitivity is demonstrated when, following acquisition of two of the three pairs of symmetrical responses, the learner is able to demonstrate that they have also acquired the third pair of symmetrical responses. Referring again to the example in Table 1, let us say that a child had acquired discriminated responses 1–4. If the child was then able to demonstrate that they had acquired responses 5 and 6 (reading comprehension and picture-word matching) for the written word "cat" then this would be an example of a child demonstrating transitivity. Transitivity is important because transitive relations often occur without any direct teaching. Taken together symmetry and transitivity are important in the learning of sets of equivalence relations because the teaching of just two discriminated responses can result in the emergence of four additional discriminated responses without further teaching.

In Sidman's original investigation into equivalence relations a boy with an intellectual disability was taught the auditory-visual equivalences, matching the dictated name to the written word, and matching the dictated name to its corresponding picture (Sidman, 1971). In this study, symmetry was demonstrated when the boy was then able to orally name the printed word without additional teaching, and transitivity was demonstrated when the boy was also able to match the printed word to the picture and match the picture to the printed word without any additional teaching. In this example, the child demonstrated the emergence of both reading and comprehension skills without being directly taught to do so. These findings have been replicated on several subsequent occasions with typically developing individuals and individuals with Intellectual disabilities (Brady & McLean, 2000; Carr, Wilkinson, Blackman, & McIlvane, 2000; Cowley, Green & Braunling-McMorrow, 1992; Gast, Munson-Doyle, Wolery, Jones Ault, & Kolenda, 1994; Kennedy, Itkonen, & Lindquist, 1994; Lynch & Cuvo, 1995; Mackay, 1985; McDonagh, McIlvane, & Stoddard, 1984; Rehfeldt & Root, 2004; Sidman & Cresson, 1973; Sidman, Cresson, Wilson-Morris, 1974; Sidman & Tailby, 1982; Sidman et al., 1986; Spradlin, Cotter, & Baxley, 1973).

Enhancing our understanding of this area of research has important implications for teaching and learning. Firstly, increased understanding of the conditions that affect the emergence of untaught equivalence relations will enable teaching to be structured so that the teaching of one or two discriminated responses results in the emergence of two or four discriminated responses without any further teaching. Secondly, a greater understanding of the variables affecting the emergence of untaught equivalence relations could help to guide us on a broader scale in devising and designing classroom

**Table 1**  
Equivalence relations for the written word "cat".

Stimulus	Taught response	Type of relation
1. Child hears the word "cat" A	Child selects the picture of a cat B	Aural comprehension A–B
2. Child sees the picture of a cat B	Child says "cat" A	Oral naming B–A
3. Child hears the word "cat" A	Child selects the written word cat C	Aural-written word matching A–C
4. Child sees the written word cat C	Child says the word "cat" A	Reading C–A
5. Child sees the written word cat C	Child selects the picture of a cat B	Reading comprehension C–B
6. Child sees the picture of a cat B	Child selects the written word cat C	Picture-word matching C–B

curriculum as well as intervention programs for children which allow for and promote the automatic generalization of skills. Thirdly, there are several different types of curriculum content that can be taught using a stimulus equivalence teaching paradigm and stimulus equivalence could potentially have applications across a range of instructional domains. Fourthly, the finding that some children with learning difficulties demonstrate the emergence of untaught equivalence relations has profound implications for teaching and facilitating generalization in children with ASD and related disorders. If teaching two stimulus-response relations leads to emergence of four additional stimulus-response relations without having to directly teach these discriminated responses then we can greatly improve the efficiency with which we conduct remedial instruction.

The purpose of this review is to analyze the existing literature in order to highlight evidence-based practice in equivalence relations among children with ASD and to investigate several unanswered questions. The first of these questions is whether there sufficient evidence to indicate that children with ASD are able to demonstrate the formation of equivalence classes. The second is to determine if there variability in the likelihood that children with ASD will demonstrate the emergence of untaught relations, and if so, whether there any evidence of developmental characteristics that may account for this variation. The third is, are there any particular teaching or procedural variables that may facilitate the emergence of untaught equivalence relations, and the fourth is to determine what additional areas of this field require further systematic investigation.

## 2. Methods

### 2.1. Search procedures

Systematic searches of the following academic databases were conducted: PsycINFO; Education Resources Information Centre (ERIC); and Education Research Complete. Keyword search terms that were entered individually into each of the aforementioned databases include: *equivalence relations*, *derived responding*, *stimulus equivalence*, *relational responding*, *relational responses*, *derived relations*, *reversibility*, *symmetry*, and *transitivity*. If a search yielded more than 500 results, then the term ASD and autism were entered separately as keywords. For example, *stimulus equivalence + autism* and *stimulus equivalence + ASD*. It was necessary to combine these search terms when entering the term stimulus equivalence, reversibility, symmetry and transitivity into PsycINFO, and when entering the terms symmetry and transitivity into Education Research Complete. At all other times, when the search terms were entered individually, fewer than 500 results came up. The search of PsycINFO yielded the greatest number of results compared to the ERIC and Education Research Complete databases.

Ancestry searches were also conducted by examining the reference lists of identified studies for possible target articles. In addition, individual electronic searches of JABA (Journal of Applied Behavior Analysis), the Psychological Record, Research in Developmental Disabilities and Research in Autism Spectrum Disorders were conducted as these journals have historically included articles that have examined the formation of equivalence classes and/or articles that focus on autism. To do this, the keywords *equivalence relations* and *stimulus equivalence* were entered as search terms within each journal's homepage.

### 2.2. Inclusionary and exclusionary criteria

Only studies published in academic, peer reviewed journals were included in this review. Dissertations and theses were not considered eligible. Articles were included regardless of the year of publication. To be eligible for inclusion in this review, it was also a requirement that there was at least one participant with a formal diagnosis of ASD. No age restrictions were applied for these participants. While there were no restrictions imposed regarding the date of publication, it is worth noting that as ASD was not included in the DSM-IV (American Psychiatric Association, 2000) prior to 1980 it is unlikely that any studies published before this date would be included.

It was required that each article included empirically investigated the emergence of untaught equivalence relations in individuals with ASD, in accordance with Sidman's (1971) definition of equivalence relations. This meant that symmetrical and transitive responses were used as the measure of emergence of untaught relations, as opposed to relational responses conceptualized within relational frame theory (e.g., mutual entailment, combinatorial entailment and the transfer of stimulus function). Studies that measured relational responding or frames of opposition and comparison as outcome measures were excluded from further consideration. It was further required that articles reported objective empirical data, when measuring the emergence of equivalence relations.

Each of the 86 articles initially selected as possible to include in this review were independently reviewed by both the first and second author to determine which articles met the inclusion criteria. There was 100% agreement that only the nine articles considered here met criteria for inclusion in this review. The remaining 77 articles were primarily excluded on the basis that they either, did not include any individuals with ASD, the paradigm used to measure derived responding was consistent with relational frame theory as opposed to Sidman's theory of stimulus equivalence, the articles were not published in English, and/or relational responses or frames of opposition were measured as opposed to equivalence responding.

### 2.3. Data classification

Each article that met criteria for inclusion in this review was analyzed according to the following criteria: (a) participants (chronological age, diagnosis, number); (b) assessments conducted and reported (e.g., outcomes of formalized developmental assessments); (c) experimental design; (d) stimulus content taught (e.g., money skills, emotions,



geographical concepts); (e) setting (where the teaching and testing was undertaken); (f) teaching procedure (how stimulus-response relations were taught); (g) independent variables (i.e., those that were specifically manipulated in each study); (h) outcomes measured (specific outcomes and outcome variables that were assessed or compared); (i) main findings; (j) retention (whether any testing was conducted to measures whether skills acquired had been maintained); and (k) reliability (i.e., whether this was recorded and if so, the percentage of agreement).

A summary of (a) participants, (b) assessments conducted and reported, (c) experimental design, (d) stimulus content taught, (e) teaching procedure, (f) outcomes measured, (g) main findings, and (h) reliability is presented in [Table 2](#).

### 3. Results

#### 3.1. Participants

The chronological age ranges, diagnoses, and information on additional assessments conducted is presented in [Table 2](#). The ages of participants in reported studies ranged between 3 and 22 years of age. The majority of the participants in each study were aged between 3 and 9 years of age (86%). The remaining participants were aged between 10 and 22 years of age. The sample size for each of the studies ranged between 1 and 15 participants. Two studies included 15 participants (O'Connor, Barnes-Holmes, & Barnes-Holmes 2011; O'Connor, Rafferty, Barnes-Holmes, & Barnes-Holmes, 2009) with ASD. The remaining studies included six or fewer individuals, with six of the nine studies including only two or fewer people. Three of the studies included a comparison group of typically developing children (Maguire, Stromer, Mackay, & Demis, 1994; O'Connor et al., 2011, 2009). None of the studies compared individuals with ASD with other groups of learners who had disabilities.

#### 3.2. Learner assessments conducted and reported

Each study included in this review recorded the chronological age and diagnosis of each of the participants. Interestingly, five of the studies did not report any additional learner characteristics that were based on standardized formal assessment measures (Keintz, Miguel, Kao, & Finn, 2011; Le Blanc, Miguel, Cummings, Goldsmith, & Carr, 2003; Miguel, Yang, Finn, & Ahearn, 2009; O'Connor et al., 2011, 2009). The remaining studies reported various additional learner characteristics that were based on the use of formal assessment tools. The type of assessment used and the information reported varied considerably. The additional assessment tools that were used in each of the studies is presented in [Table 2](#). As can be seen in [Table 2](#), two studies reported on the results of IQ testing. One of these studies measured IQ using the Wechsler Intelligence Scale for Children-III, (WISC-III; Wechsler, 1991) (Arntzen, Halstadtro, Bjerke, & Halstadtro, 2010), while the second study used the Leiter International Performance Scale (Leiter, 1959) (Eikeseth & Smith, 1992). Three studies used standardized assessment measures of language ability. These assessments included the communication domains of the Vineland Adaptive Behavior Scale (VABS; Sparrow, Balla, & Cichetti, 1984) (Eikeseth & Smith, 1992) and the Peabody Picture Vocabulary Test-III (PPVT-III; Dunn & Dunn, 1997) or the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn, 1981) (Eikeseth & Smith, 1992; Groskreutz, Karsina, Miguel, & Groskreutz, 2010, Maguire et al., 1994). Other studies also reported language ability using non-standardized measures of verbal ability through the Comprehensive Application of Behavior Analysis to Schooling (CABAS) (O'Connor et al., 2011, O'Connor et al., 2009), or they reported anecdotal information about the individual's ability to verbally communicate (Keintz et al., 2011; Maguire et al., 1994).

#### 3.3. Experimental design

8 out of 9 studies included in this review used a pretest/posttest experimental design. This enabled researchers to examine the effect of teaching the specific stimulus-response relations, on the emergence of untaught equivalence relations. The studies which utilized this design generally followed a sequence of pretesting for stimulus-relations in order to determine an individual's baseline level of performance. This was followed by teaching of the target stimulus-response relations, and finally, posttests assessed the emergence of untaught equivalence relations (Keintz et al., 2011; Le Blanc et al., 2003). The one exception to this was the study by Eikeseth and Smith (1992) which used an ABCDA design in which the baseline performance was recorded, followed by three different experimental teaching procedures. In this study the variable of assigning a common name to stimuli, was manipulated during different phases of teaching. The emergence of untaught equivalence relations was then assessed as the posttest.

#### 3.4. Stimulus content taught

Each study used stimuli presented in written, pictorial, symbolic or object form. The teaching materials used in four of the nine studies consisted of nonsense stimuli (Maguire et al., 1994), nonsense stimuli in addition to actual objects or pictures (O'Connor et al., 2011, 2009) or Greek symbols (Eikeseth & Smith, 1992) that participants would be unfamiliar with. The remaining studies explored academic or language concepts that included musical notation (Arntzen et al., 2010), noun labels such as animals (Groskreutz et al., 2010), money skills (Keintz et al., 2011), geography (Le Blanc et al., 2003), and activity schedules (Miguel et al., 2009). None of these studies have been replicated with children with ASD using the same language or academic concepts and using teaching procedures that investigate the emergence of symmetrical and transitive relations.

**Table 2**

Summary of research into the emergence of equivalence relations in individuals with ASD.

Author/s	Participant and assessment measures	Stimulus material	Teaching procedure variables	Emergent skills tested	Main findings	Reliability
Arntzen et al. (2010)	One male with autism (16 years old) WISC-III	Music	MTS OTM and MTO training procedures	Formation of equivalence classes in each training condition. Assessed reaction time to stimuli across teaching and testing	The participant formed equivalence classes in both the MTO and OTM procedures with the exception of one stimulus set trained using a MTO procedure. Reaction time from training to testing increased	Not recorded
Eikeseth and Smith (1992)	Four preschool aged children with ASD (3.5–5.5 years) LIPS (Leiter, 1959). PPVT-R (Dunn & Dunn, 1981). Communication domains of the VABS (Sparrow et al., 1984)	Greek symbols	MTS comparison of named and unnamed stimuli	Formation of equivalence classes	Initially, all subjects failed to demonstrate emergence of equivalence relations. When taught to assign the same name to members of each stimulus class, relations emerged for two participants	Interobserver agreement 96%
Groskreutz et al. (2010)	Six individuals with ASD (4–18 years of age) PPVT-III and PPVT-R	Various nouns (e.g., animals, instruments)	MTS use of complex auditory–visual stimuli (AB-C)	Formation of equivalence classes following teaching using complex stimuli	For each participant, emergence of the untaught relations was demonstrated following teaching using complex auditory–visual stimuli	Interobserver agreement 98%
Keintz et al. (2011)	Two children with ASD (6-years of age) No formal assessment	Money skills	MTS visual-visual auditory–visual	Emergence of untaught relations that included textual behavior, tacts and intraverbals	All untaught relations emerged for one participant. Second participant demonstrated emergence of 4/7 relations. The three relations that did not emerge each required vocal responses from the participant	Interobserver agreement 100%
Le Blanc et al. (2003)	Two children with ASD (6 and 13 years of age) No formal assessment	Geography	MTS compared three reinforcement procedures	Formation of equivalence classes	Both children were able to master trained geography relations and emergent CA, AC, CB and BC relations. All three testing procedures produced similar effects	Interobserver agreement 100%
Maguire et al. (1994)	Experiment 1 – one adult with ASD (21 years of age) Experiment 2–one adult with ASD (22 years of age) and four TD children (4–9 years of age). PPVT (version unspecified)	Nonsense symbols and colored circles	MTS Complex Visual-Visual stimuli (AB-D and ABC-D)	Formation of equivalence classes. Emergence of four-member equivalence classes by adding novel stimuli, including three-element sample stimuli, during teaching	All participants demonstrated the formation of three-member equivalence classes though one of the participants with autism, and one TD participant required repeated testing. All participants established four member equivalence classes when novel stimuli were included during teaching	Interobserver agreement of 99–100%

Miguel et al. (2009)	Two children with ASD (6 years of age) No formal assessment	Activity schedule	MTS	Formation of equivalence classes. Emergent ability to follow a written activity schedule	Both participants demonstrated emergence of untaught relations and were able to follow written activity schedules	Interobserver agreement 92% and 100%
O'Connor et al. (2011)	Eight TD children (6–9 years). 10 children with ASD (6–9 years) Five children mild/moderate ASD (5–8 years) CABAS system for Verbal abilities (Greer & Ross, 2007)	Nonsense and actual words and symbols	MTS. Taught symmetrical and asymmetrical responses	Formation of equivalence classes. Generalization and contextual control of symmetrical and asymmetrical responses to novel stimuli over three experiments	Typically developing children demonstrated achievement of emergent skills. Six children with ASD required additional MET in order to demonstrate generalized responses. In experiment 3, for some children with mild/moderate ASD training procedures were required to be modified individually in order to acquire target skills	Interobserver agreement 100%
O'Connor et al. (2009)	Fifteen children with ASD. (5–8 years) and 3 TD children (7–10 years) CABAS system for Verbal abilities (Greer & Ross, 2007)	Items, photographs and words and also nonsense items, sketches and syllables	MTS stimulus nameability and stimulus familiarity	Formation of equivalence classes. Examined the role of stimulus nameability, verbal competence and stimulus familiarity over three experiments	Those with more advanced verbal language produced more rapid equivalence performances and took fewer trials to reach mastery. Training and test performance was mediated at least partially by children's verbal development	Interobserver agreement 100%

TD, typically developing; ASD, autism spectrum disorder; MET, multiple exemplar training; MTS, matching to sample. Wechsler Intelligence Scales for Children-III: WISC-III. Leiter International Performance Scales: LIPS Peabody Picture Vocabulary Test-Revised: PPVT-R. Vineland Adaptive Behavior Scales: VABS. Peabody Picture Vocabulary Test-III: PPVT-III. Comprehensive Application of Behavior Analysis to Schooling: CABAS.



### 3.5. *Setting*

In six studies, teaching was conducted within the school setting. For three of these studies it was specified that the teaching took place in a secluded, quiet area of the classroom or a separate room (Keintz et al., 2011; Le Blanc et al., 2003; O'Connor et al., 2011). For the remaining three studies conducted within the school setting, the precise area is unspecified. For one of the studies, research was conducted within the home setting (Eikeseth & Smith, 1992). For two studies the setting is unspecified (Groskreutz et al., 2010; Maguire et al., 1994).

### 3.6. *Teaching procedure and independent variables*

All of the studies included in this review employed a traditional matching-to-sample (MTS) teaching procedure in order to teach the target stimulus-response relations. This meant that sample stimuli were matched with comparison stimuli during teaching. A MTS procedure is consistent with the teaching methodology employed in the original investigations conducted in this area by Sidman and colleagues (Sidman, 1971; Sidman & Cresson, 1973; Sidman et al., 1974, 1986; Sidman & Tailby, 1982; Spradlin et al., 1973).

All of the studies used some form of visual stimuli while teaching and testing. This included either visual-visual, auditory-visual or written-spoken stimulus-response relations. The stimulus modality that was used during teaching for 33% of the studies was purely visual-visual (Arntzen et al., 2010; Eikeseth & Smith, 1992; Maguire et al., 1994). A purely auditory-visual stimulus modality was used for 22% of the studies (Groskreutz et al., 2010; Miguel et al., 2009). For three studies (33%) teaching consisted of a combination of an auditory-visual and visual-visual stimulus mode (Keintz et al., 2011; O'Connor et al., 2009), or visual-visual relations in which visual stimuli was paired with a question (Le Blanc et al., 2003). Finally, a single study taught visual-spoken relations, and also auditory-visual relations in which symmetrical and asymmetrical responses were taught under the contextual control of additional visual stimuli (O'Connor et al., 2011).

In addition to the variations in response modality it is important to note that individual studies examined the effect of modifying these independent variables. One study compared One-to-Many (OTM) and Many-to-one (MTO) training structures (Arntzen et al., 2010). Eikeseth and Smith (1992) compared the role of naming by teaching students to assign a common name to each member of each stimulus class and examining the effect of this on emergence. In the study by Groskreutz et al. (2010) the formation of equivalence classes was investigated following teaching using complex auditory-visual stimuli in which AB-C relations were taught. AB-C relations were presented in the study by Groskreutz et al. (2010) when during MTS teaching, the trainer presented the complex sample (AB) by verbally labeling the word (A) while holding up the picture (B), and subsequently, presented the comparison stimuli which consisted of printed words (C).

The Maguire et al. (1994) study similarly examined the formation of three-member equivalence classes following teaching using complex stimuli, and further investigated the formation of four-member equivalence classes following the introduction of novel stimuli. The study by Le Blanc et al. (2003) examined the effect of varying reinforcement procedures during testing. O'Connor et al. (2011) examined the emergence of untaught relations following teaching of symmetrical versus asymmetrical responses. Finally, O'Connor et al. (2009) examined the effect of stimulus nameability and stimulus familiarity on the emergence of untaught equivalence relations. It is important to note that each of the studies that manipulated elements of the teaching procedure have not been replicated with individuals with autism.

### 3.7. *Emergent skills tested*

Each of the studies examined the emergence of symmetrical and/or transitive relations following the teaching of specific sets of stimulus-response correspondences. Across all studies, the emergence of untaught relations was assessed using a matching to sample format in which selection-based or topography-based responses were required. Six studies examined the emergence of selection-based matching responses during testing (Arntzen et al., 2010; Eikeseth & Smith, 1992; Le Blanc et al., 2003; Maguire et al., 1994; O'Connor et al., 2011, 2009). The remaining three studies investigated a combination of selection-based and topography-based responses (Groskreutz et al., 2010; Keintz et al., 2011; Miguel et al., 2009). None of the studies exclusively examined the emergence of topography-based responses.

Additional outcome variables were reported in some studies. For example, Miguel et al. (2009) examined whether the following of written activity schedules would emerge after participants were taught to match the dictated word to the picture and the dictated word to the written word using symbols taken from the child's daily schedule. Arntzen et al. (2010) measured each participant's reaction time to stimuli across teaching and testing in both the OTM and MTO teaching conditions. The study by Keintz et al. (2011) was also unique in that it investigated the emergence of verbal responses in the form of tacts and intraverbals following teaching.

### 3.8. *Key findings*

Outcomes for each study were classified as positive, negative or variable. Positive outcomes meant that all participants demonstrated the emergence of each of the untaught relations that were tested. Negative outcomes were those in which none of the participants demonstrated emergence of any untaught relations. Variable outcomes were when some, but not all

participant's demonstrated emergence of all of the untaught relations and/or, participants demonstrated emergence of some of the untaught relations but not others.

An analysis of the research indicated that no studies reported negative outcomes across all of the participants and all of the stimulus-response relations that were tested.

Five of the nine studies reported positive outcomes (Groskreutz et al., 2010; Le Blanc et al., 2003; Maguire et al., 1994; Miguel et al., 2009; O'Connor et al., 2009). This included the finding that children with ASD demonstrated an emergent ability to follow a written activity schedule in addition to other derived responses following teaching (Miguel et al., 2009).

Four of the nine studies reported variable findings. Of the studies that reported variable findings, some of the participants required additional or modified teaching in order for the emergence of untaught equivalence relations to be demonstrated (Eikeseth & Smith, 1992; O'Connor et al., 2011). For example, in Experiment 2 of the O'Connor et al. (2011) study, three out of ten participants required additional multiple exemplar training in order for the emergence of symmetrical and asymmetrical relations to be demonstrated. Three participants required multiple exemplar training and also the use of familiar stimuli during teaching in order to establish emergent relations, and for four out of ten participants, the emergence of untaught relations was demonstrated without any additional training. For the five participants who were included in Experiment 3 of this study, it was evident that the emergence of untaught relations improved when the teaching procedures were individualized based on the needs of each learner.

Similar findings were also reported by O'Connor et al. (2009). While each participant in this study demonstrated the emergence of untaught relations, there was variation in that those participants with more advanced verbal language demonstrated more rapid equivalence performances and took fewer trials to reach mastery. Furthermore, the typically developing children included in this study, who had more advanced verbal behavior, were also more readily able to demonstrate the emergence of untaught equivalence relations.

The final three studies reviewed reported variable findings. In the study by Eikeseth and Smith (1992) the emergence of untaught relations appeared to be mediated at least in part, by teaching in which participants were instructed to assign a common name to stimuli. In the study by Keintz et al. (2011) one participant was unable to respond correctly when the correct responses to testing required verbal responses. In the research conducted by Arntzen et al. (2010), the participant formed equivalence classes in both the MTO and OTM conditions with the exception of one stimulus set trained using the MTO procedure which involved the formation of a four-member equivalence class and, this participant also required retraining for some of the taught relations in order to respond successfully during testing.

It is important to note also, that in the three studies to have included a comparison group of typically developing children, it was evident that these children rapidly demonstrated the emergence of untaught relations, without the additional and specific training required by some of the children with ASD (Maguire et al., 1994; O'Connor et al., 2011, 2009).

### 3.9. Retention testing and reliability

None of the nine studies examined the retention or maintenance of relations that emerged following teaching. Each of the studies included in this review reported inter-observer reliability scores, with the exception of one study (Arntzen et al., 2010), which did not report any reliability testing. Inter-observer reliabilities were recorded during teaching and testing in each study for either a proportion of sessions, or for all teaching and testing sessions. Inter-observer reliability agreement across the studies ranged from 96 to 100%.

## 4. Discussion

In total there were nine studies that met criteria for inclusion in this review. Interestingly, six of the nine studies have been published since 2009, suggesting that although there are a very limited number of studies that have investigated the emergence of untaught equivalence relations in individuals with ASD, it has become an area of increasing interest.

This systematic review was guided by four important questions. The first was the question of whether there is sufficient evidence to suggest that children with ASD are able to demonstrate the emergence of untaught equivalence relations. The second, was to determine whether there is individual variation among learners with ASD with respect to their ability to form equivalence classes and if so, whether there are any developmental characteristics documented in the literature that may explain this variation. The third is to examine whether there are specific teaching or testing conditions that may have a facilitative effect on the emergence of untaught equivalence relations. The fourth was to identify any recommendations that may guide further research in this field.

### 4.1. Emergence of untaught equivalence relations in children with ASD

In total, there were only 49 participants with a diagnosis of ASD that were included in this review. In five of the nine studies (56%) there were two or fewer participants. The results for five of the nine studies indicate that individuals with ASD are able to demonstrate the emergence of untaught equivalence relations without additional or modified teaching procedures. By contrast,

the remaining four studies demonstrated variable findings in which some individuals with ASD were only able to demonstrate emergence of untaught relations under certain teaching conditions and/or the emergence of untaught relations was demonstrated for some, but not all of the relations tested. The limited number of participants with ASD for whom the formation of equivalence classes was investigated and the variability in findings, makes it difficult to draw any robust conclusions regarding whether all children with ASD are able to consistently demonstrate the formation of equivalence classes.

#### 4.2. *Learner characteristics that may affect the emergence of untaught equivalence relations*

In spite of the variation in findings, information in each study pertaining to the developmental characteristics of each learner was scarcely reported. While the chronological age and diagnosis of each individual was consistently included, few other developmental characteristics were reported, that were based on the results of standardized, norm-referenced assessment tools. Furthermore, the information pertaining to the characteristics of each of the learners that was included was largely anecdotal and subjective making it difficult to replicate these studies, and to draw inference about the characteristics of learners with ASD who are, and are not able to demonstrate the formation of equivalence classes.

Given that there was some variation among the participants in terms of the likelihood of the emergence of untaught equivalence relations, it would be of value for researchers to have included further information about the characteristics of each of the learners. For example, their cognitive functioning, prior learning history, and receptive and expressive language ability. This could help to provide a more in depth understanding of the developmental variables that may have an impact on the formation of equivalence classes.

One way of assessing whether there are unique differences in the way in which children with ASD acquire and demonstrate equivalent responses is to conduct research which includes a comparison group of typically developing individuals. This was done in three of the studies reviewed (Maguire et al., 1994; O'Connor et al., 2011, 2009). The results of each of these studies demonstrated little difference between the performance of individuals with ASD and each of the typically developing children in that all children in each of these studies demonstrated the formation of equivalence classes. It is however, important to note that some children with ASD did require additional multiple exemplar training or repeated testing in order to do so and in one study, performance was mediated in part by language ability (O'Connor et al., 2009). Further replication of these findings would contribute to our understanding of whether children with ASD have unique difficulties associated with generalization and how we may account for this.

#### 4.3. *The affect of the teaching conditions*

Each of the studies examined utilized a matching to sample procedure during teaching in which the emergence of untaught symmetrical or transitive responses was the outcome variable. Each of the studies also utilized either visual–visual, auditory–visual or visual–spoken relations.

Additional teaching procedure variations included the use of a OTM versus MTO training structures (Arntzen et al., 2010), an investigation into the role of the naming of each member of a stimulus class (Eikeseth & Smith, 1992) the use of complex versus simple stimulus (Groskreutz et al., 2010), the effect of variations in reinforcement procedures used during testing (Le Blanc et al., 2003) the emergence of untaught relations following teaching of symmetrical versus asymmetrical responses (O'Connor et al., 2009), and the effect of stimulus nameability and stimulus familiarity on the emergence of untaught relations (O'Connor et al., 2011).

Each of these studies has unique implications for this field and specifically, the teaching strategies that may facilitate the emergence of untaught equivalence relations in individuals with ASD. What we are able to tentatively conclude given the present findings, is that when MTS procedures are employed during teaching most individual's with ASD are able to demonstrate the emergence of untaught equivalence relations. This seems to be the case regardless of whether individuals are taught using OTM and MTO training structures, when complex and simple stimulus–response relations are taught, and when symmetrical and asymmetrical responses are required; provided that individuals are given sufficient training opportunities.

It may also be the case, given the findings of Eikeseth and Smith (1992), Keintz et al. (2011) and O'Connor et al. (2011) that instruction in naming or language ability has a facilitative effect on the likelihood of the emergence of untaught equivalence relations.

Before we are able to draw any robust conclusions about the validity of these findings further research which replicates the teaching procedures described in this review is required. This is of particular importance if we are to enhance our understanding of the teaching variables that may facilitate the emergence of untaught equivalence relations in those children for whom this type of responding is not automatically demonstrated.

#### 4.4. *Practical implications*

The finding that some children with ASD are able to demonstrate the emergence of untaught equivalence relations has profound implications for the teaching of sets of equivalence relations and for facilitating generalization in children with ASD and other developmental disabilities. If teaching two stimulus–response relations leads to the emergence of four additional stimulus–response relations without having to directly teach these discriminated responses, then we can greatly improve the efficiency with which we can teach new skills to children who require remedial instruction.

The evidence that some children with ASD do not demonstrate the emergence of untaught equivalence relations also has important implications. The first is that some children with ASD will be able to generalize (demonstrate symmetry and transitivity) and they will be able to be taught using an efficient teaching procedure. Others however, will not and these children will need to be systematically taught all of the discriminated responses for each concept. As demonstrated in [Table 1](#), this would mean that children would need to be taught each of the six stimulus-response relations. In addition, it may be necessary to conduct an assessment in order to determine whether a particular child is able to be taught using an efficient teaching method or whether the direct teaching of each discriminated response will be required.

The possibility that the emergence of symmetrical and transitive responding may be related to the teaching method utilized suggests that we should ensure that the appropriate method is implemented when teaching discriminated responses. For example, new skills should be practiced using a range of relevant discriminative stimuli and response modalities, pre-requisite skills that need to be taught should, in fact, be taught, sufficient practice opportunities should always be provided, and appropriate reinforcement procedures should be implemented to facilitate the emergence of untaught skills for those who are still learning to generalize in this way. In addition to the practical implications of the findings of this review, it is important to consider the implications of the findings for further research particularly, given the limited research conducted in this field to date.

#### 4.5. Recommendations for future research

One of the key recommendations of this review is that further research ensures that sufficient information pertaining to the characteristics of the learners is included. This is particularly important given the variation in the phenotype of individual's with ASD, and also given the variation in the findings in the current research in terms of the likelihood of the emergence of untaught relations. The use of more standardized assessment tools that record the language and cognitive ability of the individual's would be of value, as would more extensive examination of the individual's prior learning history. Another area that may be worthy of investigation is to conduct further research that includes typically developing children or children with disabilities other than autism. This may help to determine whether equivalence performance may be related to the developmental level of the child or whether it is a unique learning difficulty for individuals with ASD.

A second area of importance that requires further investigation is in terms of the utility of this approach across curriculum areas, and developmental domains. This finding is consistent with one of the conclusions of [Rehfeldt \(2011\)](#). If this approach is going to be adopted for use in a variety of contexts then there needs to be empirical support within the literature which demonstrates the application of a stimulus equivalence paradigm across a range of developmental areas. While there is variety in terms of the teaching stimuli utilized in the research to date, none of the studies included here have replicated previous findings in terms of the teaching materials and concepts that were taught. The study by [Miguel et al. \(2009\)](#) would be interesting to replicate or expand upon as they not only investigated the emergence of untaught relations but also the transfer of stimulus control from pictorial to written stimuli in the functional performance of following an activity schedule. Further examination of the use of a stimulus equivalence paradigm to teach functional skills, other academic, daily living, leisure and social skills would greatly enhance our understanding of the utility of this approach.

Another area that would be worthy of further study is the use of a stimulus equivalence procedure to improve the rate of acquisition and generalization of language concepts. The study by [Keintz et al. \(2011\)](#) is a unique example in which this has been investigated, and is a study in need of replication as the emergence of derived verbal responses in the form of tacts, mands and intraverbals has important implications for children with ASD who characteristically, have difficulty in language acquisition and expression. The emergence of mands, tacts and intraverbals has been investigated a lot in the research on derived relational responding ([Murphy & Barnes-Holmes, 2009, 2010](#); [Nuzzolo-Gomez & Greer, 2004](#); [Perez-Gonzalez, Herszlikowicz, & Williams, 2008](#); [Rosales & Rehfeldt, 2007](#); [Sigafos, Doss, & Reichle, 1989](#); [Sigafos, Reichle, Doss, Hall, & Pettitt, 1990](#)) however, it has not been investigated extensively using stimulus equivalence paradigm.

Another area that requires further investigation relates to the teaching context in which stimulus equivalence may apply. For example, when utilized in small-group or whole class instruction. In a study by [Ramirez and Rehfeldt \(2009\)](#) a 9-year old child was taught to match dictated Spanish names to pictures. During this teaching the child's 10-year old brother observed. Both the child who was directly taught, and the child who had observed the teaching demonstrated symmetrical responding by demonstrating oral naming of the picture in Spanish. This finding has major implications for the use of stimulus equivalence in the classroom setting as it demonstrates that a stimulus equivalence teaching paradigm can be applied in a group setting to more efficiently teach new vocabulary. If we can establish the efficacy of this approach within a classroom context then the applications of stimulus equivalence technology are greatly diversified.

Another recommendation resulting from this review is to conduct further investigation into the teaching procedures and variables that may facilitate the emergence of untaught relations. We need to understand these variables in order to effectively program educational interventions that could enhance the likelihood of the emergence of untaught relations and subsequently improve teaching efficiency. Developing a greater understanding of the variables that facilitate the emergence of untaught relations has particular implications for children with special learning needs and/or language limitations. Increasing our understanding in this area will enable teachers to implement strategies that will facilitate the emergence of untaught skills, subsequently increasing the utility of this approach and ultimately, leading to more efficient teaching.

Very few studies have also examined the retention of equivalence classes that have emerged following teaching. In fact none of the studies reviewed here have done this. [Rehfeldt and Hayes \(2000\)](#) investigated the generalization and retention of

equivalence classes and found that while most individuals retained the acquired equivalence classes this was not the case for all individuals (Rehfeldt and Hayes, 2000) and not all generalized symmetrical and equivalence relations were retained for all participants. The fact derived responses may not always be retained suggests that we need to investigate conditions which may need to conduct further investigation into conditions which may facilitate this.

Finally, further investigation in this area may also help to establish a more unified field theory which explains the emergence of untaught equivalence relations. There are currently three theories that attempt to explain derived responding. These are Sidman's theory of stimulus equivalence (Sidman, 1994), relational frame theory (Hayes et al., 2001) and naming theory (Horne & Lowe, 1996). Each of these attempts to clarify the variables that account for derived responding. However, we still do not completely understand the processes involved, or the mediating processes responsible for the emergence of derived responses and none of these three theories provide a conclusive explanation for each of the findings obtained in this study. If we are to effectively apply this teaching paradigm then we need a better understanding of the conditions responsible for this type of generalization.

## Conflict of interest

The authors report that there is no conflict of interest. It is solely the authors who are responsible for the writing of this paper and its content.

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