Perspect Behav Sci (2018) 41:69–93
https://doi.org/10.1007/s40614-017-0134-5

Meaningful Stimuli and the Enhancement of Equivalence Class Formation

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Published online: 27 December 2017

Abstract Stimulus meaningfulness has been defined by its hedonic valence, denotative (definitional) and connotative (evaluative) properties, and its influence on forming categories called equivalence classes. Positive or negative hedonic value of a meaningful stimulus transfers to the other members of an equivalence class that contains such a stimulus, and also influences likelihood of class formation. The denotative and connotative properties of meaningful stimuli are instantiated by the responses they produced (simple discriminative functions) and by the selection of other related words (conditional discriminative functions). If a meaningless cue acquires one such stimulus control function, and is included in a set of otherwise meaningless stimuli, its inclusion enhances the formation of an equivalence class. These results suggest ways to enhance equivalence class formation in applied settings. When degree of enhancement matches that produced by the inclusion of a meaningful stimulus in a class, class enhancement can be accounted for by the stimulus control functions it serves, as well as its hedonic, denotative, and connotative properties. We also linked equivalence class formation and meaningfulness to semantic networks, relational frame theory, verbal behavior, and naming.

Keywords Equivalence classes · Meaningfulness · Enhancement · Stimulus control functions · Connotation · Denotation · Hedonic value

Overview

On a commonsensical level, the meaning of an event, word, or stimulus can be instantiated by other words, phrases, thoughts, feelings, images, and actions evoked

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by the event (Russell, 1950; Ryle, 1949). On a more operational level, the meaning of a stimulus has been defined in terms of its hedonic properties and its connotative and denotative values (Sommerville & Whissell, 1994). The hedonic value of a meaningful stimulus reflects its attractant and/or repellent properties. The denotative property of a meaningful stimulus specifies its defining features. The connotative property of a stimulus specifies its emotional and evaluative features (Bortoloti & de Rose, 2009, 2011).

This article considers how the hedonic and connotative properties of a meaningful stimulus will generalize to all of the initially meaningless stimuli in an equivalence class that also includes the meaningful stimulus. The meaningfulness of a stimulus can also be defined functionally. This article, then, also considers how its inclusion in a set of otherwise meaningless stimuli can enhance the formation of equivalence classes of which it is a member. In addition, the article presents data that show how the class-enhancing effect of a meaningful stimulus is modulated by its location in the nodal structure of an equivalence class and by its order of introduction while training the baseline relations for a class.

Finally, meaningful stimuli also serve as simple and conditional discriminative stimuli. We will consider how each of these acquired stimulus control functions (ASCFs) can generalize to the other members of an equivalence class and whether inclusion of a meaningful stimulus will enhance the formation of an equivalence class of this set. The accumulated data will support the view that the connotative stimulus control functions and ASCFs served by meaningful stimuli generalize to the members of an equivalence class and also facilitate equivalence class formation. By implication, then, the class-enhancing effects of meaningful stimuli can be attributed to the ASCFs served by the meaningful stimuli along with the hedonic and connotative properties of meaningful stimuli.

Equivalence Classes Defined

Definition

The experiments discussed in this article use equivalence classes to assess the properties of meaningful stimuli. Thus, we begin by characterizing equivalence classes, which are a type of conceptual category, and a model that has been used to account for the development of symbolic behavior (Fields & Verhave, 1987; Sidman, 1994; Sidman & Tailby, 1982). An equivalence class is a finite number of stimuli that do not resemble each other (cannot be arrayed along a physically or psychometrically defined dimension) and become interchangeable after the training of a minimal number of relations among the stimuli in the set. For example, a set of five stimuli can produce 25 stimulus–stimulus relations (N^2) after the training of only four such relations ($N - 1$), each of which is called a baseline relation. The production of class-consistent responding by the 21 remaining untrained relations ($N^2 - N + 1$) would document the transformation of the set into an equivalence class. These latter relations are also called emergent or derived relations. After class formation, a response trained to one class member will also be evoked by, generalize, or transfer to the remaining class members without additional training (Barnes & Keenan, 1993; Belanich & Fields,

2003; Catania, Horne, & Lowe, 1989; Dougher, Augustson, Markham, Greenway, & Wulfert, 1994). Thus, an equivalence class also acts as a response or function transfer network.

Finally, the stimuli in an equivalence class can be viewed as functioning as members of a category if, after forming such a class, the stimuli are clustered in accordance with their presumed class membership (Bousfield, 1953; Lea, 1984). Clustering and sorting tests conducted after equivalence class formation have documented outcomes such as these (Arntzen, Norbom, & Fields, 2015b; Galizio, Stewart, & Pilgrim, 2001). In another study, stimuli were sorted into positions that represented the nodal structure of the underlying equivalence classes (Arntzen, Granmo, & Fields, 2017). The results of these tests imply that the stimuli in an equivalence class can be viewed as being members of a category.

An Example

A concrete example of these definitional matters can be illustrated by considering five representations of the number 4: *four*, *cuatro*, *4*, *IV*, and *xxxx* (four items). Assuming that a participant does not recognize the relatedness of these terms prior to training, an equivalence class can be established by training baseline relations such as four–cuatro, cuatro–4, 4–IV, and IV–xxxx. Thereafter, class formation is assessed by the presentation of the emergent relations that can be derived from the network generated by the baseline relations: cuatro–four, 4–cuatro, IV–4, xxxx–IV, four–4, four–IV, four–xxxx, 4–four, IV–four, xxxx–four, cuatro–IV, cuatro–xxxx, IV–cuatro, xxxx–cuatro, 4–xxxx, and xxxx–4. If probes for all of these emergent relations result in the selection of the second stimulus when presented with the first (this is termed "class-consistent responding"), then all of the stimuli would be interrelated, and that would document the formation of an equivalence class. After class formation, if a participant is trained to say "/FAWR/" when presented with 4, she would also say "/FAWR/" when presented with four, IV, and xxxx; these emergent discriminative performances would show that the equivalence class was acting as a response transfer network.

Equivalence-Based Accounts of Complex Cognitive Performances

In combination with other behavioral processes such as generalization and contextual control of class membership, equivalence classes produce complex emergent performances like those that characterize many higher level cognitive processes. Some of these are the extension of responding to stimuli that resemble those used in training (Fields & Moss, 2008; Galizio et al., 2001; Galizio, Stewart, & Pilgrim, 2004; Rehfeldt & Root, 2004), symbolic representation, semantics (Sidman, 1994, 2000), syntax (Lazar & Kotlarchyk, 1986; Mackay & Fields, 2009), and the higher order classification of symbols (Bush, Sidman, & de Rose, 1989; de Rosse & Fields, 2010).

Formal Representation

The aforementioned equivalence class was illustrated with actual stimuli. Equivalence class experiments, however, are usually constructed with abstract shapes or nonsense words (ABS), and these class members are usually referred to with letters such as *A*, *B*,

C, *D*, and *E*. Thus, in the example just presented, the stimuli *four*, *cuatro*, *4*, *IV*, and *xxxx* could be represented by the letters *A*, *B*, *C*, *D*, and *E*, respectively, with the baseline relations being AB, BC, CD, and DE and the emergent relations being AE, EA, BD, DB, DC, ED, and so on.

Furthermore, the set of baseline relations also define the nodal structure of the to-be-formed class (Fields & Verhave, 1987). In this example, the baseline relations AB, BC, CD, and DE would produce a class that has a structure represented as A → B → C → D → E, where the B, C, and D stimuli are "nodes" and the A and E stimuli are "singles" (Fields & Verhave, 1987). Thus, the stimuli in the class are separated by differing numbers of nodal stimuli; A and C would be separated by one node (B), whereas the A and E stimuli would be separated by three nodes (B, C, and D). This information will be used to interpret the outcomes of a number of experiments to be presented later.

Training and Testing Protocol

To determine whether the inclusion of meaningful stimuli can enhance class formation, it is necessary to use a training and testing protocol that minimizes the likelihood of class formation (i.e., that produces low yields) when administered alone and is also sensitive to other variables that increase yield. The simultaneous protocol meets this need (Fields, Landon-Jimenez, Buffington, & Adams, 1995; Imam, 2006) and involves the training of all baseline relations before assessing for class formation with the administration of all the emergent relations probes in the same test block. When the simultaneous protocol is used, the likelihood of equivalence class formation is very low, particularly when used to establish relatively large multinodal equivalence classes: yields of 0% to 15% for three-node, five-member classes (Buffington, Fields, & Adams, 1997) and increases with reduction in class size (e.g., Arntzen, Grondahl, & Eilifsen, 2010; Arntzen & Hansen, 2011). Other experiments have shown that the prior establishment of one set of five-member equivalence classes (ABCDE) using the simultaneous protocol can be enhanced by the prior establishment of other equivalence classes using the simple-to-complex protocol (Fields, Adams, & Verhave, 1993). For example, the likelihood of forming ABCDE classes under the simultaneous protocol was a linear function of size and a nodal number of previously established three-, five-, or seven-member classes that contained one, three, or five nodal stimuli (Fields et al., 2000). Similar findings were reported in other studies (Buffington et al., 1997; Fields et al., 1997). Because the simultaneous protocol produces low yields when used alone and is sensitive to variables that enhance the likelihood of class formation, we used it to study the class-enhancing effects of meaningful stimuli on equivalence class formation.

Generalization of "Meaning" to Class Members

Generalization of Connotative Value to Class Members

Bortoloti and de Rose (2009, 2011) showed the transfer of connotative value among the members of an equivalence class by use of the semantic differential, a widely used psychometric instrument initially developed by Osgood, Suci, and Tannenbaum (1957).

This is implemented with the presentation of a word or a picture along with many scales, where the endpoints of each contain two contradictory words that are judgmental or evaluative. A person places an *X* along each scale to indicate perceived affinity to the two anchor words. The connotative meaning of the word or item is indexed by the set of locations of the *X*s on each scale.

The Bortoloti and de Rose (2009) experiment involved the establishment of 3 seven-member equivalence classes, each of which had a structure represented as A ← B → C → D → E → F → G. The B stimuli in the classes were faces and the remaining stimuli were meaningless. In Classes 1, 2, and 3, the faces were angry, neutral, and happy, respectively. The experiment began with the administration of the semantic differential with all of the stimuli in the three classes. The profiles for the angry, neutral, and happy faces (the B stimuli) produced negative, zero, and positive values, respectively, whereas the initially meaningless stimuli (A, C, D, E, F, and G) produced essentially zero profile values. After class formation, the initially meaningless stimuli produced profiles like those produced by the faces in the same class. Thus, the members of an equivalence class acquired the connotative values of the meaningful stimuli that had become members of separate equivalence classes. In addition, the directions of the semantic differential values corresponded to the valences of the faces used as the B stimuli in each class.

This experiment produced another noteworthy outcome. Many experiments have shown that the relatedness of stimuli in an equivalence class is an inverse function of the nodal separation of the stimuli in the class and the type of relation that characterizes any pair of stimuli in the class (Moss-Lourenco & Fields, 2011). In the classes in the present experiment, the D and F stimuli were two and four nodes away from the B stimuli, respectively. In the semantic differentials, the magnitudes of responding produced by the D and F stimuli were inverse functions of the nodal distance that separated each of them from the B stimuli (the facial pictures). Thus, the direction and degree of acquired relatedness were functions of the valences of the meaningful stimuli used as class members and the number of nodes that separated the meaningful stimulus from the other members of the equivalence classes.

Generalization of Connotative Value by Preference Tests

Barnes-Holmes, Keane, Barnes-Holmes, and Smeets (2000) used a preference test to assess the transfer of connotative value by the establishment of 2 three-member equivalence classes, where one included the word *cancer* and the other included the word *holiday*. The other two stimuli in each of the two classes were meaningless nonsense syllables. When shown a pair of nonsense syllables—one from each class—the participants typically selected the one from the *holiday* class instead of the one from the *cancer* class. This experiment, then, used a preference test to document the generalization of connotative value from a meaningful stimulus to the other initially meaningless stimulus in the same equivalence class.

Arntzen, Fagerstrøm, and Foxall (2016b) also used preference testing to assess the transfer of connotative value. In their study, three equivalence classes were formed from meaningless stimuli, after which a picture of a smiling, neutral, or sour face became an additional member of one of the classes. When shown bottles of water that had labels from one of the classes, participants showed a preference for the water that

had a label from the class that also contained the smiling face. This experiment also used a preference test to demonstrate the generalization of connotative value among the members of an equivalence class. Finally, this experiment was replicated with class members that were other pictures (Arntzen, Eilertsen, & Fagerstrøm, 2016a).

Most recently, Mizael, de Almeida, Silviera, and de Rose (2016) showed how a proxy for racial bias could be reduced by equivalence class formation. Typically functioning children were selected because of their racial bias against people of color, as measured by ratings on the Self-Assessment Manikin (SAM) test. Thereafter, the children were given equivalence class training that associated pictures of faces of Black individuals (A) with abstract shapes (B) and the B stimuli with symbols that represented positive social status (C). After equivalence training, the SAM test was readministered, at which time the faces produced positive rankings akin to those produced by socially acceptable pictures of faces of White people. Thus, equivalence-induced changes in valence reduced the ranking of racial prejudice in children.

Summary

These experiments showed that the hedonic and connotative properties of a meaningful stimulus are extended to the other initially meaningless stimuli in an equivalence class that contains the meaningful stimulus. In addition, that extension is influenced by the nodal structure of the emergent classes. Finally, the valence acquired by the members on an equivalence class influences performances in settings that are distinct from the classes themselves.

Class Enhancement by Meaningful Stimuli

The previous section showed how the hedonic and connotative properties of a meaningful stimulus generalized to the other members of an equivalence class. Those studies, however, did not measure whether the inclusion of a meaningful stimulus in an equivalence class influenced the likelihood of forming those classes. That is the focus of the present section.

Class Enhancement by all Meaningful Stimuli

If all of the stimuli in a potential class are meaningful (have neutral or positive valences) but are not related to each other pre-experimentally, the likelihood of class formation can be quite high when compared to the formation of classes that contain meaningless stimuli only (Bentall, Dickins, & Fox, 1993; Dickins, Bentall, & Smith, 1993). In contrast, other studies have found that when a class contained stimuli with conflicting valences (e.g., Protestant and Catholic names presented to people in Northern Ireland during the Troubles or happy and sad faces for people with depression), yields were lower than those found with classes that did not have these conflicting stimuli as class members (Grehan, 1998; Leslie et al., 1993; McGlinchey & Keenan, 1997; Peoples, Tierney, Bracken, & McKay, 1998; Plaud, 1995; Tyndall, Roche, & James, 2009; Watt, Keenan, Barnes, & Cairns, 1991).

Class Enhancement by one Meaningful Stimulus In other experiments, only one of the stimuli in a class was meaningful and the others were meaningless. Arntzen (2004); Arntzen and Lian (2010); Arntzen and Nikolaisen (2011); Fields, Arntzen, Nartey, and Eilifsen (2012); Holth and Arntzen (1998); and Nedelcu, Fields, and Arntzen (2015) all found enhanced likelihood of equivalence class formation when only one meaningful picture was included in a set of otherwise meaningless stimuli. Thus, class enhancement was accomplished by the inclusion of just one meaningful stimulus in a set of otherwise meaningless stimuli.

Modulating the Class-Enhancing Effect of a Meaningful Stimulus

Is the class-enhancing effect of a meaningful stimulus a constant, or can it be modulated by aspects of the classes being formed and the protocol used for training and testing? When an equivalence class is formed, it will have a particular nodal structure (Fields & Verhave, 1987). Thus, a five-member class established by training the baseline relations AB, BC, CD, and DE would have a nodal structure depicted as A → B → C → D → E. If the class contains four meaningless stimuli and one meaningful stimulus, the latter can be assigned to any location in the class: A, B, C, D, or E.

If all of the stimuli in an equivalence class are interchangeable, as claimed (Dube & McIlvane, 1996; McIlvane & Dube, 2003; Sidman, 2000), the location of the meaningful stimulus in the class should not influence the class-enhancing effect of the meaningful stimulus; class enhancement should be constant regardless of the nodal location in the class's structure. On the other hand, numerous experiments have shown that the stimuli in an equivalence class are differentially related to each other (Doran & Fields, 2012; Fields et al., 1995; Moss-Lourenco & Fields, 2011). These data, then, suggest that the class-enhancing effects of a meaningful stimulus might be modulated by its location in a to-be-formed class. These issues were addressed in two experiments reported by Nartey, Arntzen, and Fields (2014, 2015a).

Experiment 1 began with the serial training of the baseline relations AB first, BC second, CD third, and DE last to establish a three-node, five-member class with an A → B → C → D → E structure. Four of the five stimuli were abstract shapes and one was a picture. In two groups, the picture was used as the A or E stimulus in the class. Equivalence classes were formed with a higher likelihood when the meaningful term served as the A stimulus instead of the E stimulus in the class. Thus, class enhancement was not a constant property of the meaningful stimuli. Rather, it was modulated by the nodal location of a meaningful stimulus in an equivalence class.

Experiment 2 replicated Experiment 1 with one exception: The baseline relations were trained concurrently rather than serially, and equivalence classes were not formed by most of the participants in either condition. Thus, the class-enhancing effect of meaningful stimuli was also modulated by the order in which the meaningful stimuli were introduced in training. Finally, the yields obtained when the meaningful cue was used as the A stimulus in the class were very similar to the yield reported by Fields et al. (2012) when the meaningful cue was used as the C stimulus in a class with the same size and nodal structure. The effect of using the meaningful cue in the other locations—B and D—was not studied.

Following these findings, Nartey, Arntzen, and Fields (2015b) then explored whether the class-enhancing effects of a meaningful cue could be modulated by the assignment of the meaningful stimulus to each of the possible locations in an equivalence class. As in Nartey et al. (2014), Nartey et al. (2015b) began Experiment 1 with the serial training of the baseline relations AB first, BC second, CD third, and DE last to establish a three-node, five-member class with an A → B → C → D → E structure. Four of the five stimuli were abstract shapes and one was a picture. In different groups, the picture was used as the A, B, C, D, or E stimulus in the class.

The following results were obtained when the meaningful stimulus was presented in each location in the class. Yields were equally high when the pictures served as the A or C stimulus in the classes, were lower but equal to each other when the picture served as the B or D stimulus in the classes, and were very low when the pictures served as the E stimulus in the classes. Indeed, the low E yield was the same as that seen in the ABS groups (abstract) in other experiments. An ABS group is one in which all of the class members consist of abstract shapes or other meaningless stimuli. Rather than being a constant, the class-enhancing effect of a meaningful stimulus was modulated by its location in the nodal structure of the class, and class enhancement was a nonlinear function of location. This nonlinearity is correlated with the number and types of stimuli each class member is associated with by training.

Because the baseline relations were trained in a serial order, the order of introducing the meaningful stimulus was confounded with its location in the nodal structure of the class. Thus, class enhancement might have been influenced by order of introduction instead of or in addition to nodal location. This possibility was evaluated in Experiment 2, which replicated Experiment 1 with one exception: The baseline relations were trained on a concurrent basis instead of a serial basis.

The following results were obtained when the meaningful stimulus was presented in each location in the class after serial or concurrent training of the baseline relations. For each location in the class, much lower yields were produced after the concurrent training of the baseline relations than after the serial training of the relations. Thus, the order of introducing the meaningful stimulus during training modulated the class-enhancing effect of a meaningful stimulus. The pattern of yields was the same regardless of serial or concurrent training of the baseline relations: highest when the meaningful pictures served as the A and C stimuli, lower when they served as the B and D stimuli, and lowest when they served as the E stimulus. To summarize, the class-enhancing effect of a meaningful stimulus is not constant; rather, it is modulated jointly by the location of a meaningful stimulus in the structure of an equivalence class and the order of introducing that stimulus during the training of the baseline relations for the class. Of these two variables, the order of introduction modulates class enhancement more than location in a class. These data also support the view that all of the stimuli in an equivalence class are not equally related to each other (Bortoloti & de Rose, 2009, 2011; Doran & Fields, 2012; Kennedy, 1991; Moss-Lourenco & Fields, 2011).

Proportion of Meaningful Stimuli in an Equivalence Class

In the aforementioned experiments, when an equivalence class contained only one meaningful stimulus, all reported submaximal levels of class enhancement. An equivalence class, however, can include more than one meaningful stimulus. Thus, it is

plausible to assume that increasing the number or proportion of meaningful stimuli as potential class members should increase the likelihood of class formation, perhaps to a maximal degree.

The effect of such a condition can be gleaned by considering the outcomes reported in the growing literature that deals with the use of equivalence-based instruction to establish academically relevant categories such as representations of neural structures (Fienup, Covey, & Critchfield, 2010; Reyes-Giordano & Fienup, 2015), statistical interactions (Fields et al., 2009), developmental disabilities (Walker, Rehfeldt, & Ninness, 2010), or types of trees (Arntzen, Halstadtro, Bjerke, Wittner, & Kristiansen, 2014a). In all of these experiments, all of the stimuli in the to-be-formed classes were nominally meaningful stimuli but were not related to each other prior to training. At the end of training and testing, the classes were formed by almost all participants in all of these experiments. Thus, the inclusion of all meaningful stimuli in a class should maximize the likelihood of class formation. At this time, however, we do not know the minimum proportion of meaningful stimuli in a set that would be needed to guarantee the formation of equivalence classes. This information also has the following implications for the equivalence class of "fourness" presented in the An Example section. The likelihood of forming the equivalence class of representations of "fourness" should be a direct function of the number of these representations that had some pre-experimentally established degree of meaningfulness.

Summary

A meaningful stimulus has hedonic and connotative values. When it is included in a set of other meaningless stimuli and all of them come to function as members of an equivalence class, the hedonic and connotative values of the meaningful stimulus generalize to the other members of the class. In addition, the inclusion of a meaningful stimulus in a set of otherwise meaningless stimuli enhances the likelihood of class formation by the stimuli in the set. Finally, the class-enhancing effect of a meaningful stimulus is not a constant; rather, it is modulated by its order of introduction during training and by its location in the nodal structure of the class. These variables, however, do not exhaust the possible effects of class structure on the effects of meaningful stimuli on class enhancement.

For example, an equivalence class can be of any size. When training and testing are conducted using the simultaneous protocol, the likelihood of class formation is an inverse function of class size (Fields et al., 1997). These results suggest that the size of a to-be-formed equivalence class might also modulate the class-enhancing effect of meaningful stimuli. For any proportion of meaningful stimuli in a class, they can be distributed in many ways within the nodal structure of the class. This, too, might influence the effect of their presence on the likelihood of class formation. Experiments that systematically explore the effects of variables such as these would extend our understanding of other modulatory effects of class structure and stimulus meaningfulness on likelihood of class formation.

Stimulus Control Functions of Meaningful Stimuli

As shown in Table 1, stimulus meaningfulness is defined by the stimulus's denotative and connotative properties. The denotative properties of a meaningful stimulus specify its defining features. The connotative properties of a stimulus specify its emotional and evaluative features. Any denotative or connotative property of a meaningful stimulus can be manifested in three ways, with all three listed in Table 1. First, a meaningful term can produce spoken or written words or phrases that designate its defining or evaluative properties. These stimulus–response relations are also called simple discriminative functions. These simple discriminative functions are of two forms. A simple successive discriminative function involves the presentation of a single stimulus that occasions the reinforcement of a topographically defined response, such as saying a word, pressing a key, writing a letter, or drawing a symbol. A simple simultaneous discriminative function involves the presentation of at least two stimuli concurrently where only one would occasion the presentation of a reinforcer: For example, reinforcement of the selection of a circle when presented with an array that contains a circle, a square, and a picture of a cat. In addition, each of these simple discriminative functions could be overtrained to varying degrees.

Second, the meaningful term can be related to other words or phrases that designate its defining or evaluative features. These stimulus–stimulus relations are also called conditional discriminative functions and have two forms. They can be a member of an identity conditional relation—if A, select A—or they can be a member of an arbitrary conditional relation—if A, select B. For either type of conditional discrimination, it can be established where both stimuli are concurrently present when a response is required of a participant—a so-called simultaneous conditional relation—or both stimuli can be presented with no temporal overlap—a so-called delayed conditional discrimination.

Finally, a meaningful stimulus can be a member of some type of conceptual category, of which there are three: equivalence classes, resemblance-based classes that are also called perceptual classes, or naturally occurring categories that are also called "natural kinds" (Gelman, 1988) or generalized equivalence classes (Adams, Fields, & Verhave, 1993; Fields, 2009; Fields & Reeve, 2000, 2001; Fields, Reeve, Adams, & Verhave, 1991; Galizio et al., 2004). This section considers how some of these ASCFs influence the formation of an equivalence class.

As noted previously, a neutral stimulus can acquire discriminative or conditional discriminative functions. If such a stimulus is then included in a set of other initially meaningless stimuli, will its inclusion increase the likelihood of class formation by the set? This question can be evaluated for each such function by using an experiment that contains at

Table 1 Functions Served by Meaningful Stimuli

Meaningfulness
Hedonic: attractant/repellent
Denotative: definitional
Connotative: evaluative
Stimulus control functions
Simple discriminative
Conditional discriminative

least three groups; this is outlined in Table 2. In an ABS group (abstract), participants would be trained to form equivalence classes that contain abstract or meaningless stimuli only. In a PIC group, participants would be trained to form equivalence classes that contain all meaningless stimuli along with one meaningful stimulus, such as a picture of a common object recognized by all individuals. In an ASCF group, classes would be formed with meaningless stimuli only, but only after one of the stimuli acquired a discriminative or conditional discriminative function by direct training.

The class-enhancing effects of acquiring a stimulus control function would be determined by comparing the yields produced by the three groups. First, it is assumed that the PIC group will produce a much greater yield than that produced by the ABS group. This would document the class-enhancing effect of including a meaningful stimulus as a member of an equivalence class.

If the same yields were produced by the ABS and ASCF groups, the previously acquired stimulus control repertoire and its establishing contingencies would not have enhanced the formation of equivalence classes. Assuming that meaningful stimuli probably serve these functions, by implication, they would not account for the class-enhancing effect produced by a meaningful stimulus.

If the yields of the PIC and ASCF groups were the same, the previously established stimulus control repertoire and its establishing contingencies could account for the enhanced formation of equivalence classes. Assuming that meaningful stimuli probably serve these functions, by implication, they would account completely for the class-enhancing effect produced by a meaningful stimulus.

If the yield of the ASCF group were to fall between those produced by the PIC and ABS groups, the previously established stimulus control repertoire and its establishing contingencies would account for a portion of the class-enhancing effects of a meaningful stimulus. Which of these outcomes have been documented experimentally, and for which of the ASCFs?

Simple Discriminative Functions

The first study to use such an approach was conducted by Tyndall, Roche, and James (2004). They showed that the establishment of simple discriminative functions by all of

Table 2 Research Strategy for Assessing the Class-Enhancing Effect of Meaningful Stimuli and Acquired Stimulus Control Functions Along With Potential Outcomes and Interpretations

Stimuli	Pairings	Yields
ABS	AA–BA–CA–DA–EA	Low
ASCF	AA–BA–CF–DA–EA	Unknown
PIC	AA–BA–CM–DA–EA	High
Possible outcomes		
ASCF = ABS		
ASCF = PIC		
ABS < ASCF < PIC		

Note. ABS = abstract; ASCF = acquired stimulus control function; PIC = picture

the initially meaningless stimuli in two sets resulted in a somewhat greater likelihood of equivalence class formation than that produced by a control group where none of the stimuli acquired preclass formation discriminative functions. That study, however, did not evaluate the minimal condition that might induce class enhancement—training of only one stimulus in a set.

Proof of Concept Fields et al. (2012) trained participants to form three-node, five-member equivalence classes that consisted of four or five meaningless stimuli by training AB, BC, CD, and DE relations. The ABS and PIC conditions were as described previously. The ASCF condition involved the establishment of both simple successive and simultaneous discriminations with the abstract C stimuli (SIM + SUCC). Thereafter, they were included as members of the to-be-formed ABCDE classes.

Under these conditions, the ABS condition produced a low yield (approximately 15%), the PIC condition produced a high yield (approximately 80%), and the SIM + SUCC condition produced an intermediate yield (approximately 50%). The prior establishment of simultaneous and successive discriminations accounted for some of the enhancement effect produced by a meaningful stimulus.

Overtraining of Successive Discriminations As noted previously, in real-world situations, meaningful stimuli most likely occasion a substantial degree of overtraining. Thus, the enhancement of equivalence class formation by a meaningful stimulus could also reflect the overtraining history of the meaningful stimulus. This possibility was explored by Travis, Fields, and Arntzen (2014) in the context of successive discrimination learning. The experiment included five conditions. In the ABS condition, the participants received no simultaneous discrimination training, no successive discrimination training, and obviously no overtraining. In the SIM-only condition, participants received simultaneous discrimination training only with the C stimuli. In the 0-OVR condition, participants received simultaneous and successive discrimination training but no overtraining. In the 100-OVR condition, participants received simultaneous and successive discrimination training followed by 100 overtraining trials of the successive discrimination. In the 500-OVR condition, participants received simultaneous and successive discrimination training followed by 500 overtraining trials of the successive discrimination. In the ABS and PIC conditions—and after preliminary training in the other conditions—participants were trained to form three-node, five-member equivalence classes.

Under these circumstances, the ABS condition produced a low yield and the PIC condition produced a high yield. The establishment of the simultaneous discriminations alone produced a moderate increment in class formation over that produced with no prior training (ABS). The addition of successive discriminations but with no overtraining (0) did not increase the yield to greater than that produced by simultaneous discriminations alone (SIM only).

The amount of overtraining of the successive discriminations produced a nearly linear increase in the likelihood of subsequent equivalence class formation. In addition, the most extreme amount of overtraining produced a yield that was almost equal to that produced by the inclusion of a meaningful stimulus in the classes. Assuming that

overtraining occurs in real-world conditions, overtraining could also account for the class enhancement effects produced by meaningful stimuli.

This possibility, however, does not preclude particular stimulus control functions from influencing class enhancement. Indeed, overtraining can occur in the context of many other stimulus control functions, and each could interact with the degree of overtraining to influence the enhancement of equivalence class formation. Additional research is needed to document how the overtraining of many stimulus control functions can influence the enhancement of equivalence class formation and, by implication, how overtraining that is correlated with meaningful stimuli can account for the enhancement of equivalence class formation. These issues are addressed in the Familiarity and Class Enhancement section.

Successive and Simultaneous Discriminative Functions Travis et al. (2014) explored the effects of prior training of simultaneous discriminations and then the effects of prior training of simultaneous discriminations along with successive discriminations; they did not, however, explore the isolated effects of each discriminative repertoire alone and together. This issue was addressed by Nartey et al. (2015a) in an experiment that contained five conditions.

The ABS and PIC conditions were conducted as described previously. Participants in the SIM-alone condition learned simple C-based simultaneous discriminations, participants in the SUCC-alone condition learned simple C-based successive discriminations, and participants in the SIM + SUCC condition learned both C-based simultaneous and successive discriminations. Each of these conditions ended with the administration of the simultaneous protocol to form the ABCDE equivalence classes.

As in prior experiments, the ABS and PIC conditions produced very low and high yields, respectively. The SIM-only condition produced a yield that was equal to that produced in the ABS condition, indicating that the acquisition of a simultaneous discriminative function was not responsible for enhancement produced by meaningful stimuli. The SUCC-only condition produced a yield that was greater than that produced in the ABS condition but less than that produced by PIC training, which implied that the acquisition of a successive discriminative function could account for a portion of the class enhancement produced by meaningful stimuli.

The combined acquisition of simultaneous and successive discriminations produced a yield that closely approximated that produced by the inclusion of a meaningful stimulus. This combined effect was also substantially greater than the simple sum of the yields produced by the SIM-only and SUCC-only conditions. Although SIM-only training did not enhance class formation itself, its inclusion with SUCC-only training improved the enhancement effect of SUCC-only training. Thus, the acquisition of a simultaneous discriminative function (SIM) had a large synergistic effect on the class enhancement produced by successive training alone (SUCC). Furthermore, the combined acquisition of simultaneous and successive discriminations approximated the class-enhancing effect produced by the inclusion of a meaningful stimulus as a member of an equivalence class.

Conditional Discriminative Functions

In addition to serving simple discriminative functions, meaningful stimuli can also serve conditional discriminative functions that can be identity based, or arbitrary in

format. The following experiments explored the effects of these options. In addition, they were explored in the context of a delay and the number of trained relations.

Arbitrary Conditional Relations Nedelcu et al. (2015) explored the class-enhancing effects of arbitrary conditional discriminative functions along with the number of such relations established during preliminary training. As in the other experiments, participants were trained and tested to form three-node, five-member equivalence classes with A → B → C → D → E structures. The ABS and PIC groups served as reference conditions. The ABS group was also referred to as a GR-0 condition because no conditional relations were established prior to class formation training. In the GR-1 condition, participants learned a CX arbitrary conditional discrimination. In the GR-5 condition, participants learned five arbitrary conditional discriminations that included the C stimuli: CV, CW, CX, CY, and CZ, where the V–Z and A–E stimuli were all meaningless nonsense syllables.

Under these circumstances, the ABS and PIC groups produced expected low and high yields, respectively. The ABS condition did not involve the establishment of any conditional discriminations before the training of the equivalence classes. Thus, it can be viewed as a zero training condition with respect to the number of conditional discriminations trained prior to class formation training. The training of one arbitrary conditional relation prior to class formation training produced a small increase in yield relative to the ABS (or zero) condition. In contrast, the prior establishment of five arbitrary conditional relations produced a large enhancement effect. When these three conditions were viewed together, the likelihood of equivalence class formation approximated a linear direct function of the number of arbitrary conditional relations acquired before the training of the ABCDE classes. Finally, the yield obtained after learning five arbitrary conditional relations was similar to the yield produced when the class contained a meaningful stimulus as the C member of the class.

It is likely that a meaningful stimulus serves as a member of many arbitrary relations. Thus, the results of the present experiment suggest that the class-enhancing effect of a meaningful stimulus probably reflects the presumed number of arbitrary conditional discriminative functions served by that meaningful stimulus.

Identity Relations and Delay The prior experiment explored class enhancement following the formation of arbitrary conditional relations (select X given C). Conditional relations, however, can also be identity based (select C given C). In addition, any conditional relation can be established with or without a time delay between the offset of a sample stimulus and the onset of a comparison stimulus. Thus, Arntzen, Nartey, and Fields (2014b) explored how the enhancement of a three-node, five-member ABCDE equivalence class was influenced by the prior establishment of an identity conditional relation by the C stimuli. Conditional relations can also be established in a simultaneous format where the sample and comparison stimuli are concurrently present in a trial or in a delayed format where the sample stimulus is extinguished before the presentation of the comparison in a trial. This experiment, then, also explored how delay influenced class enhancement.

The experiment contained four conditions: ABS, PIC, ID-S, and ID-D. The ABS and PIC conditions were the same as those described in prior experiments. In the ID-S group, class formation training was preceded with the establishment of identity

conditional discriminations using the C stimuli (C → C), with trials administered in a simultaneous matching-to-same format. In the ID-6s group, class formation training was preceded with the establishment of identity conditional discriminations using the C stimuli, with trials administered in a delay format in which comparison onset followed sample offset after 6 s. In addition, we conducted a preclass formation sorting test (presort) and a postclass formation sorting test (postsort). These tests involved the presentation of cards that contained each of the prospective class members with a request for the participant to stack them into related groups.

Under these circumstances, in the presorting tests, all of the participants in all groups did not stack the stimulus cards in accordance with the experimentally defined classes. Thus, the classes did not exist prior to training. It follows that the yields obtained after exposure to the simultaneous protocol could be attributed to the preliminary training conducted in each group.

When the results of the derived relations tests were considered (middle bars in each cluster), low and high yields were obtained when the classes contained no meaningful stimuli and one meaningful picture: in the ABS and PIC conditions, respectively. After forming the identity relations on a simultaneous basis, none of the participants formed the equivalence classes. In contrast, after learning the identity relations in a delayed format, an intermediate percentage of participants then formed the equivalence classes. Thus, the prior establishment of identity relations influenced the enhancement of subsequent formation of equivalence classes. In addition, delay included in these identity relations played a prominent role in class enhancement. It is plausible to assume that meaningful stimuli also serve delayed identity functions in real-world settings. Therefore, a portion of the class enhancement produced by meaningful stimuli can be attributed to the delayed identity functions served by meaningful stimuli.

Finally, the postclass formation sorting tests (rightmost bar per cluster) produced yields that were very similar to those obtained in the derived relations tests for each experimental condition. This concordance demonstrated that the presence of the equivalence classes was not dependent on only one form of testing; rather, it was somewhat independent of the mode of evaluation.

Combined Effects of Relational Type and Delay The prior experiment documented the effect of delay on class enhancement in the context of identity relations. Nedelcu et al. (2015) explored the effects of arbitrary relations on class enhancement, but in the absence of delays. Would the effect of delay on class enhancement be similar if the delay was manipulated in the context of learning arbitrary relations? Arntzen, Nartey, and Fields (2015a) addressed this question using the factorial manipulation of delay duration and relational type. Six conditions were studied. The ABS and PIC groups were as described in the prior experiments. In the ARB-S and ID-S groups, arbitrary or identity relations were established during preliminary training that used a simultaneous format. In the ARB-D and ID-D groups, the same ARB and ID relations were formed but with 6-s delays. After the successful completion of preliminary training, all participants were tested for the same three-node, five-member classes as the participants in the ABS condition.

Under these circumstances, the likelihood of equivalence class formation was much greater in the PIC condition than in the ABS condition—when a class contained one meaningful stimulus instead of no meaningful stimuli. Indeed, no participants formed

classes in the ABS condition. The preclass formation of ID relations established with no delay (simultaneous) produced a 10% increment in class formation relative to the ABS condition, whereas the establishment of the ARB relations with no delay produced a yield that was somewhat greater than that produced by the prior establishment of the identity relations. The preclass formation of ID and ARB relations with 6-s delays produced large increments in equivalence class formation relative to the yields in the ABS condition and the simultaneous conditions. Once again, the likelihood of class formation was 10% greater after the establishment of ARB relations relative to ID relations when both were established with 6-s delays. In addition to replicating the results obtained in the previously described experiment, enhanced equivalence class formation was an additive function of delay and relational type. By implication, the class-enhancing effect of a meaningful stimulus would also reflect the presumed arbitrary and identity conditional discriminative functions and delays served by them.

General Issues

Extending the Current Analysis

Synopsis Some of the experiments reviewed in this article showed that the connotative property of a meaningful stimulus that is a member of an equivalence class will generalize to the other members of the class. In addition, when a meaningful stimulus is included as a member of a to-be-formed class, its class-enhancing effect is not constant; rather, it is modulated by the location of the stimulus in the nodal structure of the class and by its order of introduction while training the baseline relations. The remaining experiments found that the class-enhancing effect of an initially meaningless stimulus is influenced by the preclass formation acquisition of a number of stimulus control functions that include simple successive and simultaneous discriminative functions as well as identity and arbitrary conditional discriminative functions. Further, equivalence class formation was enhanced by the overtraining of the successive discriminative function and by the delays that characterized the conditional discriminative functions.

Yield and Other Measures of Equivalence All of these findings were based on the use of yield as the dependent variable: the percentage of participants in a group who showed the emergence of the targeted equivalence classes. Yield, then, has been rather productive in disclosing a range of independent variables that influenced the formation of equivalence classes. Because of its molar properties, however, yield is not sensitive to the more subtle properties of the stimuli in an equivalence class, such as their differential relatedness (Fields, 2015).

Although these effects cannot be tracked with yield, they can be measured with other trial-by-trial-based procedures, one of which involves the use of within-class preference tests conducted after class formation (Doran & Fields, 2012; Moss-Lourenco & Fields, 2011). Would, then, the degree of differential relatedness of class members also be influenced by meaningful stimuli and the stimulus control functions acquired by a class member? Regardless of the outcome of experiments that explored this possibility, the

results based on yield and within-class preference tests would be complementary rather than exclusionary and would broaden our understanding of the effects of meaningful stimuli and ASCFs on equivalence class formation and the relational properties of the stimuli in such a class.

Generality of Class Enhancement All of the reviewed experiments were conducted using very similar design parameters. Thus, the generality of these findings can be addressed by conducting systematic replications that vary the many parameters used in the experiments. For example, if a given stimulus control function were to be acquired by one initially meaningless stimulus, its effect on class enhancement might be influenced by the size of the stimuli in the class and/or by the class's nodal structure. Additionally, the magnitude of class enhancement could also be influenced by the number of different stimulus control functions acquired by one of the initially meaningless stimuli in the class, which is probably the case with meaningful stimuli.

Stimulus Control Functions, Hedonics, Connotation, and Denotation We argued that meaningful stimuli serve discriminative and conditional discriminative functions in addition to being members of other stimulus classes. Based on the results of the experiments summarized in this article, the enhancement of equivalence class formation by the inclusion of a meaningful stimulus can be accounted for by the ASCFs served by that stimulus. In part, then, class enhancement can be accounted for independent of the content and/or the prior associations of a meaningful stimulus, the latter of which are instantiated by their hedonic, denotative, and connotative properties.

These conclusions, however, do not imply that the class-enhancing property of a meaningful stimulus is not also influenced by its hedonic, denotative, and connotative properties. Rather, it is probable that these latter properties influence the ability of a meaningful stimulus to enhance the likelihood of equivalence class formation in combination with its ASCFs. Although not yet tested, this notion can be evaluated by comparing the class-enhancing effects of an initially meaningless stimulus on class formation after it has acquired *various combinations* of the contingency-driven relations in combination with hedonic, denotative, and connotative factors.

For example, 40% of participants might form a five-node, seven-member class (e.g., A → B → C → D → E → F → G) when the D stimulus (e.g., XUB) had previously become a member of an arbitrary conditional discrimination consisting of two abstract stimuli (e.g., XUB → ZOV), whereas 85% of participants might form the same class when the D stimulus had previously become related to a picture of a well-known puppet such as Big Bird (XUB → BIG BIRD). The greater yield produced by the latter condition would be attributed to the many real-world associates of BIG BIRD but were associates of ZOV. Such an outcome, then, would show how the class-enhancing property of a meaningful stimulus would be determined both by its ASCFs and by the contents of its associates.

Familiarity and Class Enhancement In all of the studies reviewed in this article, an initially meaningless stimulus acquired some stimulus control function by use of differential reinforcement. Thereafter, the class-enhancing effect produced by that stimulus was attributed to its ASCFs. Of necessity, however, that stimulus was presented many times prior to being included in the to-be-formed equivalence classes.

Thus, the reported class enhancement effects could have been induced solely by an exposure-induced increase in the familiarity with the designated stimulus (Hall, 1980; Lubow, Rifkin, & Alex, 1976)—an effect that could be independent of response-contingent reinforcement. Indeed, Lubow et al. (1976) also noted that under other circumstances, an opposite effect has been observed; this is called latent inhibition. Additional experiments would be needed to evaluate this notion in the context of equivalence class formation.

Meaning and Class Enhancement in a Broader Context

Enhancement by Stimuli Belonging to Many Classes: Context and Classification Debussy, Gershwin, Voltaire, and Steinbeck can be classified by nationality and/or vocation. Classification of the stimuli by each property can be controlled by contextual stimuli that direct attention to nationality and/or vocation and has been documented in a number of studies that have simulated the process with abstract stimuli (Bush et al., 1989; de Rosse & Fields, 2010; Griffee & Dougher, 2002; Meehan & Fields, 1995; Steele & Hayes, 1991). The stimulus control functions acquired by the stimuli are more complex than simple or conditional discriminations. Thus, this more complex level of stimulus control might also influence their ability to enhance the formation of new classes of which they are members. To date, however, this has not yet been explored.

Enhancement by Stimuli Belonging to an Open-Ended Category In our introductory remarks, we noted that meaningful stimuli can serve simple or conditional discriminative functions in addition to being members of other categories. The data reviewed in this article summarize the effects of the simple or conditional discriminative functions on class enhancement. No results were presented for class membership because no experiments have as yet been conducted. Clearly, a fuller understanding of class enhancement can be provided by exploring this latter domain. For example, categories can be dimensionally defined, polymorphous (Lea & Harrison, 1978), or fuzzy (Rosch & Mervis, 1975), and each can be established using initially meaningless stimuli by multiple-exemplar training and testing. Thereafter, participants can attempt to form a new equivalence class that does or does not include a stimulus in the newly established category as a member of the to-be-formed class. Our expectation is that the inclusion of such a stimulus will enhance the likelihood of class formation. Further, the degree of enhancement ought to be systematically related to the type and/or breadth of the category established prior to equivalence class formation.

Networks, Meaningfulness, and Class Enhancement In addition to the definitions of meaningfulness described in this article, meaningfulness can also be defined in terms of its membership in a semantic memory network that contains many stimuli and concepts that are related to each other in many ways (Anderson, 1976, 1983, 2007; Collins & Loftus, 1975; Collins & Quillian, 1969). Thus, a "meaningful" word would be linked to many other stimuli based on an interconnection of conceptual categories such as sameness, difference, opposition, part–whole, IS-A or IS-NOT-A relations, and so on. Such a network is a step beyond a definition of meaningfulness defined by

membership of a stimulus in a single category. Thus, it is plausible to assume that the class-enhancing effect of the key stimulus in a semantic network should be proportional to the number of stimuli and relations with which it is linked and that the likelihood of class enhancement should exceed that engendered by membership in a single category only. Such an outcome would also imply that the key stimulus in a semantic or lexical network would be more meaningful than a corresponding stimulus that is a member of a single category.

Relational Frames, Meaningfulness, and Class Enhancement In the aforementioned networks, all of the relations are taken as givens and are assumed to reflect the linguistic norms of a given community. Using essentially meaningless stimuli, Hayes and colleagues began a line of research that is now referred to as relational frame theory (RFT) in which they established networks that were analogous to some of those found in everyday settings (Hayes, 1996; for a comprehensive listing, see Hughes & Barnes-Holmes, 2016). These networks include relational frames that are categories and linkages among the stimuli in different relational frames. All of these were established using multiple-exemplar training, a procedure like that used to establish other categories with nonhuman subjects (Cook, Cavato, & Cavato, 1995; Herrnstein, 1990; Herrnstein, Loveland, & Cable, 1976; Hull, 1920; Wasserman, Kiedinger, & Bhatt, 1988; Wright, Cook, Rivera, Sands, & Delius, 1988).

After the networks were established, the untrained relations that emerged were similar to those observed in corresponding naturally occurring semantic networks. No experiments, however, have yet been conducted to determine whether the key stimulus in such a relational frame network would enhance the formation of new equivalence classes that contained that stimulus as a potential member. Experiments such as these would extend our understanding of the effects of meaningful stimuli and ever-more-complex networks of interrelated categories on the enhancement of equivalence class formation. Thus, the key stimulus in a created network of linked relational frames should be more meaningful than a corresponding stimulus that is a member of a single category (Hayes & Grundt, 1997).

Verbal Behavior and Class Enhancement The meaningfulness of stimuli has also been addressed by Skinner (1957) in his analysis of verbal behavior (VB). Specifically, meaningfulness can be defined by the tact, mand, autoclitic, and intraverbal functions served by a verbal stimulus (Carp & Petursdottir, 2015; Sprinkle & Miguel, 2012). As with network models of meaning, to the best of our knowledge, no studies have been conducted to determine whether the inclusion of a new stimulus that has acquired one or more of these verbal functions would enhance the subsequent formation of new equivalence classes if included as a potential class member. Experiments such as these would allow for an integration of the results described in this article and the class-enhancing properties of verbal stimuli.

Naming, Equivalence, and Class Enhancement In their naming account, Horne and Lowe (1996) proposed that the meaningfulness of a word is defined by its membership in bidirectional S1–S2 and S2–R1 relations that include a term (S1), its referent (S2), and the naming of the term in its presence (R1). They then argued that the establishment of the naming relation (by use of contingencies of reinforcement) provided an

account of equivalence classes and the meaningfulness of stimuli. Many of the experiments conducted in the context of naming have identified parameters that enhance the formation of a naming repertoire. As with the other aforementioned perspectives, we know of no attempts to determine whether the inclusion of a stimulus that acquired a naming function would enhance the formation of a new equivalence class that contained such a stimulus.

The outcome of such an experiment is suggested by considering the fact that the inclusion of a "known" stimulus enhances the likelihood of class formation. It is plausible to assume that a "known" stimulus is the name of an object or event and thus expresses the naming functions identified by Horne and Lowe (1996). As such, naming could account for class enhancement. It follows that an arbitrary stimulus that comes to express the naming function would also enhance the formation of an equivalence class of which it is a member.

Conclusions

Some of the experiments summarized in this article showed that the connotative properties of a meaningful stimulus generalized to the remaining members of an equivalence class that included the meaningful stimulus. In addition, the inclusion of a meaningful stimulus in a set of otherwise meaningless stimuli enhanced the formation of an equivalence class by that set. In addition, the degree of class enhancement was influenced by the location of the meaningful stimuli in the nodal organization of the class (a structural effect) and by its order of introduction during training (a protocol effect).

We also noted that meaningful stimuli serve a range of discriminative and conditional discriminative functions. When one of them was acquired by a meaningless stimulus and that stimulus was then included in a set of other meaningless stimuli, its inclusion enhanced the likelihood of equivalence class formation. In some cases, the level of enhancement matched that produced by the inclusion of a meaningful stimulus as a class member. Thus, the class-enhancing effect of a meaningful stimulus could be accounted for the stimulus control functions served by that meaningful stimulus. Although those outcomes were achieved independent of the hedonic and connotative properties of a meaningful stimulus, those outcomes did not preclude separate effects of the latter properties on the ability of a meaningful stimulus to enhance the formation of new equivalence classes. Additional research is needed to evaluate those possibilities.

In the last section of this article, the context for studying the meaningfulness of a stimulus was broadened to include (a) contextually controlled classification by stimulus properties, (b) semantic memory networks, (c) RFT, and (d) VB and naming theory. Finally, we considered how experiments in these ever-more-complex realms could extend the findings summarized in this article. In essence, the outcomes of experiments such as these would show how the multiplicity of stimulus control functions served by meaningful stimuli differentially enhances the formation of equivalence classes.

Funding This research was funded by the PSC/CUNY Research Awards Program and Oslo and Akershus University College.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human Participants and Animal Studies All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards or were determined to be exempt from review by the committee.

Informed Consent Informed consent was obtained from all individual participants included in the experiments.

References

Adams, B. J., Fields, L., & Verhave, T. (1993). The formation of generalized equivalence classes. *The Psychological Record, 43*, 553–566.

Anderson, J. R. (1976). *Language, memory, and thought*. Mahwah, NJ: Erlbaum.

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Anderson, J. R. (2007). *How can the human mind occur in the physical universe?* New York: Oxford University Press.

Arntzen, E. (2004). Probability of equivalence formation: familiar stimuli and training sequence. *The Psychological Record, 54*, 275–291.

Arntzen, E., Eilertsen, J. M., & Fagerstrøm, A. (2016a). Preferences in equivalence classes by low potency benign valenced stimuli. *European Journal of Behavior Analysis, 17*, 142–153. https://doi.org/10.1080/15021149.2016.1247637.

Arntzen, E., Fagerstrøm, A., & Foxall, G. R. (2016b). Equivalence classes and preferences in consumer choice. In G. R. Foxall (Ed.), *The Routledge companion to consumer behavior analysis* (pp. 65–77). London: Routledge.

Arntzen, E., Granmo, S., & Fields, L. (2017). The relation between sorting tests and matching-to-sample tests in the formation of equivalence classes. *The Psychological Record, 67*, 81–96. https://doi.org/10.1007/s40732-016-0209-9.

Arntzen, E., Grondahl, T., & Eilifsen, C. (2010). The effects of different training structures in the establishment of conditional discriminations and the subsequent performance on the tests for stimulus equivalence. *The Psychological Record, 60*, 437–462.

Arntzen, E., Halstadtro, L. B., Bjerke, E., Wittner, K. J., & Kristiansen, A. (2014a). On the sequential and concurrent presentation of trials establishing prerequisites for emergent relations. *The Behavior Analyst Today, 14*, 23–30.

Arntzen, E., & Hansen, S. (2011). Training structures and the formation of equivalence classes. *European Journal of Behavior Analysis, 12*, 483–503.

Arntzen, E., & Lian, T. (2010). Trained and derived relations with pictures as nodes. *The Psychological Record, 60*, 659–678.

Arntzen, E., Nartey, R. K., & Fields, L. (2014b). Identity and delay functions of meaningful stimuli: enhanced equivalence class formation. *The Psychological Record, 64*, 349–360. https://doi.org/10.1007/s40732-014-0066-3.

Arntzen, E., Nartey, R. K., & Fields, L. (2015a). Enhancing responding in accordance with stimulus equivalence by the delayed and relational properties of meaningful stimuli. *Journal of the Experimental Analysis of Behavior, 103*, 524–541. https://doi.org/10.1002/jeab.152.

Arntzen, E., & Nikolaisen, S. (2011). Establishing equivalence classes in children using familiar and abstract stimuli and many-to-one and one-to-many training structures. *European Journal of Behavior Analysis, 12*, 105–120.

Arntzen, E., Norbom, A., & Fields, L. (2015b). Sorting: an alternative measure of class formation? *The Psychological Record, 65*, 615–625. https://doi.org/10.1007/s40732-015-0132-5.

Barnes, D., & Keenan, M. (1993). A transfer of functions through derived arbitrary and nonarbitrary stimulus relations. *Journal of the Experimental Analysis of Behavior, 59*, 61–81.

Barnes-Holmes, D., Keane, J., Barnes-Holmes, Y., & Smeets, P. M. (2000). A derived transfer of emotive functions as a means of establishing differential preferences for soft drinks. *The Psychological Record, 50*, 493–511.

Belanich, J., & Fields, L. (2003). Generalized equivalence classes as response transfer networks. *The Psychological Record, 53*, 373–413.

Bentall, R. P., Dickins, D. W., & Fox, S. R. A. (1993). Naming and equivalence: response latencies for emergent relations. *The Quarterly Journal of Experimental Psychology B: Comparative and Physiological Psychology, 46B*(2), 187–214.

Bortoloti, R., & de Rose, J. C. C. (2009). Assessment of the relatedness of equivalent stimuli through a semantic differential. *The Psychological Record, 59*, 563–590.

Bortoloti, R., & de Rose, J. C. C. (2011). An "Orwellian" account of stimulus equivalence: are some stimuli "more equivalent" than others? *The European Journal of Behavior Analysis, 12*, 121–134.

Bousfield, W. (1953). The occurrence of clustering in the recall of randomly arranged associates. *Journal of General Psychology, 49*, 229–240.

Buffington, D. M., Fields, L., & Adams, B. J. (1997). Enhancing the formation of equivalence classes by pre-training of other equivalence classes. *The Psychological Record, 47*, 1–20.

Bush, K. M., Sidman, M., & de Rose, T. (1989). Contextual control of emergent equivalence relations. *Journal of the Experimental Analysis of Behavior, 51*, 29–45.

Carp, C. L., & Petursdottir, A. I. (2015). Intraverbal naming and equivalence class formation in children. *Journal of the Experimental Analysis of Behavior, 104*, 223–240.

Catania, A. C., Horne, P., & Lowe, C. F. (1989). Transfer of function across members of an equivalence class. *The Analysis of Verbal Behavior, 7*, 99–110.

Collins, A. M., & Loftus, E. F. (1975). A spreading activation theory of semantic memory. *Psychological Review, 82*, 407–428.

Collins, A. M., & Quillian, M. R. (1969). Retrieval time from semantic memory. *Journal of Verbal Learning and Verbal Behavior, 8*, 240–248.

Cook, R. G., Cavato, K. K., & Cavato, B. R. (1995). Same-different texture discrimination and concept learning by pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 21*, 253–260.

de Rosse, P., & Fields, L. (2010). The contextually controlled, feature-mediated classification of symbols. *Journal of the Experimental Analysis of Behavior, 93*, 225–246.

Dickins, D. W., Bentall, R. P., & Smith, A. B. (1993). The role of individual stimulus names in the emergence of equivalence relations: the effects of interpolated paired-associates training of discordant associations between names. *The Psychological Record, 43*, 713–724.

Doran, E., & Fields, L. (2012). All stimuli are equal, but some are more equal than others: measuring relational preferences within an equivalence class. *Journal of the Experimental Analysis of Behavior, 98*, 243–256.

Dougher, M. J., Augustson, E., Markham, M. R., Greenway, D. E., & Wulfert, E. (1994). The transfer of respondent eliciting and extinction functions through stimulus equivalence classes. *Journal of the Experimental Analysis of Behavior, 62*, 331–351.

Dube, W. V., & McIlvane, W. J. (1996). Some implications of a stimulus control topography analysis for emergence behavior and stimulus classes. In T. R. Zentall & P. M. Smeets (Eds.), *Stimulus class formation in humans and animals* (pp. 197–218). Amsterdam: Elsevier. https://doi.org/10.1016/S0166-4115(06)80110-X.

Fields, L. (2009). The synthesis of complex categories from perceptual and equivalence classes: effects of training and testing parameters. *The European Journal of Behavior Analysis, 10*, 119–142.

Fields, L. (2015). Stimulus relatedness in equivalence classes, perceptual categories, and semantic memory networks. *European Journal of Behavior Analysis, 10*, 205–227.

Fields, L., Adams, B. J., & Verhave, T. (1993). The effects of equivalence class structure on test performances. *The Psychological Record, 43*, 697–712.

Fields, L., Arntzen, E., Nartey, R., & Eilifsen, C. (2012). Effects of a meaningful, a discriminative, and a meaningless stimulus on equivalence class formation. *Journal of the Experimental Analysis of Behavior, 97*, 163–181.

Fields, L., Landon-Jimenez, D. V., Buffington, D. M., & Adams, B. J. (1995). Maintained nodal distance effects after equivalence class formation. *Journal of the Experimental Analysis of Behavior, 64*, 129–146.

Fields, L., & Moss, P. (2008). Formation of partially and fully elaborated generalized equivalence classes. *The Journal of the Experimental Analysis of Behavior, 90*, 135–168.

Fields, L., & Reeve, K. F. (2000). Synthesizing equivalence classes and natural categories from perceptual and relational classes. In J. C. Leslie & D. Blackman (Eds.), *Issues in experimental and applied analyses of human behavior* (pp. 59–84). Reno, NV: Context Press.

Fields, L., & Reeve, K. (2001). A methodological integration of generalized equivalence classes, natural categories, and cross-modal perception. *The Psychological Record, 51*, 67–87.

Fields, L., Reeve, K. F., Adams, B. J., & Verhave, T. (1991). Stimulus generalization and equivalence classes: a model for natural categories. *Journal of the Experimental Analysis of Behavior, 55*, 305–312.

Fields, L., Reeve, K. F., Rosen, D., Varelas, A., Adams, B. J., Belanich, J., & Hobbie, S. A. (1997). Using the simultaneous protocol to study equivalence class formation: the facilitating effects of nodal number and size of previously established equivalence classes. *Journal of the Experimental Analysis of Behavior, 67*, 367–389.

Fields, L., Travis, R., Yadlovker, D. E., Roy, D., de Aguiar-Rocha, L., & Sturmey, P. (2009). Equivalence class formation: a method for teaching statistical interactions. *Journal of Applied Behavior Analysis, 42*, 575–593.

Fields, L., Varelas, A., Reeve, K. F., Belanich, J., Wadhwa, P., DeRosse, P., & Rosen, D. (2000). Effects of prior conditional discrimination training, symmetry, transitivity, and equivalence testing on the emergence of new equivalence classes. *The Psychological Record, 50*, 443–466.

Fields, L., & Verhave, T. (1987). The structure of equivalence classes. *Journal of the Experimental Analysis of Behavior, 48*, 317–332.

Fienup, D. M., Covey, D. P., & Critchfield, T. S. (2010). Teaching brain–behavior relationships economically with stimulus equivalence technology. *Journal of Applied Behavior Analysis, 43*, 19–33.

Galizio, M., Stewart, K. L., & Pilgrim, C. (2001). Clustering in artificial categories: an equivalence analysis. *Psychonomic Bulletin & Review, 8*, 609–614.

Galizio, M., Stewart, K. L., & Pilgrim, C. (2004). Typicality effects in contingency-based generalized equivalence classes. *Journal of the Experimental Analysis of Behavior, 82*, 253–273.

Gelman, S. A. (1988). The development of induction within natural kind and artifact categories. *Cognitive Psychology, 20*, 65–95.

Grehan, P. M. (1998). *Depressed subjects' formation of mood congruent and incongruent equivalence relations* (unpublished doctoral dissertation). Hofstra University, Hempstead, NY.

Griffee, K., & Dougher, M. J. (2002). Contextual control of stimulus generalization and stimulus equivalence in hierarchical categorization. *Journal of the Experimental Analysis of Behavior, 78*, 433–447.

Hall, G. (1980). Exposure learning in animals. *Psychological Bulletin, 88*, 535–550.

Hayes, S. C. (1996). Developing a theory of derived stimulus relations. *Journal of the Experimental Analysis of Behavior, 65*, 309–311.

Hayes, S. C., & Grundt, A. (1997). Metaphor, meaning, and relational frame theory. In C. Mandell & A. McCabe (Eds.), *The problem of meaning: cognitive and behavioral perspectives* (pp. 117–146). New York, NY: Elsevier.

Herrnstein, R. J. (1990). Levels of stimulus control: a functional approach. *Cognition, 37*, 133–166.

Herrnstein, R. J., Loveland, D. H., & Cable, C. (1976). Natural concepts in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 4*, 285–301.

Holth, P., & Arntzen, E. (1998). Stimulus familiarity and the delayed emergence of stimulus equivalence or consistent nonequivalence. *The Psychological Record, 48*, 81–110.

Horne, P. J., & Lowe, C. F. (1996). On the origins of naming and other symbolic behavior. *Journal of the Experimental Analysis of Behavior, 65*, 181–241.

Hughes, S., & Barnes-Holmes, D. (2016). Relational frame theory: the basic account. In R. D. Zettle, S. C. Hayes, D. Barnes-Holmes, & A. Biglan (Eds.), *The Wiley handbook of contextual behavioral science* (pp. 129–178). West Sussex: Wiley-Blackwell.

Hull, C. L. (1920). Quantitative aspects of the evolution of concepts. *Psychological Monographs, 28*, 123.

Imam, A. A. (2006). Experimental control of nodality via equal presentations of conditional discriminations in different equivalence protocols under speed and no-speed conditions. *Journal of the Experimental Analysis of Behavior, 85*, 107–124.

Kennedy, C. H. (1991). Equivalence class formation influenced by the number of nodes separating stimuli. *Behavioural Processes, 24*, 219–245.

Lazar, R. M., & Kotlarchyk, B. J. (1986). Second-order control of sequence-class equivalences in children. *Behavioural Processes, 13*, 205–215.

Lea, S. E. G. (1984). In what sense do pigeons learn concepts? In H. L. Roitblatt, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 263–276). Hillsdale, NJ: Erlbaum.

Lea, S. E. G., & Harrison, S. N. (1978). Discrimination of polymorphous stimulus sets in pigeons. *Quarterly Journal of Experimental Psychology, 30*, 521–537.

Leslie, J. C., Tierney, K. J., Robinson, C. P., Keenan, M., Watt, A., & Barnes, D. (1993). Differences between clinically anxious and non-anxious subjects in a stimulus equivalence training task involving threat words. *The Psychological Record, 43*, 153–161.

Lubow, R. E., Rifkin, B., & Alex, M. (1976). The context effect: the relationship between stimulus preexposure and environmental preexposure determined subsequent learning. *Journal of Experimental Psychology: Animal Behavior Processes, 2*, 38–47.

Mackay, H., & Fields, L. (2009). Syntax, grammatical transformation, and productivity: a synthesis of stimulus sequences, equivalence classes, and contextual control. In R. A. Rehfeldt & Y. Barnes-Holmes (Eds.), *Derived relational responding: applications for learners with autism and other developmental disabilities* (pp. 209–236). London: New Harbinger.

McGlinchey, A., & Keenan, M. (1997). Stimulus equivalence and social categorization in Northern Ireland. *Behavior and Social Issues, 7*, 113–128.

McIlvane, W. J., & Dube, W. V. (2003). Stimulus control topography coherence theory: foundations and extensions. *The Behavior Analyst, 26*, 195–213.

Meehan, E. F., & Fields, L. (1995). Contextual control of new equivalence classes. *The Psychological Record, 45*, 165–182.

Mizael, T. M., de Almeida, J. H., Silviera, C. C., & de Rose, J. C. (2016). Changing racial bias by transfer of functions in equivalence classes. *The Psychological Record, 66*, 451–462. https://doi.org/10.1007/s40732-016-0185-0.

Moss-Lourenco, P., & Fields, L. (2011). Nodal structure and stimulus relatedness in equivalence classes: post-class formation preference tests. *Journal of the Experimental Analysis of Behavior, 95*, 343–368.

Nartey, R. K., Arntzen, E., & Fields, L. (2014). Two discriminative functions of meaningful stimuli that enhance equivalence class formation. *The Psychological Record, 64*, 777–789.

Nartey, R. K., Arntzen, E., & Fields, L. (2015a). Enhancement of equivalence class formation by pre-training discriminative functions. *Learning & Behavior, 43*, 20–31.

Nartey, R. K., Arntzen, E., & Fields, L. (2015b). Training order and structural location of meaningful stimuli: effects on equivalence class formation. *Learning and Behavior, 43*, 342–353. https://doi.org/10.3758/s13420-015-0183-0.

Nedelcu, R., Fields, L., & Arntzen, E. (2015). Conditional discriminative functions of meaningful stimuli and enhanced class formation. *Journal of the Experimental Analysis of Behavior, 103*, 349–360.

Osgood, C., Suci, G., & Tannenbaum, P. (1957). *The measurement of meaning*. Urbana: University of Illinois Press.

Peoples, M., Tierney, K. J., Bracken, M., & McKay, C. (1998). Prior learning and equivalence class formation. *The Psychological Record, 48*, 111–120.

Plaud, J. J. (1995). The formation of stimulus equivalences: fear-relevant versus fear-irrelevant stimulus classes. *The Psychological Record, 45*, 207–222.

Rehfeldt, R. A., & Root, S. (2004). The generalization and long-term retention of equivalence relations in adults with mental retardation. *The Psychological Record, 54*, 173–186.

Reyes-Giordano, K., & Fienup, D. M. (2015). Emergence of topographical responding following equivalence-based neuroanatomy instruction. *The Psychological Record, 65*, 495–507. https://doi.org/10.1007/s40732-015-0125-4.

Rosch, E. H., & Mervis, C. B. (1975). Family resemblances: studies in the internal structure of categories. *Cognitive Psychology, 7*, 573–605.

Russell, B. (1950). *An inquiry into meaning and truth*. New York: Routledge.

Ryle, G. (1949). *The concept of mind*. London: Hutchinson.

Sidman, M. (1994). *Equivalence relations and behavior: a research story*. Boston, MA: Authors Cooperative.

Sidman, M. (2000). Equivalence relations and the reinforcement contingency. *Journal of the Experimental Analysis of Behavior, 74*, 127–146.

Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: an expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior, 37*, 5–22.

Skinner, B. F. (1957). *Verbal behavior*. New York, NY: Appleton-Century-Crofts.

Sommerville, W., & Whissell, C. (1994). Differences among slopes and intercepts for regression lines predicting children's connotative and denotative knowledge of familiar and unfamiliar words on the basis of age. *Perceptual and Motor Skills, 79*, 219–225.

Sprinkle, E. C., & Miguel, C. F. (2012). The effects of listener and speaker training on emergent relations in children with autism. *The Analysis of Verbal Behavior, 28*, 111–117.

Steele, D. L., & Hayes, S. C. (1991). Stimulus equivalence and arbitrarily applicable relational responding. *Journal of the Experimental Analysis of Behavior, 56*, 519–555.

Travis, R., Fields, L., & Arntzen, E. (2014). Discriminative functions and over-training as class-enhancing determinants of meaningful stimuli. *Journal of the Experimental Analysis of Behavior, 102*, 47–65.

Tyndall, I., Roche, B., & James, J. E. (2004). The relation between stimulus function and equivalence class formation. *Journal of the Experimental Analysis of Behavior, 81*, 257–266.

Tyndall, I., Roche, B., & James, J. E. (2009). The interfering effect of emotional stimulus functions on stimulus equivalence class formation: implications for the understanding and treatment of anxiety. *European Journal of Behavior Analysis, 10*, 121–140.

Walker, B. D., Rehfeldt, R. A., & Ninness, C. (2010). Using the stimulus equivalence paradigm to teach course material in an undergraduate rehabilitation course. *Journal of Applied Behavior Analysis, 43*, 615–633.

Wasserman, E. A., Kiedinger, R. E., & Bhatt, R. S. (1988). Conceptual behavior in pigeons: categorization of both familiar and novel examples from four classes of natural and artificial stimuli. *Journal of Experimental Psychology: Animal Behavior Processes, 3*, 235–246.

Watt, A., Keenan, M., Barnes, D., & Cairns, E. (1991). Social categorization and stimulus equivalence. *The Psychological Record, 41*, 33–50.

Wright, A. A., Cook, R. G., Rivera, J. J., Sands, S. F., & Delius, J. D. (1988). Concept learning by pigeons: matching-to-sample with trial-unique video picture stimuli. *Animal Learning and Behavior, 16*, 436–444.