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On the relation between variability and creativity: a summary of conceptual work and advancements from applied research

Sobre la relación entre variabilidad y creatividad: un resumen del trabajo conceptual y los avances de la investigación aplicada

Sobre a relação entre variabilidade e criatividade: um resumo do trabalho conceitual e avanços da pesquisa aplicada

ABSTRACT: Creativity, or previously unobserved behavior, is a topic of interest to scientists and the general public alike. Researchers outside behavior analysis have focused on creativity as a trait. Behavior analysts, however, have focused on the variables that give rise to novel responses. Conceptual work has included discussions of environmental variables that may promote creativity, the role of the response class, and the selective nature of reinforcement. Most basic researchers, and some applied researchers, have focused on response sequences. Although fruitful in understanding variability as an operant dimension, these limited response classes have prevented a more robust understanding of novelty. Following the development of the lag schedule, applied researchers began using lag schedules to increase complex behavior such as responses to questions, social skills, and martial arts skills. This applied literature has provided intriguing evidence that variability is a key contributor to novelty, thus bringing creativity well into our scientific understanding of behavior.
Keywords: creativity, variability, novelty, conceptual analysis, application

RESUMEN: La creatividad, o comportamiento previamente no observado, es un tema de interés para los científicos y el público en general. Los investigadores fuera del análisis de comportamiento se han centrado en la creatividad como un rasgo. Los analistas de comportamiento, sin embargo, se han centrado en las variables que dan lugar a nuevas respuestas. El trabajo conceptual examinó variables ambientales específicas que pueden promover la creatividad, el papel de la clase de respuesta y la naturaleza selectiva del refuerzo. La mayoría de los investigadores básicos, y algunos investigadores aplicados, se han centrado en las secuencias

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de respuesta. Aunque fructífera en la comprensión de la variabilidad como una dimensión operante, estas clases de respuesta limitada han impedido una comprensión más sólida de la novedad. Tras el desarrollo del esquema de refuerzos *lag,* los investigadores aplicados comenzaron a usar este esquema *lag* para aumentar el comportamiento complejo, como las respuestas a preguntas, habilidades sociales y habilidades de artes marciales. Este trabajo aplicado ha proporcionado pruebas intrigantes de que la variabilidad es un contribuyente clave a la novedad, por lo que aporta creatividad a nuestra comprensión científica del comportamiento.
Palabras clave: creatividad, variabilidad, novedad, análisis conceptual, aplicación

RESUMO: Criatividade, ou comportamento anteriormente não observado, é um tema de interesse para os cientistas e para o público em geral. Pesquisadores externos à análise do comportamento se concentraram na criatividade como um traço. Os analistas de comportamento, no entanto, se concentraram nas variáveis que dão origem as novas respostas. O trabalho conceitual examinou variáveis ambientais específicas que podem promover a criatividade, o papel da classe de resposta e a natureza seletiva do reforço. A maioria dos pesquisadores básicos e alguns pesquisadores aplicados se concentraram nas sequências de respostas. Embora frutífero para compreender a variabilidade como uma dimensão operante, essas classes de resposta limitadas impediram uma compreensão mais robusta da novidade. Após o desenvolvimento do esquema lag, os pesquisadores aplicados passaram a usá-lo para aumentar a frequência de comportamentos complexos, como responder as perguntas, habilidades sociais ou habilidades de artes marciais. Essa literatura forneceu evidências intrigantes de que a variabilidade é um fator-chave para a inovação, trazendo assim a criatividade para nossa compreensão científica do comportamento.
Palavras-chave: criatividade, variabilidade, novidade, análise conceitual, aplicação

Two foundational researchers on creativity, Amabile (1985) and Csikszentmihalyi (1988) have argued that society determines the creativity of an outcome. Practically speaking, absent a coordinated effort, a single individual may determine something is creative based on their unique history. That is, a person's determination of creativity is directly the result of the number of similar, and different, items with which they have interacted. Therefore, at the core of creativity is variation. Creativity is a special type of variation, novel variation, but variation nonetheless. Much of the psychological and social science literature focuses on models of creativity based on internal states (e.g., Barron, 1988). However, behavior analysis has taken a different approach: the study of the conditions under which variable, novel, and creative responses occur.

Early work on the behavioral analysis of creativity focused on a conceptual analysis. In the paper, "Creating the Creative Artist," Skinner (1970) discussed the variables that may account for art. As part of this, he noted that typical accounts of creativity eschew any reference to controlling variables. For most, creativity "comes" from a person. However, as Skinner noted, this view is at odds with cultural practices; there are various curricula and schools dedicated to teaching art. Although a given response may be novel, and thus creative, the components of the response have likely occurred many times in the past. For example, Skinner noted that a painter may make a brush stroke using a primary color on a canvas many times. What makes something creative, then, is what Skinner referred to as "mutations" (Skinner, p.

69). That is, a creative response is one that may have repeated components but differs in some meaningful way from previous responses. In other words, a core component of creativity is variability. The foremost researcher on variability, Allen Neuringer, has written about the relation between variability and creativity. A seminal paper (Neuringer, 2003) on these topics was published in a collection of presentations from the 2000 conference on Behavior Theory and Philosophy.

Justification

As all-encompassing science of behavior, it is important for behavior analysis to provide not only a conceptual account but also an empirical account of even the most complex responses, such as creativity.

Goals

I will begin by reviewing some of the work discussed by Neuringer, including some additional explanation and extension. I will then discuss some more recent applied research that provides some unique insight into the relation between variability and creativity.

Early Work on the Relation Between Variability and Novelty

As Neuringer (2003) noted, behavior analytic researchers have conceptualized creativity as novelty. For example, Maltzman, Bogartz, and Berger (1958) evaluated the role of instructions and general praise to vary on participants novel responses to repeatedly presented stimuli. They found that instructions plus general praise produced the highest rate of novel responses. However, a determination of whether a given response was novel was based on experimenter memory. That is, the comparisons Maltzman et al. made were not based on pre-defined criteria but rather were based on the experimenter recalling previous responses and subjectively comparing the currenet response to the previous responses the experimenter could recall. At the very least, participants produced higher levels of variation when receiving instructions and general praise. The role of variation is further supported by applied research on reinforcing novelty.

Both Lalli, Zanolli, and Wohn (1994) and Goetz and Baer (1973) examined the role of praise on novel toy play (Lalli et al.) and novel block building (Goetz & Baer). In each study, novel interactions with materials resulted in social praise. Both groups found that praise increased novel interactions. However, as in the Maltzman et al. (1958) study, there were no study-based measures of novelty. That is, the researchers did not measure whether a given response had ever occurred before. Rather, researchers delivered reinforcement if some component of the response was different from those before. For example, a participant could emit the following response: cube on tube, triangle on cube, ball in tube, and triangle on cube. One could consider each response novel the first time the participant emitted each response. However, because Lalli et al. and Goetz and Baer did not record whether a given response had previously occurred, it was possible for a participant to access continuous reinforcement by emitting the same sequence of responses in each phase. Taken together, these studies provide preliminary evidence of the importance of variation in novelty and creativity. This is an important distinction for several reasons.

First, in each study, a response was comprised of multiple components. For example, in Goetz and Baer (1973), a response was a block structure. The authors developed a list of 20 components and evaluated each structure that contained a combination of components that had not occurred in that same session. Although each structure needed to have

at least one novel component to produce reinforcement, it was possible for the remainder of the structure to have the same combination of components. Additionally, because this criterion reset after each session, the changes in components could have been the same across sessions. At the least, the high rate of reinforcement indicates variation was occurring but it is not clear to what extent the entire structure would be considered novel or creative. This is an important distinction because of the role of history of the observer in determinations of novelty. Without sufficient exposure to a large number of responses, an observer making determination of novelty may be based on variation amongst previously emitted, but unseen by the observer, responses. Further, the number of components that must vary has not been, and may not be able to be, objectively defined. Therefore, each observer making a determination of novelty may "require" more or less numbers of components that are novel to classify a multi-component response as novel.

The second distinction, as highlighted by Neuringer (2003), presents a more difficult conceptual issue. For a response to be operant, it must be maintained by its consequences. For a response to be maintained by consequences, it must be emitted at least once, contact a consequence, and occur at least once more. Of course, this presents a particular problem for the study of creativity from an operant perspective. Creative responses are typically viewed as those that have never occurred before, or some new combination of previously learned responses (e.g., adduction; c.f., Andronis, Layng, & Goldiamond, 1997; Arieti, 1976; Hennessey & Amabile, 2010). If a response has never occurred, it is difficult to call that response operant. However, the radical behaviorist perspective offers a solution. Specifically, three principles of operant behavior seem most relevant: probability of responding, the response class, and variability as an operant dimension. The notion of a functional response class as a unit (Catania, 1973; Iversen, 2012; Skinner, 1935) brings to question the possibility of pure novelty. Neuringer (2003) noted this may be at the core of understanding how creativity can be sensitive to reinforcement. Reinforcement acts to alter the probability of the response class rather than individual topographies separately. When focusing on a single response, we may refer to two types of novelty: "objective" novelty and "functional" novelty. "Objective" novelty may be considered a response that an organism has never emitted. "Functional" novelty may be considered a response that an outside observer has never observed another organism emit. An analysis of "objectively" novel responses presents the most difficult issue for a science of behavior. When reinforcing an "objectively" novel response, for reinforcement to occur, a response must never have contacted reinforcement previously. If that response had previously contacted reinforcement, it would not be "objectively" novel. However, for responding to continue to occur, something must be contacting reinforcement. This presents two potential issues. First, it is not clear how a response class could be established if each topography produced reinforcement once. For example, if a novelty contingency is in place, the first time a response occurs, it would produce reinforcement. Subsequent instances of that topography would produce extinction. In that case, the first member of the class would have greater exposure to extinction than reinforcement (see Cammilieri & Hanley, 2001 for some demonstration of these effects). One alternative mechanism that may account for the issue of one-reinforcment-per-response is the variability-inducing effects of extinction (e.g., Antonitis, 1951; Morgan & Lee, 1996). That is, the extinction may immediately induce a new response, which contacts reinforcement, and the pattern is repeated as the response class grows. Second, reinforcement of novelty only

would require an infinitely large response class. Although this is theoretically possible (e.g., depending on the sophistication of measurement systems, one could observe multiple, albeit subtle, novel components of a response from instance to instance – see Catania, 2012, for a discussion of the possibility that all responses are novel), in practice, it is not clear if this is functionally possible. Additionally, several researchers have questioned the possibility an "infinite" response class (cf. Machado, 1989, Machado & Tonneau, 2012; Neuringer, 2012). Given these issues, a broader perspective of behavior-environment relations may be necessary to clarify the relation between response variability and creativity.

The first possible solution to the establishment of a response class when the first response only produces reinforcement once is changing focus to "functional" novelty. "Functional" novelty is predicated on an observer's history with respect to the response class. That is, if one cannot predict what topography will occur, low probability responses may appear novel. This understanding is found in even Skinner's earliest writings on operant behavior (e.g., Skinner, 1938). In fact, the very idea of reinforcement is predicated on altering only the probability of future responses. Therefore, behavior analysts have long viewed any given instance of a response as probabilistic (e.g., Machado, 1997). More recently, several behavior analysts have developed methods to quantify the relative probability of a response. In one of the seminal papers on response variability, Page and Neuringer (1985) described the lag schedule and the U-value. The lag schedule is a schedule in which reinforcement is based on a response differing from a specified preceding number of responses. For example, a common response in basic research on response variability in Page & Neuringer, one of the response-sequence requirements wasis a four-peck sequence across two keys. Under a lag 10, to produce reinforcement, the four- peck sequence would have to differ from the 10 preceding four-peck sequences. Therefore, lag schedule allows one to reinforce alternation in responses. In addition to producing moment-to-moment changes in responses, Page and Neuringer were also interested in the predictability of a response, anotherwhich could be considered another component of variability. They developed the U-value to determine the uncertainty of response sequences, based on comparisons of the probability of components of the sequence (a single response, pairs of responses, and triplicates of responses). As the U-value approaches 1, the predictability of responses approaches 0. Page and Neuringer found that as lag schedules increased, the U-values increased in a curve-linear fashion. Although the U-value is a measure of predictability, it is may not be sufficiently sensitive to all responses emitted by an organism. This is particularly important when studying creativity, as it is a comparison to all previous responses that is most relevant in determine the "creativity" of a response rather than the unpredictability of a response or the relative frequency of components of the response. Additionally, the U-value is not sensitive to repeated patterns of responding (i.e., higher order stereotypy). For example, if an organism emits 10 responses sequences in a fixed order, the U-Value could approach 1.0 but most would not call that pattern variable or creative.

An alternative approach to the study of response probability was used by Machado (1989; 1992). Machado evaluated the effects of a percentile schedule on the variability of response sequences. In a percentile schedule, reinforcement is available for responses that fall below a specified relative frequency value. Machado then determined the predictability of responses using Markov-chain analysis. Overall, Machado found that responses were nearly stochastic under lean percentile schedules (e.g., probability

below .25). In the study of creativity, there is a distinct advantage to percentile schedules over lag schedules. In a percentile schedule, determining the probability of a response is not limited to a comparison with a subset of response components. Instead, the comparison is will all previous responses. Additionally, with sufficient exposure and a sophisticated measurement system, one could determine the overall probability of a response, based on a comparison to all previous responses. Taken together, analyzing the probability of response may be one metric by which to evaluate the creativity of a response. That is, the lower the probability of a response, the more likely it is a novel response. However, this supposition is not without issues, namely the understanding that repertoires are not isolated components. Additionally, to calculate the relative probability of a response, one must know all possible responses. In the research literature, this has been possible because most of the responses have been sequences, with a fixed-number of combinations (e.g., Dracobly, Dozier, Briggs, & Juanico, 2017; Page & Neuringer, 1985; Machado, 1997). As one begins analyzing more complex, "open-ended" responses, this becomes more difficult. Finally, a novel response may This issue becomes clear as one moves beyond the analysis of discrete responses into that of more complex behavior, such as artistic behavior.

Translating the Response Class to Common Notions of Creativity

An artist often has a "style" that can be identified by the public. In behavioral terms, one might conceptualize this as the artist's responding producing response products that have correspondence across instances of the final product. That is, in creating a piece of art, an artist may repeat many components, such as a brush stroke, the placement of a color, or the placement of an object. Across instances of an art product, these components be combined in different ways and the components themselves may vary along some dimension (e.g., the intensity of a color). Given this, it appears creativity may not be as much about the individual components of responses but rather the ultimate product of those components. This notion fits well with the science of behavior.

As we advance in our understanding of behavioral variability, it may be useful to shift our focus from analysis of discrete responses to analysis of a larger unit. As in the example of a painting, the relevant variability may be at the level of the response product rather than the moment-to-moment changes in components/instances/etc. The idea of focusing on a collection of responses that produce the same outcome is not new in behavior analysis. Our understanding of operant behavior includes some formal relations between responses, with the most common being the notion of the response class (e.g., Catania, 1973; Iversen, 2012; Skinner, 1938). In a functional response class, the individual topographies, however varied, all produce the same reinforcer. Additionally, because the response class is descriptive, the "size" of the class is not pre-defined. In fact, much of the treatment of severe problem behavior is predicated on the ability to expand the response class by choosing a simple response that produces the same reinforcer as problem behavior (e.g., Carr & Durand, 1986; Fisher et al., 1973; Tiger, 2008).

One issue with this approach is that it appears to limit our ability to predict and control behavior (e.g., Skinner, 1953). That is, if a response class is infinite and new responses can be "added" at any time, it would be, practically speaking, impossible to ever predict what response will occur, let alone have sufficient control to make a response occur or not occur. Several other researchers have made points similar to these and have posited alternative explanations for changes in variability, such

asreinforcement of switching (e.g., Machado, 1997; see Barba, 2014, for a review of various accounts). An alternative is to shift the focus of where one looks for prediction and control.

When one examines the notion of a response-class account of variability, taken apart, there are two primary premises of this account. First, reinforcement operates on the response class as a whole rather than on individual members discretely. Second, the individual members of the response class are not particularly useful or relevant to the prediction and control of behavior - the response class is strengthened even if single members do not occur at an increasing rate. This first component is relatively uncontroversial. The functional approach to the study of behavior relies on relations between behavior and environment. Insofar as a response produces the same reinforcer as another response under the same conditions, we may say those responses are related in some way. However, this relation is merely one of verbal contrivance - if it is useful, we may use it, as in the case of functional communication training (e.g., Carr & Durand, 1985; Fisher et al., 1996). However, in terms of the natural relation, it is the relation of the consequence and the antecedent conditions that are what control the responses. The second premise, the limited utility of the individual members of a response class in the prediction and control of behavior, may be a bit more tenuous (see Barbara, 2014, for a discussion of the discriminative properties of prior responses)

One of Skinner's most unique contributions to the science of behavior was to change the emphasis from the form of a response to the consequences of a response. However, in some ways, this notion is reversed when studying response variability. In much of the research on behavioral variability, the primary dependent measures have been based on sequences of responses (e.g., Dracobly et al., 2017; Machado, 1989; Machado, 1992; Machado, 1997; Morris, 1987; Neuringer, 1991; Page & Neuringer, 1985). Because of this, the size of the response class is fixed and can be determined at the beginning of the study using simple mathematical formulas. In one sense, then, responding is always predictable and controllable - a response will come from that set response class. At another lever, however, responding is not predictable, as one may not be able to predict or control the specific sequence that will occur. In fact, researchers have found that responding can approach near stochasticity based on variability specific U-values (e.g., Page & Neuringer, 1985; Miller & Neuringer, 2000) or common mathematical analyses of stochasticity such as Markov-chain analyses (e.g., Machado, 1997).

With respect to creativity, variability appears to be the most important factor. Before addressing this, I will note that there is likely an important contribution of verbal behavior, particularly on the part of an observer. The tact, "creative" is likely controlled by an organism's history and the specific training of the verbal community. However, an analysis of this is beyond the scope of the paper. Returning to variability, when a creative response occurs, it is unlikely that it includes components that are entirely novel. One of my favorite comprehensive artistic structures are the Medici Chapels in in the church of San Lorenzo in Florence, Italy. Within the chapels, there are frescoes, carved stones, tombs made of stone and precious materials, sculptures, mosaics, and other forms of art and sculpture. Each of these was made by artisans who spent years perfecting their craft. As a whole, I have never seen another location that looks just like the chapels. However, each part of the chapel, in some way, is repetitive. For example, the frescoes contain shapes and colors that the artist likely used many times before creating frescoes in the chapel. Likewise, the sculptures, including the carved plaques, included names, faces, and bodies that the artists had sculpted before (i.e., as either stand-alone

pieces or in other materials in preparation for the final stone versions in the chapels). Why, then, do we consider the chapels to be creative?

The most parsimonious answer may be that the individual responses, including the order they occur and the products they produce, are highly variable and thus are a unique combination that has not been replicated. For example, although the artist may have used colors, shapes, faces, and the like in previous works, the final fresco and the location in which the fresco appears are new and thus the fresco is uniquely creative. In this case, then, it is the specific combination of variable responses that is what makes the response unique and creative. More recent applied work may highlight the need to shift from an analysis response sequences to analysis of response products in order to study creativity.

Applied Research on Response Variability

Reinforcement of Novelty

Early applied research on creativity focused on analyzing responses that were comprised of many components that could vary. Two seminal studies in this area, Pryor, Haag, and O'Reilly (1969) and Goetz & Baer (1973), demonstrated that reinforcement of novel response products increased behavioral variability. Pryor et al. provided reinforcement for novel responses by porpoises. As they reinforced the novel responses, defined as "trick performances" by the porpoises, they found that the two porpoises began emitting novel responses that had never before been emitted. Additionally, within sessions, they found that there was variation between previously reinforced responses and novel responses. In a more direct evaluation of the effects of reinforcement on response products, Goetz and Baer provided descriptive praise for children's novel block forms. At the end of each session, Goetz and Baer took photographs of the final structures and coded the components of structures according to 20 pre-defined categories. Goetz and Baer found that when they reinforced the emission of novel block forms, children emitted an increasing number of novel block forms. Likewise, when they reinforced repetitive block forms, the children reliably repeated the same forms. Taken together, Pryor et al. and Goetz and Baer provided initial evidence that novel responding was sensitive to reinforcement and that reinforcement of moment-to-moment novel responding produced systematic changes in the novelty of response products.

Reinforcement of Variability

More recent applied research has focused on several different response forms, from block designs to responses to questions, to martial arts skills. Using procedures similar to those used by basic researchers, in Study 2, Dracobly et al.2017) evaluated the effects of several lag schedules on children's four-block sequences. The lag schedules involved reinforcing a response if it differed from a previous number of responses. For example, in the fixed-lag 4 conditions, a response had to differe from the preceding four responses. In the variable-lag 4 conditions, the average lag value was 4, but on each trial, the lag value could vary from 0 (any response produced reinforcement) to 8 (a response had to differ from the eight preceding responses). Under both fixed-lag 4 and variable-lag 4 (in which the lag value averaged 4 but varied between 0 and 8 across the 20 trials), Dracobly et al. found that as moment-to-moment variation increased, so did the production of novel responses, with the highest production of novel responses occurring in the variable-lag 4 conditions.. Interestingly, this novelty included responses never before seen from the participant across the entirety of the

study. Napolitano, Smith, T., Zarcone., Goodkin, and McAdam (2010) found similar results. Even under a lag 1 schedule, in which responses only had to differ from the immediately preceding response, Napolitano et al. found that as moment-to-moment variation increased, so did novelty along other dimensions of responses (e.g., form or color). Although the responses were block structures, both Dracobly et al. and Napolitano et al. provided a demonstration that while sequence components were constrained, directly reinforcing variability could produce response product (final sequence comprised of four blocks) products. However, as stated earlier, this focus on response sequences limits the applicability of these results to understanding the relation between response variability and creativity per se (i.e., because not all responses are comprised of a pre-determined number of components).

Other researchers have chosen response forms that allow for broader moment-to-moment variation in response components and overall response product novelty. Lee, McComas, and Jawor (2002) evaluated a lag 1 schedule on responses to social questions (e.g., questions about preferences, how one was feeling, etc.). After identifying questions that produced repetitive responses, Lee et al. provided either a token or praise with physical interaction when a response to a question differed from the immediately preceding response to the same question. Overall, Lee et al. found that the lag 1 schedule was effective in increasing the variability of responses to questions. Additionally, although the number of different responses remained relatively low, the lag 1 schedule was effective in producing novel responses to questions. These results are promising in advancing our understanding of the relation between variability and creativity. First, although the overall number of novel responses remained low, a major contributor to this was likely the low lag value. That is, because a lag 1 requires only alternation between two responses, applied researchers have reliably found that participants will alternate between a small number of responses (see Fonseca Júnior & Hunziker, 2017, for a contrary finding under a lag schedule in an avoidance arrangement). Despite this, Lee et al. found that more than two novel responses occurred, indicating that even minor exposure to contingencies that promote variability can also increase novelty. Second, the response form chosen by Lee et al. was much more relevant to assessing the effects altering variability on novelty. Because responses to questions are not as constrained in permutations as responses with limited physical materials, the possibility for novel response products is increased. For example, in the Lee et al. study, one of the questions was, "What do you like to do?" (p. 393). There are many possible responses to this question that could vary in multiple ways. For example, a response could simply be the name of an activity. Alternatively, a response could include a complete sentence with multiple parts of speech. Additionally, a response could include imaginary responses, a skill commonly considered creative. Subsequent researchers have found similar results.

In a similar study, Lee & Sturmey (2006) compared the effects of a lag 0 (all responses produce reinforcement) and lag 1 schedule on appropriate responses to social questions. Overall, they found the lag 1 schedule was effective in increasing the variability, novelty, and appropriateness of responses, with all parameters decreasing under lag 0. Radley, Moore, Hart, Ford, and Helbig (2019) obtained similar results. Radley et al. compared behavioral skills training (BST) alone and BST plus lag schedules on increasing four appropriate social skills. Three of the four skills were verbal skills: "Maintaining a Conversation," "Expressing Wants and Needs," and, "Responding to Questions" (p. 69). Overall, Radley et al. found that both lag 2 and lag 4 schedules pro-

duced increases in varied responses. However, lag 4 produced the greatest increase, including the generation of novel responses. In summary, when investigating the effects of lag schedules on vocal responses, there is emerging evidence from the applied literature that increasing response variability can produce similar increases in response novelty. Additionally, given the potential for very large verbal responses classes (i.e., due, in part, to the variety of components of vocal-verbal responses), the potential for variable responding producing creativity remains promising.

Although these results are promising, responses to questions requires repetition of the question. In a given social interaction, it is unlikely that a question or statement from another person will be repeated multiple times. Instead, a person may ask a question once, and then begin making a variety of statements. To date, there have been no investigations of the response variability and novelty in the context of a typical conversation. However, there has been one applied study that may serve as a reasonable metaphor. Harding, Wacker, Berg, Rick, and Lee (2004) evaluated the effects of lag schedules on martial arts performance. Although martial arts are topographically dissimilar to vocal-verbal responding, what occurs during a sparring session (or during the use of martial arts in a defense of oneself) is similar to that of a conversation. When sparring or defending oneself, an individual must respond to the behavior of another person and this pattern continues for an often unspecified period of time. Additionally, what makes this different from any standard social interaction is that the response of one person directly affects the parameters of appropriate responses of the other person. In this study, Harding et al. evaluated the effects of a lag "infinite" schedule on variable punching and kicking during martial arts training and sparring. The lag "infinite" schedule was similar to the schedule used by Goezt and Baer (1973) – a given response could produce reinforcement only once, for the entire duration of the study. Across all phases of the study, the authors assessed systematic changes in the variability of responses during sparring sessions that involved 20 strikes from the instructor. Prior to the lag evaluation, the instructor directed punches for participants to counterstrike as baseline of the participant's variability of counterstrikes. When the lag schedule was implemented, each novel counterstrike produced verbal praise. Overall, Harding et al. found that the novelty of counterstrikes increased during both the training (with lag) and sparring (without lag) sessions. In other words, once novel counterstrikes increased during training, novel counterstrikes continued to be emitted in the absence of direct reinforcement. The most intriguing result of this study is the necessity of novel, or creative, responses during sparring. During the sparring sessions, the initial strike from the instructor could be fixed. However, because the counterstrikes were variable, the instructors behavior had to immediately change. The next strike from the instructor was highly variable, which required immediate adaptation of the participant. This pattern continued for the entire sparring session. To an outside observer, then, each sparring session would look like a unique "match," full of creative back and forth strikes from the two participants. However, the moment to moment changes were based on the direct reinforcement of variability in the training sessions and, likely, the likely the result of two factors. First, the direct reinforcement of varied responding likely created a history in which variable responding was more likely to occur in sparring situations. Second, the novel strikes from the instructor may have also induced variable responding, as they served as on-going, novel antecedent events. Relating this back to vocal-verbal responding, the sparring sessions could be considered somewhat equivalent to conversations - a repetitive

statement by a conversation initiator (e.g. asking a name) leads to a reply that then evokes a variable response by the conversation initiator and this pattern continues to increase in variability as the conversation progresses.

Taken together, given the potential size of the response classes for these complex, socially significant responses, the results of these applied studies examining the effects of reinforcing varied responses provides intriguing information about the relation between variability and creativity. In each of the applied studies with vocal-verbal responding or martial arts, the behavior of one individual evokes a response in another individual. However, the response that is evoked is not highly constrained like those in response sequences. Additionally, the back and forth nature of these types of social interactions may not only make variable responses more likely but they may be the clearest example of how environmental variables, including reinforcement, can directly affect creativity.

Summary, Conclusions, and Future Directions

Creativity is a topic of interest to society at large. As a natural science, the science of behavior has sought to understand the variables that control these types of complex responses. Because creativity involves responses that are novel, an account based on past reinforcement of a specific response form appears to be inadequate. A possible solution to this issue is to examine the functional response class. Because reinforcement operates at the level of the response class, it may not be necessary to account for the occurrence of an individual topography. That is, as reinforcement strengthens the response class as a whole, accounting for the occurrence of a single response may be irrelevant. However, one must then account for the occurrence of this novel response by examining other variables. One possibility is the reinforcement of variability.

Across the basic and applied literature on response variability, one common response form is sequences of responses (e.g., Machado, 1989; Page & Neuringer, 1985; Dracobly et al., 2017). Because sequences are comprised of pre-determined components, the size of the response class is restricted. In a very broad sense, then, none of the responses may be considered "creative" because one can always know all the possible responses. In this case, one may consider groups of sequences as novel. However, even with restricted response classes, researchers have observed the occurrence of novel responses from those restricted classes. Given these findings, the seeming incompatibility between production of novel responses and the notion of a non-infinite response class may be due to, in part, procedural and analytical decisions.

More recent applied researchers have investigated responses that may be part of very large, even of indeterminate size, response classes: vocal-verbal responses to open-ended questions (e.g., Lee et al., 2002) and martial arts (Harding et al., 2004). Researchers have found that by reinforcing variability of responses, participants will not only vary in their responses to the preceding behavior of others but that the responses of participants are often novel. The antecedent influence of the behavior of others on subsequent variable responding is a particularly interesting finding. Because creativity is, in part, based on an observer's history, the influence of another person, in the moment, presents another variable to consider in a behavioral analysis of variability and creativity. Although these findings are preliminary and in need of much replication and further examination of the basic processes at work, they do provide intruding insight into how reinforcement-based processes may produce creative behavior. For example, even in relatively restricted response classes (e.g., a young child with a very limited verbal repertoire), the reinforcement of variability may

increase the likelihood that very infrequent responses are emitted. Given the social control of the classification of creativity, these infrequent responses may be novel if one's history interaction with the individual is limited. As one begins investigating responses that are more complex (e.g., involving multiple components), the possibilities become even greater. In creating a painting, many of responses may be repetitive (e.g., colors used, brush strokes, shapes, etc.). However, reinforcement of variability, such as praise for the same object in multiple colors or including different objects on the same painting, may increase the likelihood that novel responses of repetitive components are emitted. As one moves beyond responses involving a single individual, understanding the role of operant processes in creativity becomes even more exciting.

In social situations, the behavior of one person evokes a response in a second person. Social responses, then, may provide a unique context for studying creativity. A common skill from early childhood education may be helpful to explain this. In teaching children conversation skills, a teacher may reinforce a child's talk about different topics. This reinforcement of variable topics may then produce a growing response class. As that child begins talking to peers, that history of reinforcement for variable topics may be the mechanism by which creative talk occurs. For example, two children may begin talking about a tree outside. If each child has a history of varying topics, each child may quickly talk about different aspects of the tree, such as the color, size, or location, and different ways of interacting with the tree, such as climbing the tree or throwing objects onto tree branches. As one child makes a statement, that statement may evoke a variable response from the other child. Because the response is variable, a large diversity of possible conversations quickly becomes possible. In other words, that variable responding makes a creative conversation possible. Over time, as the children's repertoires expand and if reinforcement of variable conversations continues, the potential for unique, creative conversations grows even more. At the core, however, is a history of reinforcement for variable behavior, which makes possible variable responses to variable initiations from another individual.

At this point in time, much of this analysis of the relation between variability and creativity is conceptual. In studying variability, as we move from an empirical analysis of response sequences to an empirical analysis of open-ended response classes, the opportunity for a more complete understanding of the relation between variability and creativity becomes possible. Ultimately, it is clear that the science of behavior not only has much to say about creativity, but may also be uniquely positioned to describe how creativity develops. As the world looks for unique solutions to a variety of problems, it is clear that the science of behavior may provide just the creative solutions we need.

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