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In Memoriam: Peter J. Urcuioli (1952-2022)

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In Memoriam: Peter J. Urcuioli (1952-2022)

Peter J. Urcuioli passed away on November 27, 2022, after a decade-long battle with Large Cell Non-Hodgkin's Lymphoma. Peter touched the lives of many people, and we—his mentees—are honored to write about some of his accomplishments.

Peter completed his undergraduate training at the University of New Hampshire, where he enjoyed time learning about experimental psychology and behavior analysis by working in Tony Nevin's rat lab. Peter saw his career in large part as a reflection of Tony's mentoring and friendship. Peter had fond memories of student dinners at Tony's house in Durham, and they maintained their personal connection for more than 40 years. Peter completed his graduate training in experimental psychology at Dalhousie University in 1979, under the mentorship of Werner Honig. These years in Canada prompted his interest in stimulus generalization and discrimination (e.g., Honig & Urcuioli, 1981), which eventually led to a fruitful and influential career in the general field of stimulus control. He moved from Nova Scotia to Texas to continue his research in basic stimulus control and vision in pigeons as a postdoctoral fellow with Tony Wright at the University of Texas Health Science Center at Houston. In 1981, Peter joined the Department of Psychological Sciences at Purdue University, where he quickly earned Full Professor. Over the years, he developed and maintained research collaborations with several labs, which often led to lifelong friendships. He retired from Purdue in 2020, earning the status of Emeritus Professor.

There are many ways to measure the impact of Peter's career. We would like to highlight some of Peter's many professional accomplishments and his contributions to science across several domains of the experimental analysis of behavior. More than that, we want to highlight the influence that Peter had on those around him. Peter was an excellent teacher; he was awarded the School of Humanities, Social Science, and Education Departmental Award for Excellence in Teaching in 1986. Over the course of his career, he taught a range of undergraduate and graduate courses in research methods in psychology, learning, animal memory and cognition, stimulus generalization and stimulus control, and the experimental analysis of behavior. Although he taught courses with challenging material, he was skilled at presenting the material in a digestible, memorable, and fun format.

Peter's scholarly work is impressive. He earned nearly continuous external funding for his research on stimulus control in pigeons from the National Science Foundation and the National Institute of Mental Health, covering a period of 35 years. This resulted in a collection of 89 publications spanning across multiple areas within behavior analysis and psychology, including stimulus control, acquired equivalence, associative symmetry, and the differential outcomes effect. Peter was an engaging speaker with the ability to make complicated research questions accessible to a general audience. He gave more than 75 conference presentations and invited lectures to a range of national and international audiences, including the American Psychological Association, the Association for Behavioral Analysis International, the Psychonomic Society, the Comparative Cognition Society, and the Society for the Quantitative Analysis of Behavior. Interest in his research across these broad disciplines is evidence that his work was an important bridge between the experimental analysis of behavior and comparative cognition.

Peter served on numerous masters, preliminary examination, and doctoral committees, helping to form the careers of 29 students. Additionally, he served as a research mentor for countless undergraduate students who completed a semester or more working in the pigeon lab. His service to the Department of Psychological Sciences and the broader university was extensive and included multiple terms in the animal care committee, terms as Associate Department Head and Director of both Graduate and Undergraduate Studies, and terms as the Area Coordinator for Learning and Memory. Finally, he was a member of the College of Health and Human Services transition team, helping to lead the reorganization of the Department of Psychological Sciences from the College of Liberal Arts into the newly formed College of Health and Human Services.

Peter helped shape the field by serving as associate editor of the *Journal of the Experimental Analysis of Behavior*, as consulting editor for the *International Journal of Psychology and Psychological Therapy* and *Psychonomic Bulletin and Review*, and as ad hoc reviewer for numerous journals. He served as a reviewer and study section member for several external review panels. He was a Fellow of the American Psychological Association, a Charter Fellow of the Midwestern Psychological Association, and a co-founder of the Tri-State Plus conference. His contributions to behavioral sciences were recognized with the Med Associates Distinguished Contribution to Basic Behavioral Research Award in 2015.

Although Peter was serious about his work, he was able to find humor in most situations, including negative experimental outcomes. One of his conference presentations at the meeting for the MidAmerican Association for Behavior Analysis was a collection of his unsuccessful attempts to find evidence for emergent relations (i.e., reflexivity, symmetry, and transitivity) in pigeons. He navigated to several slides and punctuated his results with a “Nothing!” to summarize. He was in good company because many other researchers were also unable to design a training procedure that would afford stimulus class formation in pigeons (see Lionello-DeNolf, 2009; 2021 for reviews). Thankfully, all his years of “nothing” eventually resulted in something

(Urcuioli, 2008). In the following sections, we briefly summarize a few of the research areas on which Peter has had a major impact.

The Differential-outcomes Effect

Peter was interested in how discrimination learning is affected when different outcomes are contingent upon different responses. The interest was empirical but also theoretical, for the many variations of the differential-outcome paradigm had, in his view, much to contribute to our understanding of instrumental learning processes (see Urcuioli, 2005). In a typical preparation, a pigeon might learn to match a horizontal line comparison stimulus (i.e., R1) to a red sample (i.e., S1) with access to mixed grain and the hopper light for 3 seconds (i.e., O1) and to match a triangle comparison stimulus (i.e., R2) to a green sample (i.e., S2) with access to the hopper light only (i.e., O2). See Table 1 for the complete matching-to-sample training. Learning the hue-form relations (i.e., S1→R1 (O1) and S2→R2 (O2)) with different outcomes is contrasted with learning the hue-form relations with the same outcome (i.e., 3-s access to mixed grain + hopper light; S1→R1 (O1) and S2→R2 (O1)). With this procedure, the differential outcomes effect is typically characterized by two patterns of performance: faster acquisition of the matching-to-sample relation and more accurate final performance on that relation for animals that learn with differential outcomes when compared to those that learn with the same outcome (e.g., Trapold, 1970). More generally, it is now clear that differential outcomes facilitate the acquisition of discriminative performance (e.g., simple two-choice and go/no-go successive discriminations, conditional discriminations, and complex feature-ambiguous discriminations; Urcuioli, 2005) and working memory performance when a retention interval intervenes between the stimulus and the response (e.g., Peterson et al., 1980). These findings suggest that viewing the reinforcer as a simple catalyst for stimulus-response associations may be too simplistic a position. The differential-outcome effect hints at a more complex association matrix.

Through systematic experimentation and conceptual analyses, Peter came to believe that, as Trapold (1970) in his two-process account, the reinforcer is part of what is learned in discrimination tasks. In particular, he proposed that when specific reinforcers are correlated with specific responses, the subject's ability to anticipate the upcoming reinforcer (EO1 and EO2 in Table 1) can act as any other discriminative stimulus and thus guide action. In other words, the specific stimulus-outcome expectancies generated via Pavlovian processes in the differential-outcomes paradigm comes to control instrumental responses. "Responses differentially reinforced in the presence of certain stimuli—be they external or internal—will come under control of those stimuli" (Urcuioli, 2005, p. 17–18).

Coding in Matching-to-Sample Tasks

Another of his predilect puzzles was the coding strategy used by animals when solving delayed matching-to-sample tasks (MTS). The issue was whether animals remember past events (the sample) or predictable upcoming events (the correct comparison) when solving these tasks (e.g., Urcuioli et al., 1989). When animals remember the sample throughout the retention interval, the memory "code" is said to be retrospective; when they remember the correct comparison, the code is called prospective. He was keenly aware that there was no *a priori* reason to assume that only one coding process guided performance in MTS. Animals might flexibly adapt their coding strategy according to the characteristics of the task (e.g., the discriminability of samples, the discriminability of comparisons, the number of comparisons, etc.), adopting the one yielding less forgetting. Nonetheless, demonstrating the independent existence of each process and figuring out the circumstances under which one or the other might predominate were conceptually and experimentally stimulating interrogations. Over the years, his research examining what pigeons held in memory during the delay of delayed matching to sample led him to favor the primacy of retrospective coding (e.g., Urcuioli & Zentall, 1986). Pigeons may flexibly use retrospective and prospective coding, but remembering the samples seems to be the default strategy in two-alternative delayed MTS.

His fascination with memory mechanisms inspired him to investigate other iterations of the matching-to-sample paradigm, including many-to-one matching (MTO). In MTO matching, the selection of each comparison is reinforced after more than one sample. For instance, pigeons may learn to match both a red hue and a vertical line to a vertical line comparison and a green hue and a horizontal line to a horizontal line comparison. The left column of Table 2 illustrates the procedure. Instead of the typical one-to-one retrospective coding usually seen in standard MTS, Peter found that samples associated with the same comparison (red and vertical, and green and horizontal in Table 2) are commonly coded by pigeons (e.g., Urcuioli et al., 1989; see also Zentall et al., 1995). The content of this common code seems derived from the samples' common comparison but is not isomorphic with it. In other words, associatively related samples in MTO matching evoke the same representation. This, in turn, raised the provocative hypothesis that they could be interchangeable with one another. This was the seed for his work on acquired equivalence and stimulus equivalence, fields to which Peter devoted the last decades of his career.

Acquired Equivalence

Associative concept learning involves the ability to form categories of arbitrary stimuli wherein each member can represent the others under certain conditions (Zentall et al., 2014). The finding that MTO matching promotes common coding suggested that associatively related samples may join a common class and thus be interchangeable. This turned out to be true (Urcuioli, 1996). One way to show it is the transfer of control protocol developed by Peter and his associates (e.g., Urcuioli & Zentall, 1992). Suppose that pigeons are trained in the MTO mapping shown in the left column of Table 2. The hypothesis is that the red and vertical samples join a common associative class because they are separately paired with the vertical comparison, and similarly for the other two samples paired with the horizontal comparison. The test consists of training a new set of comparisons (e.g., blue and yellow) with two of the original samples (e.g., red and green; cf. second column of Table 2). For instance, blue may be reinforced after the red sample and yellow after the green sample. After these new relations are learned, we ask if these new associations will transfer to the remaining samples (vertical and horizontal). Specifically, will pigeons peck blue after seeing the vertical sample and yellow after the horizontal sample in the absence of direct training? There are a couple of different ways to run this test, but Peter's preferred method was to differentially reinforce choices during the test sessions. For one group of birds, food would be delivered for pecking blue (but not yellow) after the vertical sample and for pecking yellow (but not blue) comparison after the horizontal sample (viz. contingencies consistent with the hypothesized acquired equivalence). For the other group, the reinforced contingencies would be inconsistent with acquired sample equivalence. Typically, and as predicted on the basis of acquired equivalence, the consistent birds are generally very accurate, matching well above chance, whereas the inconsistent birds are inaccurate, matching at or below chance. In other words, pigeons behave as though hue and line samples that occasion the same reinforced comparison choice in MTO matching belong to the same associative class.

Peter was also interested in the nature of the common sample representations underlying these classes. Initially, he favored prospective mediated generalization in the form of implicit mediating responses, but he had the healthy habit of believing his data! Eventually, he came to believe that a common retrospective code supported sample equivalence as produced in MTO matching (e.g., Urcuioli et al., 1989).

Stimulus Equivalence

The finding that learning a small number of conditional discriminations can lead to a variety of untaught (or emergent) performances in humans generated an intense empirical and theoretical interest in the topic of stimulus equivalence. As defined by Sidman and Tailby (1982), stimulus equivalence requires the emergence of three types of relations: reflexivity, symmetry, and transitivity. Specifically, after learning to choose B after A and C after B (A-B and B-C matching, respectively), humans often spontaneously match each stimulus to itself (reflexivity; e.g., A-A matching), do the reverse of what they were explicitly taught (symmetry; e.g., B-A matching), and match C to A (transitivity). What excited Peter was the possibility that these emergent performances were a natural consequence of the reinforcement contingencies themselves, as suggested by Sidman (1990; 1994; 2000). If that were the case, non-human animals should, to some extent, exhibit such derived relations, too. For years, he and others searched for evidence for reflexivity, symmetry, and transitivity in other species, but the net result had been equivocal (see Lionello-DeNolf, 2009, for a review). Some suggested that these emergent relations were language-mediated and thus beyond the capacities of non-humans (e.g., Hayes, 1989). Yet, the tide would soon turn.

It turned out that the experimenters' questions got lost in translation—the lack of evidence for stimulus equivalence in non-human animals was an issue of methodology (Urcuioli, 2008). For years, the preferred paradigm involved training animals in two-alternative MTS and then asking the critical question. For instance, a test for symmetry would involve training animals to choose B after A and then asking whether they would choose A after B. However, we now know this is not a valid test. The reason is that the functional matching stimuli for animals consist of their nominal features (e.g., red) as well as their temporal (e.g., first or second) and spatial positions (e.g., on the side or center key) within a trial. So, in the previous MTS example, animals learned to match A (e.g., red + center key + first) to B (e.g., green + side key + second); therefore, asking whether they would now match B' (green + center + first) to A' (red + side key + second) is not assessing symmetry. At testing, because the matching stimuli appear in different spatial and temporal locations, they are functionally new stimuli to the animal. A similar rationale applies to reflexivity and transitivity.

Success at demonstrating all the properties of stimulus equivalence came when these difficulties were either eliminated or made irrelevant. Using successive matching, Frank and Wasserman (2005) found that pigeons responded more to the symmetrical versions of the trained symbolic A-B relations than to the symmetrical versions of non-reinforced relations, provided that they also received concurrent training on identity A-A and B-B matching. Peter suitably understood the benefits of successive matching: first, samples and comparisons always appear at the same spatial location in both training and testing, rendering the location problem irrelevant; second, concurrent training with identity (or even oddity) matching ensures that animals experience the relevant nominal stimuli at each possible temporal location; and third, throughout training, one-half of the sample-comparison combinations are non-reinforced.

In 2008, Peter advanced his theory of equivalence class formation. The theory proposes that: (1) the experience of reinforcement versus non-reinforcement continually present in successive matching yields stimulus classes containing the stimuli involved in each reinforced sample-comparison combination; (2) the functional matching stimuli are compounds of the nominal stimuli and their temporal and spatial locations within a trial; and (3) classes sharing a common member merge. From his theory, Peter carefully devised the protocols that should be conducive to the emergence of symmetry, reflexivity, and transitivity (and sometimes their opposite) and proceeded to test them in pigeons in collaboration with his students (e.g., Campos et al., 2014; Sweeney & Urcuioli, 2010; Swisher & Urcuioli, 2013). The assays were elegant and successful throughout. His findings stand as the most robust and systematic demonstration of stimulus equivalence in a non-human species to date.

Personal Impact and Mentorship

In addition to his scholarly contributions, the personal impact Peter had on his students has been profound. Peter's fascination with the basic principles of conditioning and his enthusiasm for science was shared with us as his research mentees and with hundreds of Purdue students who took his courses in research methods, learning, and experimental analysis of behavior. At least an hour before every class, even courses he had been teaching for over 20 years, you could find him poring over his lined yellow sheets of paper with his handwritten notes and his feet propped up on his desk. He had a quick wit and a quirky sense of humor that made him an entertaining teacher and helped him connect with students and friends alike. When he entered the third floor of the Psychological Sciences building where his office was located, you could hear his joyful laugh echo through the hallway. He was often found chatting with colleagues about research or some article in the campus newspaper over his morning cup of coffee. His impressive knowledge and overall *joie de vivre* were key to cultivating each of our interests in scientific research. He was proof that science should be fun. Equally formative was the fact that Peter was unafraid to show interests outside of work, like cheering on Purdue basketball or sharing the latest pictures of his grandchildren. It was encouraging to know that attending scientific conferences could sometimes be sacrificed for good causes, like attending the Indy 500 (his passion is well demonstrated in Figure 1).

Peter's strengths as a mentor were his ability to lead by example, teach through stories and casual conversation, and recognize the different areas in which his students needed to grow and provide those opportunities kindly but insistently. Peter had high standards for himself and for his students, but he was gentle and patient when giving criticism. He would always work with his students to find a solution to a research problem and ask probing questions to guide the interpretation of results and the development of new research studies. At first, the mentee might think that they arrived at the solution independently, but after careful reflection, each of us have come to see how Peter's carefully constructed prompts and thoughtful guidance for relevant readings shaped our collaborations and built upon his prior contributions to science. Throughout our careers, Peter was always willing to lend an ear and provide guidance, and he was the first to celebrate his students' achievements long after we left his lab. Our personal memories are too many to share in detail, but they include: proud hallway pronouncements after a successful defense, personal coverage of a lab shift as a 21st birthday present, and a one-hour tour of the Psychology building turning into an energetic full-day crash course in stimulus categorization by pigeons. We will cherish our memories of him and make our best efforts to pay forward his unflappable enthusiasm and generous mentorship in the years to come.

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Table 1

Differential and Nondifferential Outcomes Training

Differential Outcomes	**Outcome Expectancies**	**Nondifferential Outcomes**	**Outcome Expectancies**
S1→R1 (O1)	S1-E1→R1	S1→R1 (O1)	S1-E1→R1
S2→R2 (O2)	S2-E2→R2	S2→R2 (O1)	S2-E1→R2

Note. S1 and S2, discriminative stimuli; R1 and R2, reinforced responses; O1 and O2, outcomes contingent upon responding; E1 and E2, expectancies of O1 and O2, respectively.

Table 2

Many-to-one matching

MTO Matching	Reassignment	Test	
		Consistent	Inconsistent
R → V+	R → B+		
G → H+	G → Y+		
V → V+		V → B+	V → Y+
H → H+		H → Y+	H → B+

Note. R = red, G = green, V = vertical, H = horizontal, B = blue, Y = Yellow, + = reinforcement.

Figure 1

Peter, Prepared for his Three Laps Around the Indy 500 Track (June 2013).

Note. Photo courtesy of Maggie Sweeney.