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Learning Words in Space and Time: Probing the Mechanisms Behind the Suspicious-Coincidence Effect

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Abstract

A major debate in the study of word learning centers on the extension of categories to new items. The rational approach assumes that learners make structured inferences about category membership, whereas the mechanistic approach emphasizes the attentional and memory processes that form the basis of generalization behaviors. Recent support for the rational view comes from observations of the *suspicious-coincidence effect*: People generalize category membership narrowly when presented with three subordinate-level exemplars that share the same label and generalize category membership broadly when presented with one exemplar. Across three experiments, we examined the mechanistic basis of this effect. Results showed that the presentation of multiple subordinate-level exemplars led to narrow generalization only when the exemplars were presented simultaneously, even when the number of exemplars was increased from three to six. These data demonstrate that the suspicious-coincidence effect is firmly grounded in the general cognitive processes of attention, memory, and visual comparison.

Keywords

language, cognitive processes

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Explanations of word learning can be broken into two broad classes—rational and mechanistic. In the rational approach, the problem of word learning is viewed as one of rational inference and described in terms of hypotheses, evidence, and structured inference (e.g., Chater & Manning, 2006; Heibeck & Markman, 1987; Xu & Tenenbaum, 2007b). In the mechanistic approach, word learning is viewed as the product of memory and attentional processes and the dynamic representational states they engender (e.g., Gershkoff-Stowe & Hahn, 2007; Plunkett, 1997; Regier, 2003; Smith & Samuelson, 2006; Stokes & Klee, 2009). The relation between the rational and mechanistic accounts is unresolved and controversial (Griffiths, Chater, Kemp, Perfors, & Tenenbaum, 2010; McClelland et al., 2010). Some researchers argue that the two approaches are complementary rather than directly competitive (see Regier, 2003; Sakamoto, Jones, & Love, 2008), and others claim that these explanations are valid at different levels of analysis with different goals (Kemp & Tenenbaum, 2009). We do not attempt to resolve this controversy in this article, but we add to the discussion by offering a mechanistic view of a phenomenon called the *suspicious-coincidence effect*, which was predicted by Xu and Tenenbaum's (2007b) rational account of structured probabilistic inference.

Studies on the suspicious-coincidence effect have been inspired by situations like this: A learner sees a big white dog with black spots and hears, "Look at the pretty *fep*!" Next, the learner sees another white dog with black spots and hears, "Look, another *fep*!" The learner then sees a person walking two white dogs with black spots and hears, "Two more *feps*!" The predicted inference is that the learner will infer that *fep* refers to this specific type of white dog with black spots and not to the class of dogs. To quote Xu and Tenenbaum (2007b),

> Intuitively, this inference appears to be based on a *suspicious coincidence*: It would be quite surprising to observe only Dalmatians called feps if in fact the word referred to all dogs and if the first four examples [the learner saw] were a random sample of feps in the world. (p. 249)

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Xu and Tenenbaum (2007b) reported that both children and adults make this type of inference when learning the referent of novel words. For example, when shown three Dalmatians and given a novel name—*fep*—participants only generalized the name to other Dalmatians. By contrast, when participants were shown a single item—a single Dalmatian—and given a novel name—*fep*—participants generalized the name to all variety of dogs. This result might seem surprising: Learners show broader generalization from just one instance (one Dalmatian) than from multiple instances (three nearly identical Dalmatians). Moreover, the result provides strong evidence for a learning system that represents probability distributions and makes structured inferences over those distributions. Xu and Tenenbaum (2007b) concluded that "an intuitive sensitivity to these sorts of suspicious coincidences is a core capacity enabling rapid word learning, and we argue it is best explained within a Bayesian framework" (p. 249).

The striking finding that led Xu and Tenenbaum (2007b) to this conclusion—broader generalization from a single instance than from three (nearly identical) instances—is also consistent with mechanistic accounts couched in terms of memories and representations for learning events. This proposal takes as its starting point a hundred years of research in experimental psychology indicating that the breadth of generalization depends on the diversity of instances, the diversity of the contexts in which those instances are experienced, whether they are presented simultaneously versus sequentially (e.g., Gibson, 1969; Hahn, Bailey, & Elvin, 2005; Honig & Day, 1962; James, 1890; Mackintosh, 1965; Rips & Collins, 1993), and the order with which instances are encountered (Garner, 1974; Medin & Bettger, 1994; Samuelson & Horst, 2007; Sandhofer & Doumas, 2008; Schyns, Goldstone, & Thibaut, 1998). In the case of the suspicious-coincidence effect, two such task factors may be particularly critical: The fact that the exemplars are simultaneously visible in the task space and that they are nearly identical instances in close spatial proximity. Such simultaneous presentation in close proximity is expected to increase discrimination, fine-grained comparison, and memory for specific shared features (Garner, 1974; Gentner & Namy, 2006; Gibson, 1969; Samuelson, Schutte, & Horst, 2009; Sandhofer & Smith, 2001). The presentation of a single instance by itself with no comparison exemplar may be expected to yield less-focused representations and, thus, broader generalization (see, for example, Garner, 1974; Gibson, 1969; Honig & Day, 1962).

Accordingly, in the experiments reported here, we replicated Xu and Tenenbaum's (2007b) task to examine the narrowness and breadth of generalization across manipulations of the spatial-temporal details of the experienced instances. We showed that learners' categorizations depend critically on whether the instances are simultaneously visible in the task space—a result expected from mechanistic accounts given that the processes that perceive, encode, and remember events are spatially and temporally extended. This dependence on simultaneous presentation was evident across two experiments, even when the number of exemplars was increased from three to six. This increase in the number of exemplars provided a critical test because Bayesian accounts predict that category extensions should become narrower as the number of subordinate exemplars is increased.

General Method

Participants

There were 58 adult participants across the three experiments (19 in Experiment 1, 20 in Experiment 2, and 19 in Experiment 3). Participants received credit in a college course or monetary compensation for their participation. All participants reported normal vision and gave informed consent to participate.

Stimuli

The stimulus set matched that used by Xu and Tenenbaum (2007b). The stimuli consisted of 45 digitized color photographs of real objects from the vegetable, vehicle, and animal domains. Seven photographs from each domain were designated as exemplars: one was a singleton exemplar, two others belonged to the same subordinate-level category as the singleton exemplar, two more belonged to the same basic-level category as the singleton exemplar, and two others belonged to the same superordinate-level category as the singleton exemplar (see Fig. 1). As Figure 1 shows, the one singleton exemplar was repeated at all levels (see Xu & Tenenbaum, 2007b).

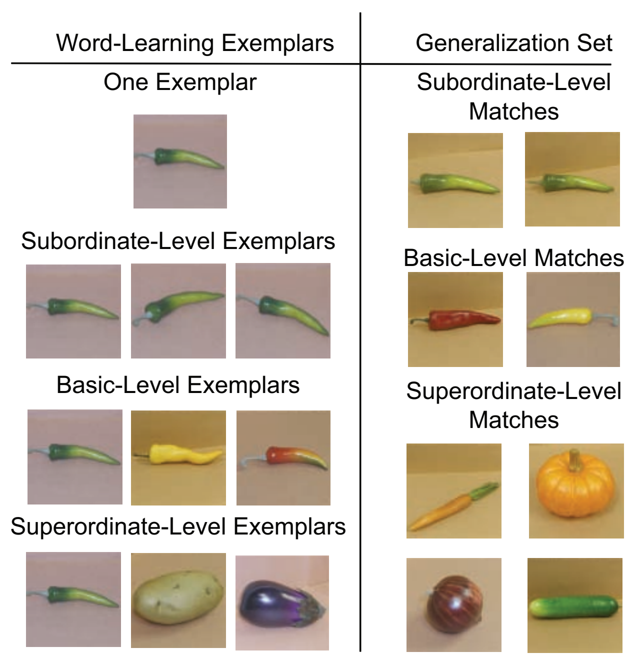

Fig. 1. Exemplars and items in the generalization set for one stimulus domain (vegetables) used in the experiments. On a given trial, one subordinate-level exemplar or three subordinate-, basic-, or superordinate-level exemplars were shown. The generalization set for each domain included two subordinate-level matches, two basic-level matches, and four superordinate-level matches.

Eight photographs from each domain were designated as generalization stimuli: These photographs depicted two subordinate-, two basic-, and four superordinate-level objects (Fig. 1). Twelve nonsense words (e.g., *foo*) were created to describe the exemplars.

Design and procedure

Following the procedure used in Xu and Tenenbaum (2007b), we told participants that they were playing a game with Mr. Frog. One or three target exemplars appeared at the bottom of a computer screen in one or each of three possible locations, depending on the trial type and the experiment (see Fig. 2). A nonsense label for the exemplars was provided to the left of the images (e.g., a chili pepper was identified as a "wug"). Twenty-four different generalization stimuli from the three domains appeared in a random distribution across a 4 × 6 grid above the exemplars. Participants were asked to find all the objects from the generalization set that matched the exemplar (e.g., "give Mr. Frog all the other wugs"). Participants selected each picture that matched the target exemplar by clicking on it with the mouse. The selected items were highlighted by a green box. Participants clicked a "Done" button when they finished making their selections.

For each of the three domains, there were four trial types, in which participants were presented with one exemplar, three subordinate-level exemplars, three basic-level exemplars, or three superordinate-level exemplars (see Fig. 1). Nonsense words were assigned to exemplars randomly across participants. Participants completed all trials of one type (e.g., the one-exemplar trials for animals, vegetables, and vehicles) before moving on to the next trial type (e.g., the basic-level-exemplars trials for animals, vegetables, and vehicles). The first block of trials always involved either one exemplar or three subordinate-level exemplars from each domain. The remaining blocks of trials were randomly ordered for each participant.[1]

General Results

The suspicious-coincidence effect is about how people generalize novel words in two critical conditions: when a single exemplar is presented versus when three subordinate-level exemplars are presented. This phenomenon is also primarily about differential generalization at one specific level—the basic level. In particular, when Xu and Tenenbaum (2007b) presented participants with a single exemplar (a Dalmatian), people generalized this item to roughly 57% of the basic-level matches (averaged across children and adults). By contrast, when presented with three subordinate-level exemplars (three Dalmatians), people generalized these items to roughly 7% of the basic-level matches. Responses at the subordinate and superordinate levels were comparable across these two conditions (participants generalized to roughly 95% of the subordinate matches and roughly 7% of the superordinate matches).

Although we included all conditions in each experiment to fully replicate Xu and Tenenbaum's (2007b) experiment, we focused our analyses on changes in basic-level responding in the one-exemplar and three-subordinate-level-exemplars conditions (see results for Experiments 1–3). Analyses of data from the remaining conditions in the full data set (including two supplemental experiments) revealed no significant differences in responding across experiments (see Table 1 for the full set of results). In particular, as in Xu and Tenenbaum's experiment, participants generalized to a high percentage of the subordinate-level matches across all exemplar conditions and experiments. An analysis of variance (ANOVA) comparing

Fig. 2. Examples of the experimental display when a single exemplar was presented (left) and when three subordinate-level exemplars were presented (right). Exemplars were presented in the lower portion of the screen and described by a nonsense word (e.g., "wug"). Participants were instructed to select objects similar to the exemplar from the 24-item generalization set shown above. They clicked the "Done" button after they selected the matches on each trial. The selected items were highlighted by a green box (not shown).

Table 1. Mean Percentage of Items Selected From Each Categorization Level of the Generalization Set During Each Trial Type Across Experiments

Generalization choice and experiment	Trial type			
	One exemplar	Three subordinate-level exemplars	Three basic-level exemplars	Three superordinate-level exemplars
Subordinate-level objects				
Xu and Tenenbaum: adults	96	95	76	94
Xu and Tenenbaum: children	96	94	75	94
Experiment 1	99.12 (3.82)	98.25 (5.25)	96.49 (8.92)	94.74 (16.71)
Experiment 2	95.00 (13.35)	88.33 (16.31)	94.17 (22.47)	90.83 (26.19)
Experiment 3	94.74 (13.66)	92.98 (16.02)	98.25 (7.64)	93.86 (13.84)
Experiment S1	93.86 (9.95)	96.49 (11.88)	99.12 (3.82)	96.49 (8.92)
Experiment S2	91.23 (23.81)	93.86 (13.84)	91.23 (23.81)	88.60 (26.67)
Basic-level objects				
Xu and Tenenbaum: adults	76	9	91	97
Xu and Tenenbaum: children	40	6	75	88
Experiment 1	48.24 (40.40)	10.53 (24.97)	92.10 (20.31)	85.09 (27.72)
Experiment 2	30.83 (37.18)	53.33 (36.11)	90.00 (13.68)	86.67 (26.27)
Experiment 3	39.91 (35.20)	51.75 (42.63)	92.10 (15.08)	72.81 (33.43)
Experiment S1	24.56 (32.09)	16.67 (25.45)	82.45 (25.74)	69.30 (45.22)
Experiment S2	15.79 (24.51)	11.40 (24.25)	85.96 (20.23)	80.70 (37.37)
Superordinate-level objects				
Xu and Tenenbaum: adults	9	1	4	87
Xu and Tenenbaum: children	17	0	8	62
Experiment 1	7.02 (16.01)	0.88 (2.62)	15.35 (11.20)	81.31 (23.54)
Experiment 2	5.83 (20.42)	2.50 (4.75)	13.33 (21.01)	75.41 (30.04)
Experiment 3	4.82 (14.24)	14.47 (21.66)	17.54 (21.31)	67.98 (30.83)
Experiment S1	6.14 (17.75)	0.88 (2.62)	21.49 (29.30)	61.40 (43.76)
Experiment S2	1.75 (5.94)	0.00 (0.00)	11.84 (12.20)	67.26 (32.43)

Note: The table presents results from the three experiments reported here and two supplemental experiments (information available in the online Supplemental Material), as well as from a previous study by Xu and Tenenbaum (2007b). Standard deviations are given in parentheses.

the percentage of subordinate matches selected across exemplar types (one, three subordinate level, three basic level, and three superordinate level) and experiments (1, 2, 3, S1, S2) revealed no significant effects.

Table 1 also shows that, as in Xu and Tenenbaum (2007b), participants rarely selected superordinate matches after being presented with one exemplar or three subordinate-level exemplars. The selection of superordinate-level matches increased when three basic-level exemplars were presented, and it increased even further when three superordinate-level exemplars were presented. It is critical to note that an ANOVA comparing superordinate-level responses showed no significant differences across experiments.

Finally, we examined generalization at the basic level across two conditions that were not central to the suspicious-coincidence effect—when three basic-level and three superordinate-level exemplars were presented. When participants saw three basic-level exemplars, they generalized at the basic level more often than when they saw three superordinate-level exemplars. Once again, an ANOVA revealed no significant differences in basic-level responding across experiments for these two conditions.

Experiment 1

This experiment replicated Experiment 1 from Xu and Tenenbaum (2007b). On trials with three exemplars, the exemplars were displayed simultaneously. Our results were consistent with Xu and Tenenbaum's previous findings: Participants selected a significantly higher percentage of basic-level matches when they saw one exemplar than when they saw three subordinate-level exemplars, $t(18) = 3.40$, $p < .01$, two-tailed (Fig. 3). The magnitude of basic-level selections in the one-exemplar condition was comparable to the overall mean performance in Xu and Tenenbaum's (2007b) study, but it was higher than children's basic-level performance and lower than adult's basic-level performance. It is not clear why adults in our experiments were more conservative in their responding at the basic level than the adults in Xu and Tenenbaum's study were. Nevertheless, our results robustly replicate the suspicious-coincidence effect: Participants showed significantly narrower generalization when three subordinate exemplars (e.g., three Dalmatians) were presented relative to when a single exemplar (e.g., one Dalmatian) was presented.

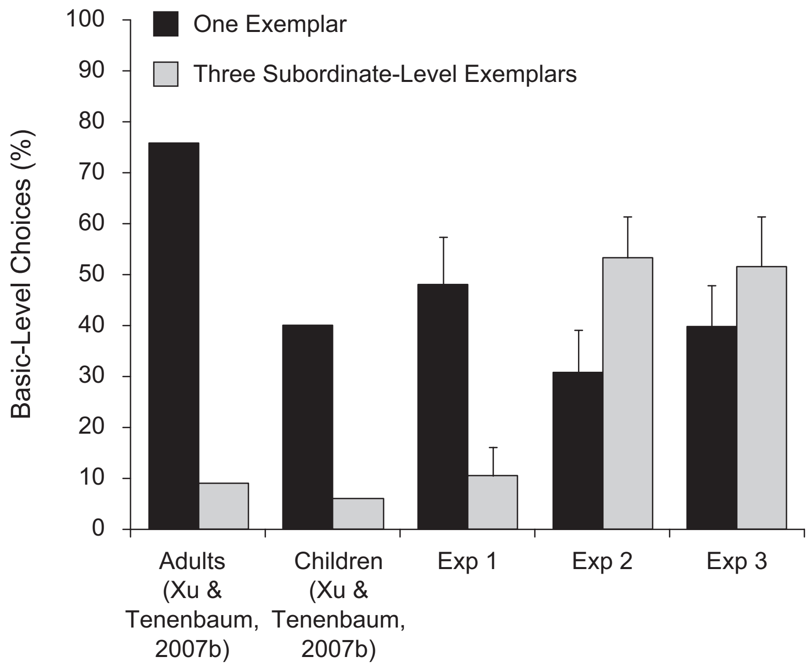

Fig. 3. Mean percentage of basic-level exemplars selected from the generalization set on trials with one exemplar and trials with three subordinate-level exemplars. Results are shown for Experiments 1 through 3, as well as for adults and children in Xu and Tenenbaum's (2007b) study. Error bars show standard errors.

Experiment 2

In Experiment 1, the exemplars were simultaneously in view and in close spatial proximity; this procedure is known to foster comparison, attention to shared features, and fine-grained discrimination (e.g., Gentner & Namy, 2006; Gibson, 1969; Samuelson et al., 2009). In Experiment 2, we manipulated this aspect of the task by presenting the three subordinate-level exemplars sequentially at the three different locations along the bottom of the screen. This sequential presentation is arguably more consistent with experienced instances in everyday word learning, which are, as in our Dalmatian example, not usually experienced at the same time or place.

Procedure

In this sequential version of the task, the first exemplar was presented at the left location for 1 s and then removed, then the second exemplar was presented at the middle location for 1 s and removed, and then the third exemplar was presented at the right location for 1 s and removed. This sequence was repeated two times prior to the presentation of the generalization set, for a total of 6 s of study time. The display continued to loop through the three subordinate-level exemplars continuously until the participant clicked "Done." Note that we presented the three subordinate-level exemplars in the first block of trials to ensure that performance on these critical trials was not influenced by generalizations on the other trials. We conducted two supplemental experiments, Experiments S1 and S2, which confirmed that this manipulation in isolation did not modify the robustness of the suspicious-coincidence effect, nor did the addition of an initial study phase (see the Supplemental Material available online for details of Experiments S1 and S2).

Results and discussion

As Figure 3 shows, manipulating the manner of presentation of the three subordinate-level exemplars had a dramatic effect on participants' performance—it reversed the suspicious-coincidence effect. In particular, participants generalized more broadly at the basic level when they saw three subordinate-level exemplars in a sequence than when they saw one exemplar in isolation, $t(19) = -3.01$, $p < .01$, two-tailed. The broader generalization when participants saw three subordinate-level exemplars differed significantly from performance in the replication of Xu and Tenenbaum's (2007b) study in Experiment 1, $t(37) = -4.28$, $p < .0001$, two-tailed. By contrast, the slightly narrower generalization in the one-exemplar condition did not differ from performance in Experiment 1, $t(37) = 1.40$, $p = .17$, two-tailed. These results are consistent with findings reported in the large literature on comparison processes (e.g., Gentner & Namy, 2006; see also Vlach, Sandhofer, & Kornell, 2008). They suggest that the suspicious-coincidence effect is critically linked to these processes and is sensitive to the space-time details of experience.

Experiment 3

Experiment 2 showed that people generalize novel words differently when the exact same stimuli are presented sequentially at three locations versus simultaneously at three locations; this result is consistent with findings reported in the large literature on the effects of simultaneous and sequential presentation on perceptual learning (e.g., Gibson, 1969), attention (e.g., Chun & Nakayama, 2000), and relational and category reasoning (Gentner & Namy, 2006). One might argue, however, for an alternative interpretation that is perhaps more in line with statistical inference. At the limit of sequential presentation (e.g., with long temporal delays between presentations as might be experienced in everyday life), the instances might not be remembered in detail or identified as multiple different exemplars of the same subordinate group. This raises the question: Did participants detect that multiple different exemplars of the same type of thing were present? If not, they might have generalized broadly in Experiment 2 because they interpreted the display as containing only a single item (even though the display indicated that three items were present, for example, "Here are three wugs"). Informal discussions with participants after the testing session suggested that they knew, for instance, that the dogs were different examples of the same type of dog; nonetheless, we sought to provide direct evidence on this issue in Experiment 3.

Another way to vary presentation to highlight commonalties and differences among similar items is to present the items sequentially, but all at the same location. When sequential items are presented in the same location with no delay between presentations, differences are easy to detect because visual attention does not have to shift to a new location and the viewer can rely on lower-level sensory memory (e.g., Phillips, 1974). Thus, in Experiment 3, we showed exemplars sequentially at a single location to facilitate the task of identifying that multiple different exemplars from the same subordinate-level group were being presented.

In addition to this manipulation, we made a second modification to directly pit the mechanistic and rational accounts. According to the "size" principle in Xu and Tenenbaum's (2007b) account, subordinate-level hypotheses will be assigned greater probability than hypotheses at other hierarchical levels, and such differences are amplified exponentially as the number of consistent examples increases. For instance, with three examples as in Experiments 1 and 2, the likelihood ratio of subordinate- and basic-level hypotheses is inversely proportional to the ratio of their sizes, raised to the third power. Accordingly, we increased the number of exemplars in Experiment 3 to six. If Xu and Tenenbaum's (2007b) analysis is right, the suspicious-coincidence effect should be more dramatic, and generalization should be very narrow. By contrast, if the suspicious-coincidence effect depends principally on the type of detailed comparison afforded by simultaneous presentation, then, given the sequential presentation in our experiments, we should once again fail to see this phenomenon.

Procedure

Experiment 3 was identical to Experiment 2, except that we presented six subordinate examples. These examples were presented for 1 s at a time at a single central location, and the text on the screen said that there were six objects instead of three objects. As before, participants were given 6 s of study time before the generalization set appeared, and the sequence of exemplars looped continuously until the trial was done. The central question was whether participants would generalize narrowly on the basis of the suspicious coincidence that six exemplars were all given the same novel label or generalize broadly given the challenges of remembering and comparing multiple subordinate items presented sequentially.

Results and discussion

As Figure 3 shows, the results replicated the key finding from Experiment 2—sequential presentation led to broad generalization at the basic level, even when six exemplars were presented. Indeed, participants generalized broadly across both critical conditions, with no significant difference between conditions with one exemplar and six subordinate-level exemplars, $t(18) = -1.30$, $p = .21$. The broad generalization with six subordinate-level exemplars differed significantly from generalization with three subordinate-level exemplars in Experiment 1, $t(36) = -3.64$, $p < .001$, two-tailed. The broad generalization with one exemplar was comparable to performance in the same condition from Experiment 1, $t(37) = -0.78$, $p = .44$, two-tailed. Thus, even when participants saw six subordinate exemplars all given the same label, they still generalized broadly at the basic level when the exemplars were presented sequentially.

Across experiments, then, participants showed a striking inability to detect a suspicious coincidence when exemplars were presented sequentially. This shows that the spatial and temporal details of experience matter critically to identifying suspicious coincidences. Indeed, these details had a more profound influence on performance than the number of exemplars, a result suggesting that space and time might be more of a constraint on performance than the size principle proposed by Xu and Tenenbaum (2007b).

General Discussion

Outside of the laboratory, people (including young children) experience objects and hear labels distributed in space and time across many different locations and many different times. Thus, understanding how the spatial and temporal dynamics of experienced instances influence word learning is important in its own right. The suspicious-coincidence effect reported by Xu and Tenenbaum (2007b) is also important because it illustrates a core principle of statistical learning and thus provides support for a specific Bayesian model of probabilistic structured inference. As reported by Xu and Tenenbaum (2007b), this effect is not consistent with hypothesis-elimination approaches (Berwick, 1986; Pinker, 1984; Siskind, 1996), nor is it consistent with connectionist or associative accounts (Colunga & Smith, 2005; Gasser & Smith, 1998; Regier, 1996; Roy & Pentland, 2004). Xu and Tenenbaum's Bayesian model—a rational approach to word learning—is currently the only formal theory that has quantitatively captured this experimental result.

Our experiments considered the suspicious-coincidence effect in the context of more basic perceptual and cognitive processes and prior research probing the impact of simultaneous and sequential presentations of instances in learning experiments. Results of Experiments 2 and 3 indicate that people do not generalize narrowly when multiple subordinate-level exemplars are presented sequentially, even when twice as many subordinate-level exemplars are presented. A critical question is why. We contend that the answer lies in how participants compare items and extract similarities and differences with these different modes of presentation. Simultaneous presentation invites an emphasis on fine-grained similarities and differences. Participants might, for instance, notice that the green peppers from the exemplar set in Figure 1 all have a dark green region near the stem. This observation might lead them to select other green peppers with this same dark-green region in the generalization set (the subordinate-level matches), but reject peppers that do not share this feature (the basic-level matches). Sequential presentation, by contrast, affords a more global interpretation of similarity (see Samuelson et al., 2009), leading participants to emphasize the overall light-green shade of the peppers in the exemplar set. In this case, they would select the two subordinate-level matches and also the yellow-green pepper in the basic-level set.

To our knowledge, there are five previous experiments showing the suspicious-coincidence effect: Experiments 2 and 3 in Xu and Tenenbaum (2007b); Experiment 1 in Xu and Tenenbaum (2007a); and Experiments 1 and 2 in Gweon, Tenenbaum, and Schulz (2009). In all of these cases, the exemplars were simultaneously visible in the task space in close spatial proximity. If the narrow generalization effect in these studies depends on the fine-grained comparisons afforded by simultaneous presentation, then the meaning of the suspicious-coincidence effect itself may have to be rethought. At the very least, our data limit the applicability of the Bayesian model to situations in which exemplars are in close temporal and spatial proximity. This is a critical boundary condition if the goal is to explain real-world word learning: The simultaneous experience of multiple instances of a subordinate-level category in close proximity is not the typical word-learning context.

Space and time were not included in Xu and Tenenbaum's (2007b) model. Thus, the perceptual, attentional, and memory processes that led us to test the effects of sequential presentation are outside the purview of that account. Nevertheless, their model is designed to provide insight into word learning, and space and time matter to word learning. Experiment 3 did manipulate a factor that the Bayesian account claims is central to category extension—the number of exemplars. Our findings directly contradict the model's claim that the likelihood of generalizing at a particular level is scaled exponentially by the number of exemplars at that level. Sequential presentation effectively trumps the number of subordinate-level exemplars.

One question is whether the Bayesian model can be modified to capture our results. For instance, Xu and Tenenbaum (2007a) reported broader generalization at the basic level in a "learner-driven" condition, in which participants—rather than a knowledgeable teacher—selected a set of subordinate-level exemplars. This result was predicted on the basis of the assumption that learners treat items selected by a teacher as independent samples from the real extensions of novel words; this is in contrast to their own selections, which are uninformative about the extensions of novel words. Is it possible, then, that sequential presentation led participants in our study to treat the samples as biased or nonindependent, yielding broader basic-level generalization? We know of no reason why participants might do this. Moreover, the Bayesian model predicts a drop in subordinate-level responding when independence is not assumed (Xu & Tenenbaum, 2007a). This did not occur in our experiments (see Table 1). Thus, it is not clear how the Bayesian model might explain our results.

The perceptual and memory factors that motivated this study do not offer straightforward explanations of other findings that were directly predicted by the Bayesian account, for example, the role of the distribution of the generalization set (Gweon et al., 2009) and differential generalization in teacher-driven versus learner-driven conditions (Xu & Tenenbaum, 2007a). This brings us to the doorstep of the current controversy over rational and mechanistic accounts of word learning and categorization. Clearly, rational, structured inference captures something real about human cognition; just as clearly, human cognition is grounded in the real-time dynamic processes of memory and attention at another level of description.

All of this underscores the utility of thinking about Marr's (1982) levels of analysis, not as separate levels, but as mutually informative and reciprocal (see Sakamoto et al., 2008). In the end, computational-level accounts will have the greatest impact (and endure as explanations) when they connect to other levels and to the details of behavior in substantive ways. In this context, our data present a challenge to one particular Bayesian account and show that it must move to greater specificity with respect to the role of space and time in learning from instances. There are a large number of phenomena in experimental psychology—such as the effects of simultaneous versus sequential comparison—that are both principle-like in their robustness across experimental tasks and principally about the dynamic properties of memory, attention, and generalization (Samuelson & Smith, 2000). Our results suggest that properties of statistical learning and outcomes such as the suspicious-coincidence effect are critically connected to these more general processes.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

Note

1. Xu and Tenenbaum (2007b) did not block the three-exemplar trials; rather, they presented these trials in a pseudorandom order, counterbalanced across participants. These researchers also used only nine distinct words as labels for the 12 exemplar sets; they used the same labels to refer to the singleton exemplar and the three subordinate-level exemplars. Unfortunately, these details were not in Xu and Tenenbaum's article; instead, they came to light in the review of our manuscript. We regret this inconsistency across studies; however, our three replications of the key findings (Experiment 1 and Supplemental Experiments S1 and S2) demonstrate that these details are not critical to learners' categorizations.

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