The Effects of Learning and Retrieval Contexts on Cross-situational Word Learning

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Abstract— Natural linguistic environments usually provide structured input, in that words that are semantically-related are likely to occur in the same situation. The current study examined whether this kind of semantically-themed structure facilitated cross-situational word learning. Results from two experiments consistently showed that participants had higher performance in semantically-themed learning contexts. In contrast, themed retrieval contexts did not affect performance. Our work suggests that learners' ability to use statistical information to acquire word-to-object mappings is enhanced when learning is put in a more naturalistic and structured context.

***Index Terms*—contextual effects, semantic cues, cross-situational learning, word learning**

I. Introduction

One of the most challenging tasks that children face in language acquisition is to learn the meanings of different words. In natural learning environments, children usually have many different objects simultaneously in view each time they encounter a novel object label. The challenge is to figure out the correct word-to-object mapping among potentially infinite number of possible mappings, a phenomenon known as the *indeterminacy of reference* [1]. It has been proposed that one way to solve the word-to-object mapping problem is through tracking the co-occurrences between words and objects across different situations, which is known as *cross-situational word learning* [2]. An increasing body of experimental research has shown that infants, children, and adults are all capable of using co-occurrence information accumulated across situations to learn novel word-to-object mappings [3-5]. In addition, the idea of cross-situational learning has been used to build artificial systems that can associate words with their meanings in the physical world, in particular, to solve the symbol grounding problem in the AI systems [6]. For example, Belpame and Morse [7] compared a cross-situational learning model with an interactive model and showed that both can successfully build word-meaning associations. Fontanari and Cangelosi [8] demonstrated that cross-situational learning as an unsupervised learning mechanism can perform as well as supervised operant conditioning learning. Furthermore, the general framework of cross-situational learning has been expanded to combine with different constraints and biases or with additional cues, such as mutual exclusivity bias, affordance information, social cues, linguistic cues, or perception-action associations, which leads to more efficient learning in the AI systems [9-11].

Most previous experimental studies on cross-situational word learning mainly focused on investigating to what extent human learners can solely use statistical co-occurrences between individual words and objects to build correct word-to-object mappings. In real life, however, in addition to statistical information, learners are usually also provided with social, linguistic, attentional, and different contextual cues; and children are known to be capable of using those cues in their word learning [12, 13].

Moreover, in most previous cross-situational word learning experiments, participants were presented with either novel objects that had no apparent association with each other or real objects that were randomly assigned in different learning trials. Yet, in daily conversation, we rarely randomly assemble unrelated words in discourse. Instead, we tend to talk in a thematically-related way. Discourse analyses have shown that children's input is often organized topically around different activities. Through analyses of real-life child-directed speech, Roy, Frank, & Roy [14] found that semantically or thematically relevant words usually go together in the input children receive. For example, when parents talk about *milk* in their conversation with children, they also tend to mention *water*, *tea*, *cookies*, and *cup*. On the other hand, when they talk about a *ball*, they are also likely to mention other types of balls, such as *basketball*, or actions that can be associated with the ball, such as *catch*, *bounce*, *throw*, or *kick*. These examples show that in real life, words are often presented in a more structured context.

The question, then, is whether this type of semantically-themed learning context is beneficial for word acquisition. If so, structuring the learning environment in this way may facilitate word learning in both humans and artificial agents. One potential advantage of using themed contexts is that semantically-related items may serve as contextual cues and

facilitate retention and recognition of each other. However, one potential disadvantage of having themed contexts is that simultaneously learning multiple semantically-related words may increase the confusability among items and thereby the errors in retrieval. Findings from memory research have shown both positive and negative effects of themed learning contexts. For example, it is easier to recall lists consisting of words from the same semantic category than lists consisting of words belonging to different categories [15]. On the other hand, research on false memory has shown that after memorizing a list of semantically-related words (e.g., *hospital*, *nurse*, *sick*), adults are more likely to falsely recall or recognize semantically-related words that are not in the list (e.g., *doctor*) [16, 17].

In a recent study, Dautriche and Chemla [18] used an artificial word learning task in which adult participants heard one novel word in each trial (e.g., "There is a *blicket* here.") and had to guess its referent from 4 real objects (e.g., dog, cat, pan, and hat). On their first exposure to a novel word, participants had no information of which referent was associated with the target word and had to guess randomly. However, whenever participants heard a word in a trial, its target referent was always present in that same trial. Therefore, the design allowed learners to use cross-situational statistics to learn correct word-to-object mappings. The results showed that the participants were more efficient in learning and had higher accuracy in a condition where semantically-related objects (e.g., dog, cat, cow, rabbit) were presented in the same trials within the same block than in a condition where objects that were semantically related were randomly assigned across different trials. This finding pointed to the possibility that semantically-themed learning contexts facilitated word learning. However, since words referring to semantically-related objects were also presented in consecutive trials in that study, it was not clear whether the blocked presentation also contributed to the observed facilitative effect, as massed presentation has been shown to enhance performance in immediate tests [19]. Another noteworthy finding of that study was that artificially induced categories (i.e., semantically-unrelated objects that co-occurred frequently) had similar, albeit weaker, facilitative effect. Therefore, it is possible that the facilitative effect was not due purely to the semantically-themed design. Instead, a more general structured design, be it induced by semantics or by co-occurrences, along with the blocked design may jointly contribute to the improvement in word learning in that study.

The major goal of our study was to test the effect of semantically-themed learning contexts on adults' cross-situational word learning. There are many ways to create semantic themes (e.g., by actions or locations). In this study, we focused on semantic relations based on taxonomic categories. Instead of asking participants to select the referent of a novel word in every learning trial, as was done in Dautriche and Chemla [18], we used a cross-situational word learning task proposed by Yu and Smith [5], in which participants went through all learning trials before being tested. The reason for this choice was that having trial-by-trial response could sometimes encourage learners to adopt a single-referent tracking method and perform in a more hypothesis-testing than an associative learning manner [20]. Yet in real-life word learning, one usually has to keep track of multiple words and objects across different situations without being asked to identify the referent of each word in every situation. This latter cross-situational word learning design allowed us to test the effect of semantically-themed contexts in a more cumulatively tracking scenario.

Two experiments were designed to investigate the effects of semantically-themed contexts on cross-situational word learning. In Experiment 1, we compared adult participants' word learning in either a Themed learning condition or a Non-themed condition and tested their accuracy in a Themed retrieval context. In Experiment 2, we replicated the findings by testing participants' word learning in a Non-themed retrieval context. Together, these two experiments allowed us to examine whether semantically-themed learning and retrieval contexts affected performance and whether there was an interaction between learning and retrieval contexts.

II. Experiment 1

Experiment 1 was designed to test whether seeing semantically-related objects occurring in the same trials affected cross-situational word learning. Participants were assigned to either a Themed-condition, where objects in a trial mainly came from the same category, or a Non-themed condition, where objects in a trial usually came from different categories. After going through a series of learning trials, participants were then tested on how well they learned. This design allowed us to examine whether simultaneously learning the labels of semantically-related objects facilitated word learning or whether it increased the confusability among items and hindered learning.

A. Participants

Participants were 64 undergraduate students (34 females, mean age: 18.79, SD=1.21) at Indiana University who received course credits for volunteering. Thirty-four of them participated in the Themed condition and thirty in the Non-themed condition.

B. Materials

The stimuli used in this experiment were 48 novel words and 48 pictures of real objects. Each participant was exposed to 24 word-object pairs. The novel words consisted of 1 or 2 syllables and followed English phonotactic rules (e.g., *dax*, *toma*). The objects belonged to 8 different categories (e.g., animal, vegetable, vehicle, and furniture), with 6 items in each category. Each participant was only exposed to 4 of the categories (4 category * 6 items = 24 items).

C. Design and Procedure

There were 2 conditions in the experiment, a Themed condition and a Non-themed condition (Panels A and B of Figure 1). Participants in both conditions went through a

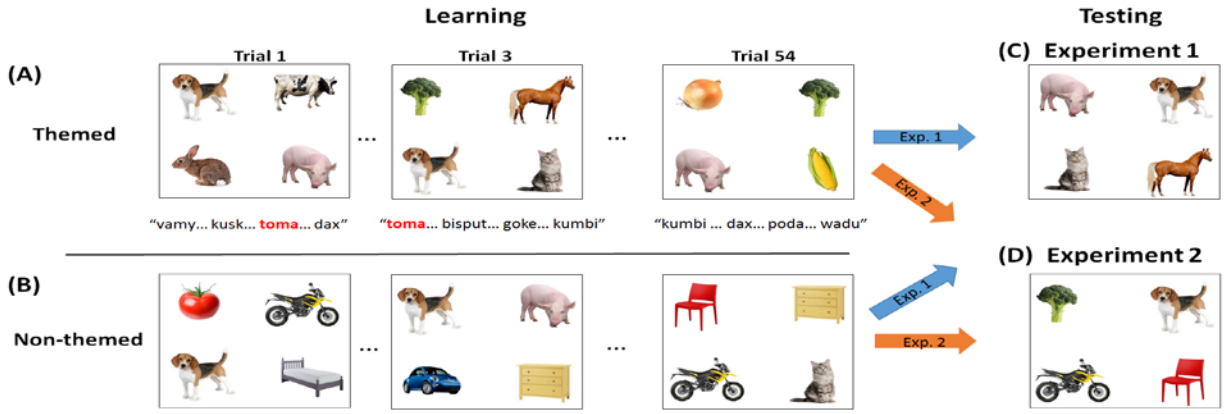

Figure 1 A schematic of the Learning and Testing sessions in Experiments 1 and 2. (A) Themed Condition: The majority of Learning trials consisted of at least 3 items from the same category. (B) Non-themed Condition: Most Learning trials had no more than 2 items from the same category. (C) In the Testing session of Experiment 1, participants heard 1 trained word and had to pick its referent from 4 same-category objects they had seen in the Learning session. (D) In Experiment 2, participants heard 1 trained word and had to pick its referent from 4 objects, each coming from a different category.

Learning session followed by a Testing session. In the Learning session, participants saw 4 pictures of real objects and heard their labels presented in a random order in each learning trial. Figure 1 illustrates a schematic of the Learning and Testing sessions of the study. Take Tria1 1 in Panel A (the top-left box) as an example. Participants saw a dog, a cow, a rabbit, and a pig and heard 4 novel words *vamy*, *kusk*, *toma*, and *dax* but were not given any information of which object was associated with which word. However, in Trial 3, participants saw the dog and heard the word *toma* again. If they remembered having heard the word *toma* while seeing the dog in the same trial previously, they should be able to infer that the word *toma* referred to the dog. Therefore, even though the word-to-object mappings were ambiguous within each trial, participants should still be able to find correct word-to-object mappings by tracking co-occurrences across trials.

Over the Learning session, each word-object pair occurred 9 times, yielding a total of 54 learning trials (24 objects* 9 repetitions/ 4 objects per trial). Even though we wanted to create a Themed learning session with most (if not all) trials consisting of objects from the same category, we recognized the problem that if an object co-occurred with the same set of distractors (i.e., objects from the same category) too often, learning the correct word-to-object pairings could become almost impossible. Therefore, we added one constraint to the design that each word could not co-occur with any non-target object for more than 4 times. This constraint ensured that each word co-occurred with its referent over twice as frequently as with any other objects (i.e., 9 vs. less than 4 times).

To seek the balance between having most trials in the Themed condition containing objects from the same category and keeping correct mappings learnable in both Themed and Non-themed conditions, we used 4 different trial structures. As can be seen in Table 1, in the Themed Condition, 14 trials had the 4-0-0-0 structure with all 4 objects coming from the same category; 20 trials had the 3-1-0-0 structure with 3 of the objects from one category and the other one from another category; 14 trials had the 2-1-1-0 structure with 2 objects from one category and the other two each coming from a different category; and 6 trials had the 1-1-1-1 structure with all 4 objects each coming from a different category. In contrast, the majority of trials in the Non-themed condition were either 2-1-1-0 or the 1-1-1-1 trials.

Table 1 Number of Trials with Different Trial Structures in the Themed and Non-themed Conditions

Trial Structure	Learning Condition	
	Themed	Non-themed
4-0-0-0	14	0
3-1-0-0	20	2
2-1-1-0	14	34
1-1-1-1	6	18

Following the Learning session, participants were tested for their knowledge of the word-object pairings. In each test trial, participants heard 1 word and had to pick its referent from 4 objects. Items in each test trial all came from the same category (Panel C of Figure 1). From the perspective of co-occurrence frequency, the test trials in the Themed condition should be harder than the Non-themed condition, because the foil probability in the Themed condition was higher than the Non-themed condition. Or put it differently, because items in the same category often co-occurred in the same learning trials in the Themed condition, the same-category foil objects at test generally were stronger competitors; and this should make the Test trials "harder". In contrast, because the same-category foil items in the Non-themed condition rarely co-occurred with the target words during Learning, based on co-occurrence frequencies, they should not be strong competitors and thus should make the Test trials in this condition "easier". On average, the foil objects in the Test trials in the Themed condition co-occurred with the target words 2.417 times (range: 1-4 times) while the foil objects in the Non-themed condition co-occurred with the target words 1.208 times (range: 0-3) during Learning session ($t(46)=10.636$, $p<.001$). Therefore, if co-occurrence frequency is the only factor that determines test accuracy, one should expect to see higher performance in the Non-themed condition. Alternatively, if Themed contexts facilitate learning, one should expect to see higher performance in the Themed condition.

D. Results and Discussion

We first tested whether participants successfully learned correct word-to-object mappings. As seen in Figure 2, participants in both Themed and Non-themed conditions learned more word-object pairs than expected by chance (Themed: $M = 0.856$, $SD = 0.191$, $t(33) = 18.521$, $p < 0.01$; Non-themed: $M = 0.700$, $SD = 0.306$, $t(29) = 8.053$, $p < 0.01$). This indicated that participants were able to use co-occurrences to learn word-to-object mappings.

The next question was whether learners in the Themed and Non-themed conditions performed differently. As illustrated in Figure 2, participants in the Themed condition had significantly higher accuracy than their counterparts in the Non-themed condition ($t(62) = 2.467$, $p < .05$). As mentioned above, from the perspective of foil probability, the test trials in the Themed condition should be "harder" than those in the Non-themed condition. Yet, learners still had better performance in the Themed condition. This result indicated that the facilitation effect resulted from the Themed learning context could override the effect of the foil probability at test.

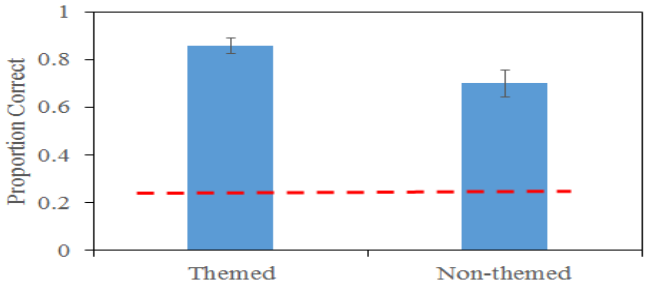

Figure 2 Word learning performance in the Themed and Non-themed conditions in Experiment 1. The dashed line indicates chance level (1/4).

Participants' superior word learning performance in the Themed condition in this experiment suggests that Themed contexts facilitate word learning. However, it could be argued that this effect could be due to the match between the learning context and the retrieval context in the Themed condition, as both were semantically-themed. It has long been recognized in memory research that the match between encoding and retrieval conditions can usually facilitate retention or recall of information [17, 21]. In a recent study on children's word learning, Vlach and Sandhofer [22] found that young children were more likely to have correct responses in a condition where the background cloth on which they learned the name of a novel object matched the background cloth on which they were tested than in a condition where the background cloths in the learning session and test session mismatched. It is possible that the match between the learning context and test context in the Themed condition had a similar effect. Experiment 2 was designed to rule out this explanation.

III. Experiment 2

The Learning session in Experiment 2 was identical to Experiment 1 in that some participants were trained in a Themed condition while others were trained in a Non-themed condition. The test trials in Experiment 2, however, used a Non-themed design, with each object in a trial coming from a different category. If the superior performance in the Themed condition in Experiment 1 was due purely to the match between learning and retrieval contexts, learners in the Non-themed condition in Experiment 2 should benefit from the Non-themed test trials. Following this logic, one should then expect that learners in the Non-themed condition in Experiment 2 will outperform their counterparts in Experiment 1. In addition, learners in the Themed condition in Experiment 2 will have worse learning performance than their counterparts in Experiment 1, because of the mismatch between learning and test contexts. In contrast, if the superior performance in the Themed condition in Experiment 1 was due to the contextual support from semantically-related objects, we should expect to see the learning patterns in Experiment 2 similar to those observed in Experiment 1.

A. Participants

Participants were 64 undergraduate students (31 females, mean age: 18.83, SD=1.41) at Indiana University who received course credits for volunteering. Thirty-four of them participated in the Themed condition while thirty in the Non-themed condition.

B. Materials

The stimuli included the 48 words and 48 pictures used Experiment 1. Each participant was exposed to a total of 24 word-object pairs, with the objects belonging to 4 different categories (6 items per category) in the Learning session.

C. Design and Procedure

The design of the Learning session was identical to that of Experiment 1. However, each Test trial in Experiment 2 consisted of 4 objects, each from a different category (Panel D of Figure 1).

In Experiment 2, the foil probabilities at test were matched for the Themed condition and the Non-themed condition. On average, the test foils in the Themed condition co-occurred with the target words 2.306 times (range: 1-3 times) in the Learning session while the foils in the Non-themed condition co-occurred with the targets 2.333 times (range: 1-4 times). There was no significant difference between the co-occurrences between the target words and the foil objects in these two conditions ($t(46) = -.624$, $p > .05$).

D. Results and Discussion

In this section, we first tested whether participants learned correct word-to-object mappings in the Themed and Non-themed conditions. We then compared learners' performance in these two conditions. Following that, we conducted a cross-experiment analysis by testing whether there were consistent effects of learning or retrieval contexts, as well as an interaction between learning and retrieval contexts.

As can be seen in Figure 3, participants in both Themed and Non-themed conditions learned more word-object pairs than expected by chance (Themed: M = 0.830, SD = 0.241, $t(33)$ = 14.046, $p < 0.01$; Non-themed: M = 0.683, SD = 0.292, $t(29)$ = 8.137, $p < 0.01$). This, again, suggested that participants were able to keep track of the co-occurrences among words and objects across trials and use the information to form correct word-to-object mappings.

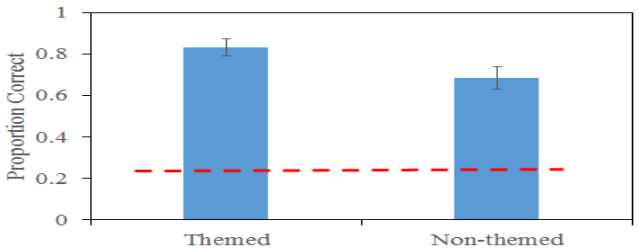

Figure 3 Word learning performance in the Themed and Non-themed conditions in Experiment 1. The dashed line indicates chance level (1/4).

The next question was whether participants in the Themed and Non-themed condition performed differently, given that the test trials used a Non-themed design in the current experiment. Consistent with the findings in Experiment 1, learners in the Themed condition in Experiment 2 also had significantly better performance than learners in the Non-themed condition ($t(62)$=2.198, p <.05). Even though there was a match between the learning and retrieval contexts in the Non-themed condition, participants in the Themed condition still had superior word learning performance.

The last set of analyses examined the effects of learning contexts and retrieval contexts by comparing Experiments 1 and 2. Table 2 provides a summary of the mean accuracy in the Themed and Non-themed conditions in these two experiments.

Table 2 Proportion of Accuracy as a Function of Learning and Retrieval Context

Retrieval Context	Learning Context		
	Themed	Non-themed	M
Exp. 1: Themed	.856	.700	.778
Exp. 2: Non-themed	.830	.683	.757
M	.843	.692	

Overall, learners in the Themed Learning conditions had better performance than the Non-themed conditions. In contrast, Retrieval contexts did not seem to affect performance. The reliability of the learning and retrieval context effects were assessed by using an Analysis of Variance (ANOVA). Consistent with the observation, there was a significant effect of learning contexts, $F(1, 124) = 10.846$, p =.001. However, there was no effect of retrieval contexts, $F(1, 124) = .214$, p >.05, nor was there any interaction between learning and retrieval contexts, $F(1, 124) = .01$, p >.05. These results further indicated that the superior word learning in the Themed condition found in Experiment 1 was not due to the match between the learning and retrieval contexts. Results from Experiment 2 suggested that the Themed learning context alone was sufficient to induce superior word learning.

IV. General Discussion

Natural linguistic environments provide structured input, in that words that are semantically-related are likely to occur in the same situation. The current study investigated whether this kind of semantically-themed structure facilitated cross-situational word learning. Two experiments were conducted to test the effects of Themed learning contexts and Themed retrieval contexts on adults' novel word acquisition. Experiment 1 showed that participants had higher performance in the Themed condition where individual learning trials usually consisted of objects from the same category than in the Non-themed condition where objects presented in each trial were not related to each other. Experiment 2 replicated the finding and further ruled out the possibility that the superior performance observed in the Themed condition was due purely to the match between the learning and retrieval contexts. In contrast to previous memory and word learning research that emphasized encoding-retrieval match [17, 21, 22], the current study indicated that whether or not the structure of the retrieval context matched the structure of the learning context did not affect adults' cross-situational word learning.

One question to ask, then, is why are semantically-themed contexts beneficial for word learning? One possibility is that semantic-relatedness among items in the Themed learning trials served as a contextual cue that facilitated encoding of object features in the Learning session and created richer representations of those objects. Previous studies on visual word recognition suggested that the richness of semantic representations can affect visual word recognition and implicit word learning [23, 24]. Similar effect may have played a role in the current study as well. In addition, objects from the same category share multiple features with each other. It has been suggested that highly inter-connected cues can sometimes bootstrap learning [25]. The Themed condition may facilitate detection of related features among items; and items from the same category may mutually reinforce the learning and retention of each other.

On a related note, compared to many previous cross-situational word learning studies [5, 20], the accuracy was much higher in the present experiments. In the current study, each word-object pair occurred 9 times across the Learning session. On average, participants in the Non-themed conditions learned over 16 word-object pairs (out of 24). This learning rate was comparable to a design used in Romberg & Yu [19], in which participants learned around 16 word-object pairs (out of 18) after being exposed to each pair 12 times. Moreover, participants in the Themed conditions, on average, learned over 20 word-object pairs, a rate higher than seen in many other studies. One possible reason for the performance differences between the current study and previous studies is that the objects used in the current study were all familiar objects whereas the objects in previous studies were unfamiliar objects. The familiarity of the objects in the current study may make the encoding of the visual stimuli easier. This, in turn, may make tracking word-object co-occurrences less effortful and lead to better learning.

In sum, our work points to the importance of grounding statistical learning in context. A growing body of research on

infant and robot learning has stressed the importance that learning cannot be dissociated from the world [26]. Our study further contributes to the literature by showing that semantically-themed learning trials provide learners with contextual support and facilitate learning. The effect of the Themed learning contexts can even override the effects of encoding-retrieval match and foil probability. Statistical word learning is not one powerful mechanism that only exists in vacuum but disappears when other types of cues are available. Our findings demonstrate that learners' ability to use statistical information to acquire word-to-object mappings is enhanced when learning is put in a more naturalistic and structured context. Learners can take advantage of structured input and use statistical information and semantic cues jointly in their acquisition of novel words.

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