# A Model-based Approach to Second-Language Learning of Grammatical Constructions

**Gwen Frishkoff (gwenf@pitt.edu)**
Learning Research & Development Center, University of Pittsburgh
3939 O'Hara Street, Pittsburgh PA 15260 USA

**Lori Levin, Phil Pavlik, & Kaori Idemaru (lsl, ppavlik, idemaru@cs.cmu.edu)**
Carnegie Mellon University
5000 Forbes Ave, Pittsburgh, PA 15213 USA

**Nel de Jong (cornelia.dejong@qc.cuny.edu)**
Linguistics and Communication Disorders, Queens College of CUNY
65-30 Kissena Blvd., Flushing, NY 11367

**Abstract**

The goal of this work is to examine how second-language learners acquire grammatical knowledge. To measure this knowledge, our research examines how native speakers of English choose between constructions that have similar meanings, but occur in different discourse contexts. An example is the dative alternation (*give someone the book* vs. *give the book to someone*). The distribution of these two constructions is explained by a four-factor model that describes the patterns or rules that underlie native-speaker usage. We hypothesized that training examples could be selected to instantiate these four factors in a way that would lead to improved learning of the dative alternation. In addition, we predicted that explicit instruction of the four grammar principles would further enhance learning. Two studies were conducted. Results showed rapid learning and good retention across a week-long delay. Examples that were labeled as "easy" or prototypical by the grammar model were learned faster than "hard" examples. In addition, explicit instruction gave an additional boost in performance. We conclude with a description of ongoing work in computational modeling and new studies that test transfer of learning based on the four-factor model. The long-term goal is to use this approach to design learning interventions that are cognitively and linguistically based and that lead to robust learning of grammar in a second language.

**Keywords:** second language acquisition, grammar, linguistic modeling, cognitive modeling.

## Introduction

Grammar acquisition presents some interesting challenges for a theory of learning. From previous work in linguistics, we know that languages often possess multiple grammatical forms that express roughly the same meaning (called grammatical "alternations"). For example, English has different ways to express events in present time, including the present perfect (*has/have been here*) and simple present tense (e.g., *am/are here*). However, these forms are not interchangeable: appropriate usage depends on context. Thus, it is fine to say, *I <u>have been</u> here for two years*, whereas the simple present (**I <u>am</u> here for two years*) is infelicitous, or has a different meaning (future rather than present time reference). Moreover, there are often many linguistic variables that determine the appropriate use of a grammatical form, and these variables may combine to determine when it is most appropriate to use a particular form in a particular context. Given this complexity, it is challenging for second-language learners to learn the semantic and pragmatic functions of grammatical forms. Furthermore, this problem is widespread. There are many examples of grammatical forms that have similar meanings, but are distributed nonrandomly, suggesting they may have different meanings, or discourse-pragmatic functions (Givón, 1988, 1990; Pinker, 1989).

In the present paper, we suggest a new approach to this problem in second-language learning. This approach rests on a theory of grammatical knowledge and a methodology for capturing this knowledge in statistical models. These models can then be used to design grammar learning experiments in order to test hypotheses about second-language learning of grammatical alternations. More specifically, our approach draws on three methods: (a) ***corpus linguistic research***, which yields precise models of the principles that account for native-speaker (L1) usage of grammatical forms (b) ***experiments*** designed to manipulate and measure student learning of these principles, and (c) ***computational models*** that specify conditions for optimal learning in natural language contexts. In effect, we propose that students must learn the underlying principles that determine how alternating forms are distributed in natural language in order to use them accurately, fluently, and in the appropriate contexts.

The present paper describes results from two grammar learning experiments that provide initial support for our proposal. These experiments were designed to examine learning of the so-called "dative" alternation in English. We present background for these experiments and discuss how computational modeling helps to clarify the cognitive and linguistic mechanisms underlying skilled performance in our task. We then discuss more recent work that tests the independence of the "knowledge components" identified in our studies and shows evidence for transfer of learning, consistent with our model predictions.

## Learning the Dative Alternation

In the present paper, we examine second-language learning of the ***dative alternation***, i.e., the two alternative forms or that are used to express "giving" or "transfer" events in English. These two forms differ in the ordering of the two noun phrases (NP) that come after the verb. In one form, the ***Recipient NP*** (one who receives/is given something) comes before the ***Theme NP*** (thing that is given/received). We refer to this form as the NP-NP construction (e.g., *give someone something).* In the alternate form, the Recipient appears in a prepositional phrase (PP) and comes after the Theme. We refer to this form as the NP-PP construction (e.g., *give something to someone).*

Over the years, linguists have identified a variety of linguistic variables that determine when native speakers will use the NP-NP or the NP-PP form. These variables include the length, animacy, and grammatical number of the Recipient and Theme NPs, the relative length of the two NPs, and verb class (e.g., whether the verb expresses physical transfer of an object or verbal communication). Many of these variables are thought to reflect core linguistic principles that link grammatical forms to communicative meanings and goals, such as the relative *topicality* or importance of NP referents over the course a conversation (Givón, 1988). Mastery of these principles may therefore be important for achieving accurate and fluent communication in a second language.

In some contexts, the multiple variables that have been linked to the dative alternation are "aligned" to create a strong bias towards one of the two forms; other contexts support the opposite bias. Consider examples (a) and (b) below.

| | |
|---|---|
| (a) When I got pulled over yesterday, I didn't have my driver's license with me, so the policeman gave… | (b) I have a six month old baby. When I go back to work it will break my heart to give… |
| ***… me a ticket.*** (NP-NP) | … a stranger her. (NP-NP) |
| … a ticket to me. (NP-PP) | ***… her to a stranger.*** (NP-PP) |

Recently, Bresnan and associates (Bresnan & Hay, 2006; Bresnan & Nikitina, 2003; Bresnan, et al., 2005) proposed a model that makes quantitative predictions about which form is likely to occur in a given context. This model reflects the contribution of many, or perhaps all, of the variables that have been previously linked to the dative alternation (see Methods for details). The existence of such a model has important implications for teaching the dative alternation. For the first time, we have a model that specifies the concrete linguistic "cues" that a learner must attend to in order to approximate native-speaker usage of alternating grammatical forms. This knowledge is critical, because we know that robust learning of grammar, as of any complex skill, requires frequent and regular practice. The question is, ***What kind of practice*** — that is, which examples of the dative alternation, and can they be presented to learners in a way that supports optimal learning? To address the first question (which examples), it is important to know what features of the linguistic context make a difference for learning. The Bresnan model provides a tentative answer to this question, by specifying what combinations of cues result in strong or weak responses among native English speakers. The answer to the second question (how to present these examples) is addressed through learning experiments that test hypotheses about optimal scheduling of practice to support robust learning (Pavlik & Anderson, 2005). Thus, the existence of an explicit model of the dative, together with a learning model, leads to several predictions regarding optimal learning of the dative alternation. Two predictions were of particular interest in the present study:

1. Learning was predicted to be more effective when training examples were selected to maximize alignment of model cues ("easy" or prototypical examples); and
2. Explicit teaching of the linguistic rules for the task were expected to boost performance, relative to learning based solely on implicit practice.

In effect, we propose that model-based selection of examples for instruction can guide second language learners to acquire sensitivity to grammatical cues and to learn the appropriate weightings of these cues in real, natural language contexts. Our long-range goal is to use the Bresnan model, together with our cognitive (ACT-R) model, to select training examples in a way that leads to optimal learning of grammatical alternations.

# Methods

Using the Bresnan model as a blueprint, we designed a series of experiments to explore how English language learners respond to manipulation of different linguistic cues during learning of the dative alternation.

## Grammatical Model

The goal of the Bresnan et al. (2005) corpus analysis was to determine how various linguistic features are statistically weighted, or combined, to determine the likelihood that a native speaker will select either the NP-NP or the NP-PP form in a particular discourse context. Fourteen variables were examined, including the following: the definiteness, pronominality, animateness, and discourse accessibility of the Recipient and Theme NPs, the verb class (giving verbs vs. telling verbs) and the relative length of the Recipient and Theme NPs. The Bresnan team used these attributes to mark-up a subset of the Switchboard corpus, a collection of phone conversations on topics relating to politics, sports, and family life (Godfrey et al., 1992). Bresnan et al. identified 2600 instances of verbs that allow their arguments to undergo dative shift (*give, tell, pay,* etc.). Every sentence that contained such a verb was coded as either NP-NP or NP-PP and was annotated for the 14 features. A logistic regression model was then trained on the annotated subset of contexts. The resulting 14-feature model predicts which form (NP-NP or NP-PP) is likely to occur in a given discourse context (accuracy, ~92%).

We applied Principal Components Analysis (PCA) to the 14-factor model to obtain a smaller set of variables that would be more amenable to experimental manipulation. The input to the PCA consisted of 2360 rows X 14 columns, where columns represent the 14 linguistic variables in the original Bresnan model, and rows are speech samples from the Switchboard corpus that include examples of the dative alternation (NP-NP and NP-PP constructions). The data were decomposed using PCA with promax rotation. The resulting Factor Pattern Matrix showed a sensible clustering of variables. Givenness, Definiteness, and Pronominality of the Recipient noun phrase (NP) — which correspond to accessibility of the recipient NP in memory (or "topicality") — loaded on Factor 1 (~23% variance). Givenness, Definiteness, and Pronominality of the Theme loaded on Factor 2 (~15% variance). Concreteness of the Theme and verb loaded on Factor 3 (~ 9% variance). Length split across Factors 1 and 2 in the first analysis. The four variables that had the smallest contribution were dropped from the second analysis, resulting in a new 5-factor structure, where length loaded separately on Factor 4. The first four factors were selected for manipulation in our learning experiments, as described in the following section.

## Stimulus Development

The Bresnan annotated contexts were labeled as either "easy/high contrast" or "hard/low contrast," depending on the score they were assigned by the regression model. When all four factors favor the same construction in a given context, one of the two forms (NP-NP or NP-PP) is clearly preferable. Thus, it is fairly easy to decide which form to select. When the factors favor different constructions (i.e., when there are competing cues), both forms may be acceptable. In this case, the decision is harder.

For our first two experiments, training stimuli were selected from the Bresnan corpus (an annotated subset of examples from the Switchboard corpus). Eighty sentences (20 easy and 20 hard for each of NP-NP and NP PP) were selected for each of the four factors. For example, we selected 20 NP-NP high-contrast ("easy") sentences with definite, pronominal, and given Recipient NPs. Another 20 low-contrast ("hard") NP-NP sentences were selected with definite, pronominal, and given Recipient NPs. This procedure was repeated for the NP-PP form, and for the other three factors.

In selection of corpus examples, we excluded sentences that contained a formulaic use of the dative shift (e.g., *give it a try*) and included a variety of verbs as they appeared in the corpus.

To investigate whether learners can process and respond to the grammatical features that we manipulated for our experiments, it was important to ensure that subjects could comprehend the semantic content of the sentences. Therefore, we made the following changes to the Switchboard corpus examples: (1) long sentences were shortened, (2) low frequency vocabulary words were replaced by high frequency synonyms, (3) culture-specific references were changed to culture-neutral content, and (4) false starts and hesitations were removed. These modifications were applied with caution so that values for the Bresnan features were unperturbed. Finally, each example was altered to generate the alternative (i.e., the nonpreferred) ending. For example, if the sentence appeared as NP-NP in the corpus, a corresponding NP-PP sentence was constructed.A total of 320 examples were used in the dative experiments.

A pilot study was conducted with 20 native-English speakers using the modified corpus stimuli. The goal was to verify that native English speaker preferences for NP-NP or NP-PP constructions were consistent with the Bresnan model predictions. A repeated-measures ANOVA revealed main effects of factor ($F$=7.5, $p$<.001) and contrast ($F$=110, $p$<.001). The strong contrast effects in the data show that the stimuli selection and creation procedures resulted in stimuli that retain the differences the model predicts should occur.

## Study Participants

Study participants were volunteers recruited from intermediate-level grammar courses at the English Language Institute (ELI), University of Pittsburgh. Native English speakers were also tested to assess the accuracy of the reduced (4-Factor) model. We expected native-speaker task performance to be higher and less variable in the high-contrast vs. low-contrast condition.

Data from 109 subjects were acquired in Studies 1 and 2; 24 datasets were excluded due to technical problems during acquisition, leaving 85 datasets for analyses, including data from 40 native English-speaking (NES) and 45 non-native (ESL) subjects. The mean class level for ESL subjects was the same across the two experiments (mean Level 4.05 in the Explicit study, and 3.96 in the Implicit study).

## 2.4. Experiment Design and Protocol

Participants completed two sessions, scheduled one week apart. They were paid for their participation ($15/hour plus an additional amount that was contingent on task performance, averaging ~$5-8). Prior to Session I, participants completed a Language History Questionnaire and read and signed a consent form. They then completed a sequence of 8 blocks (16 trials per block). On each trial, they were presented with a context (one or two short sentences), which ended with a ditransitive verb (*give*, *tell*, etc.), followed by two alternative completions (either an NP-NP or an NP-PP structure). Subjects selected the best completion by pressing the '1' or '2' key on the keyboard (response mapping randomized). A trial counter at the top of each screen tracked and displayed subject accuracy on each trial (number correct/number trials completed). ELI subjects took approximately 1.5-2 hours to complete Session I, and native English speakers took ~1-1.5 hours.

In Session II (one week later), subjects completed another 4 blocks (64 trials). At the end of the task, they answered a 3-page questionnaire that was designed to test learning and retention of the grammar rules that were introduced in the first session. Subjects completed Session II in 1-2 hours.

Two versions of the task were conducted. In Study 1 (***Implicit version***), participants completed the protocol described above. Training in all 12 experiment blocks was the same, with accuracy feedback given on each trial, but with no explicit feedback on why a particular response was right or wrong. The study was designed to support implicit pattern learning. In Study 2 (***Explicit version***), participants completed the same protocol, but with two types of additional, explicit instruction. First, the four grammar principles (factors) were explicitly introduced between Blocks 2 and 3. Second, in Blocks 5-6 (Session I) and Blocks 9-10 (Session II), we provided rule-based (explanatory) feedback on incorrect trials, to inform subjects of the relevant rule that determined the correct response.

## Study Hypotheses

The goal of these two experiments was to test the following hypotheses:

(A) Learning will be more effective when training examples are selected to maximize the strength of model cues (high-contrast/easy/prototypical versus low-contrast/hard/nonprototypical examples).

(B) Explicit instruction in the model-based grammar principles will accelerate learning, because it will draw the learner's attention to relevant information in the context that they case use to select the appropriate form.

# Results

We first examined the learning curves for Studies 1-2 for overall patterns, and then conducted Analyses of Variance (ANOVAs) to test our study hypotheses.

## Learning Curves

As shown in Figures 1 and 2, native English speaking (NES) subjects performed close to ceiling, whereas English language learners (ELI subjects) showed an increase in performance across blocks.

In addition, task performance was more accurate in the high contrast condition for both groups, consistent with the model predictions.

Interestingly, there was a marked decrease in ESL task performance in Block 5, with the introduction of explanatory (rule-based) feedback (see final section for discussion).

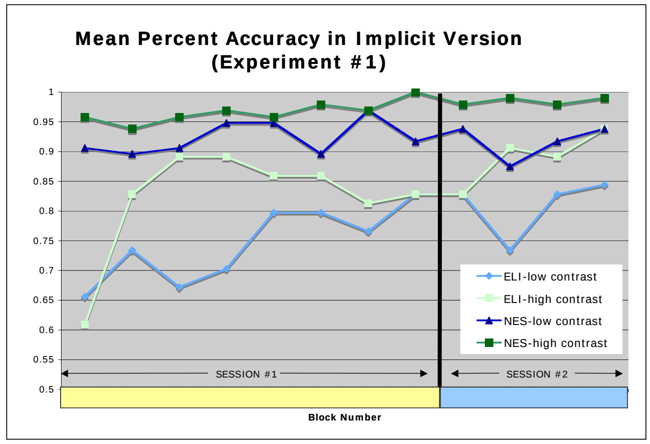


**Figure 1**. Study 1 (Implicit Instruction). Solid black line indicates 1-week delay between Sessions 1 and 2.

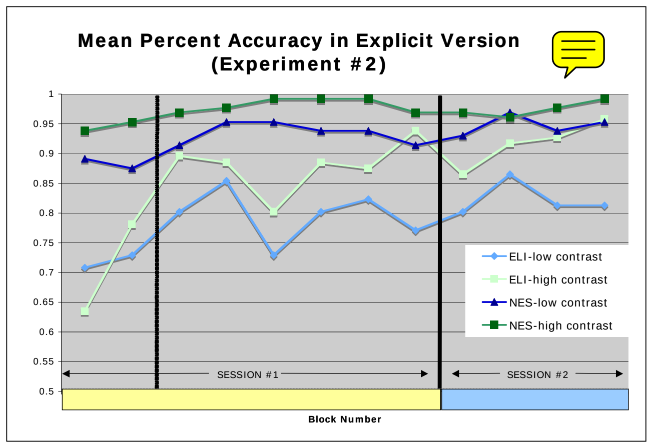


**Figure 2**. Study 2 (Explicit Instruction). Dotted line separating Blocks 2, 3 indicates presentation of grammar rules. Transparent green shading overlaying Blocks 4-5 and 9-10 indicates use of explanatory (rule-based) feedback on incorrect trials. Solid black line indicates 1-week delay between Sessions 1 and 2.

## Analyses of Variance

To examine the effect of explicit instruction (due to the introduction of rules between Blocks 2 and 3 in the Explicit group, Study 2), we compared mean accuracy in Blocks 3-4 for the Implicit and Explicit study groups. A mixed Analysis of Variance was conducted, in which Contrast was the within-subject variable, and Study Version (Explicit vs. Implicit) was the between-subjects variable.

Results showed a significant interaction between Contrast and Version, $F(42) = 4.47$, $p < .05$), suggesting there was a beneficial effect of providing explicit grammar instructions. Although the 3-way interaction was not significant, the benefit of explicit instructions was only apparent for low-contrast examples (Fig. 3). This may be due to a relative ceiling effect for the high-contrast examples.

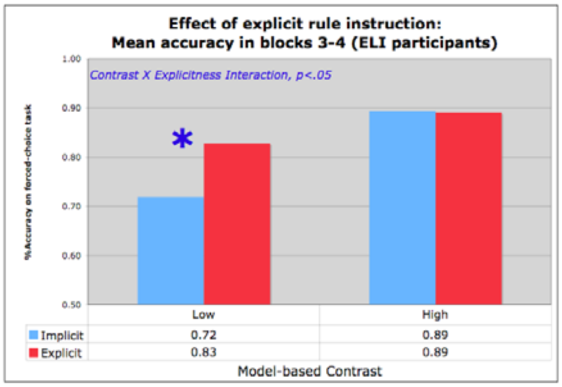


**Figure 3**. Mean accuracy (ESL participants) in Blocks 3-4 for the Implicit and Explicit study participants.

## Computational Modeling within ACT-R

Our goal in this overall project is to use the data we collect to describe a mathematical model of the learning that takes place. Having this model we then hope to analyze its implications to determine the optimal way to deliver practice of our stimuli to improve ESL learners production of the dative construction. This model is a version of the ACT-R (Adaptive Character of Thought - Rational) declarative memory model, which is a mathematical model consisting of a system of equations for describing expected performance as a function of a history of performance (Anderson & Lebiere, 1996; Pavlik & Anderson, 2005). The model of learning that is used to interpret this data is already being used for optimized scheduling in other projects to optimize practice delivery (Pavlik & Anderson, 2008), but the issues in this domain are different and more complex.

Our prior ACT-R work has been applied to vocabulary learning and has made the assumption that each item being learned is independent of other items. This assumption is almost certainly false in the present context, because each item (grammatical example) is controlled by (at least) 4 factors. Bresnan et al. (2005) proposed a model that describes how these factors can combine to predict native speaker performance. It is conceptually straightforward to assume that the sensitivity to each factor is learned as participants are exposed to our experimental stimuli. In this model, which tries to describe how the sensitivities in Bresnan’s (2005) model are learned, learning from each stimulus would result in learning to all 4 factors since each stimuli has some level of affinity with each factor (one factor being dominant which controls the category it was assigned to). Learning is complex according to our results, however, so that it seems to be proportional to the factor strengths of each factor in the stimuli. Thus, if the Accessibility of the Recipient NP is the dominant factor, then learning should occur primarily as a function of the learner's sensitivity to this factor.

It also seems likely that the overall contrast level for a particular example should control learning, since low-contrast items are more discrepant and may therefore attract increased attention, which would in turn lead to increased learning. On the other hand, low-contrast examples might lead to “negative learning”: factors that are not aligned with the preferred response may become less sensitive with learning. As a whole, this set of issues suggests that we need to perform additional studies to understand how the presentation of examples that instantiate different combinations of factors affects learning of these 4 factors in our task.

Assuming that the discussion above is a correct analysis, it does suggest a strategy for training where ESL learners are given stimuli selected to maximally reduce the difference between their skill (sensitivity) levels for the 4 factors and the skill profile for a native speaker. Early on, the best items to maximally reduce this difference would probably be the high contrast items since they should result in the largest change in sensitivity. However, once performance levels neared native speaker levels, it should become more important that we don’t exaggerate the sensitivity for any one factor, so low-contrast examples may become more appropriate to allow the learner to distinguish the fine gradations of factor relevance when factors compete.

Based on our initial datasets, we have succeeded in generating initial computational (ACT-R) models to account for the results described in Figures 1-3. As described previously, stimuli representing each of the four linguistic "factors" that account for native-speaker performance were characterized as high- or low-prototypicality, according to how strongly the model predicted a particular response (NP-NP or NP-PP). Studies 1-2 showed the validity of this high/low prototypicality split: high prototypicality examples resulted in more accurate and less variable performance. Our current modeling has proposed a 4-KC model based on the corpus analysis. This model says that a learning event for a KC occurs when an example from that category is presented for test (with review in the case of error). Further, differences in learning curves for low prototypicality examples as compared to high prototypicality examples were captured by the notion that low prototypicality examples result in performance that is both more variable (modeled by noise on the strength of the KC) and less accurate (modeled by a higher strength threshold for correct performance).

In summary, our work has reached the stage of making test models that can explain our grammar learning results in terms of basic cognitive and learning principles. Ongoing work is examining whether the 4 grammatical factors can be learned independently, which should be the case if they truly have the status of knowledge "components."

## Summary & Conclusion

We began this project with an analysis of the multiple factors (or "cues") that determine when native English speakers select one of two grammatical constructions in a particular context. Our model of the dative alternation benefits from recent large-scale corpus analyses by Bresnan and associates. Simplification of the original Bresnan model allowed us to identify and manipulate four grammatical principles that explain how the NP-NP and NP-PP forms are distributed in native English usage. Moreover, we suggest that mastery of the principles that govern these patterns is the sine qua non of robust grammatical knowledge. In effect, we propose that by learning the principles that determine the correct usage of a grammatical form, they are coming to know the “meaning” (or function) of the form (cf. Pinker, 1989; Givon, 1990). To test this idea, we designed an experiment that makes use the dative models to test two hypotheses about optimal learning of the dative alternation.

The first hypothesis was that learning would be more effective when training examples were selected to maximize the strength of model cues (high- versus low-prototypical examples). Consistent with this prediction, task performance for both groups was more accurate for high vs. low prototypicality sentences.

The second hypothesis was that explicit presentation of the linguistic rules for the task would boost performance, relative to implicit learning (Study 1 versus 2). Results confirmed our prediction. This outcome is not obvious, given prior work on L2 grammar learning (DeKeyser, 2005).

Finally, we predicted that if instructions improved performance, then explicit cueing after errors would enhance this benefit. Interestingly, this prediction was disconfirmed. There was a decrease in L2 performance in Block 5, with the introduction of explanatory feedback. There are several possible explanations for this pattern. One possibility is that feedback cued learners to focus on a particular cue or cues. However, the next trial would be likely to represent a different cue (Factor), requiring participants to switch attention. Mixed designs, in general, may promote this kind of attentional switching. In general, an important issue for future research may be to understand effects of mixing versus blocking of like stimuli. It is possible that while blocked designs eliminate attentional "switch costs," mixed designs may promote more flexible and robust learning.

Ongoing work is aiming to discover precisely what is learned in our task. In one recently completed study we are testing how learning correct usage of the dative alternation might affect usage of other grammatical constructions, including closely related constructions such as the Benefactive (e.g., *I fixed him a plate of spaghetti vs. I fixed a plate of spaghetti for him*), versus more dissimilar alternations, such as the Resultative (*bag the groceries* vs. *put the groceries in a bag)*. Preliminary results suggest that the amount of transfer depends on the degree to which the untrained constructions share the same distribution of cues — i.e., the same grammatical knowledge components — as the trained (dative) construction. If confirmed, these results would support our theory that a L1 grammar model can be used to support predictions regarding L2 learning of specific (model-based) components of grammatical knowledge.


## Acknowledgments

We thank Colleen Davy for assistance with subject recruitment, data acquisition, and coding and entry of study results. This work was supported by the Pittsburgh Science of Learning Center, which is funded by the National Science Foundation, award number SBE-0354420.


## References


Anderson, J. R., Reder, L. M., & Lebiere, C. (1996). Working memory: Activation limitations on retrieval. *Cognitive Psycholy*, 30(3), 221-256.

Bresnan, J. & Hay, J. (2006). Gradient grammar: An effect of animacy on the syntax of give in varieties of English. [draft downloaded from http://www-lfg.stanford.edu/bresnan/download.html]

Bresnan, J. & Nikitina, T. (2003). On the gradience of the dative alternation. [draft downloaded from http://www-lfg.stanford.edu/bresnan/download.html]

Bresnan, J., Cueni, A., Nikitina, T., & Baayen, R. H. (2005). Predicting the dative alternation. Paper presented at the *KNAW Academy Colloquium: Cognitive Foundations of Interpretation*, Amsterdam.

DeKeyser, R. (2005). What makes learning second-language grammar difficult? A review of issues. *Language Learning*, 55, 1-25.

Dienes, Z. & Perner, J. (1999). A theory of implicit and explicit knowledge. *Behavioral and Brain Sciences*, 22(5), 735–755.

Ellis, N. (2007, March 19, 2007). Language use, language change, language acquisition, language instruction: The dynamics of SLA. Paper presented at *LRDC Symposium*, Pittsburgh, PA.

Givón, T. (1988). The pragmatics of word order: Predictability, importance, and attention. In M. T. Hammond, E. A. Moravcsik & J. R. Wirth (Eds.), *Studies in syntactic typology* (Vol. 18, pp. 243-284). Amsterdam: John Benjamins.

Givón, T. (1990). *Syntax: A functional-typological introduction*. Volume II. Amsterdam: John Benjamins.

Godfrey, J., E. Holliman, and J. McDaniel (1992). Switchboard: Telephone speech corpus for research and development. In *Proceedings of ICASSP-92*, pp. 517-520.

Pavlik Jr., P.I. & Anderson, J.R. (2005). Practice and Forgetting Effects on Vocabulary Memory: An Activation-Based Model of the Spacing Effect. *Cognitive Science*, 29, 559-586.

Pavlik Jr., P. I., & Anderson, J. R. (2008, in press). Using a model to compute the optimal schedule of practice. *Journal of Experimental Psychology: Applied*.

Pinker, S. (1989). *Learnability and cognition: The acquisition of argument structure*. Cambridge: MIT Press.