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Abstract

This paper introduces *W*ordcraft, a new interactive tablet
application that allows children to explore sentence
structures and their meanings. *W*ordcraft uses a
constructionist design: children manipulate word cards to
build sentences which, when grammatically well formed,
come to life in a storybook-like animated world to
illustrate their meaning. Such visual feedback helps
children play with parts of speech and understand how
they fit together to form grammatically correct sentences.
Preliminary studies of the use of *W*ordcraft by 17 children
between the ages of 4 and 8 suggest that children were
able to observe how different sentence constructions result
in different meanings and encouraged children to engage
in metalinguistic discourse, especially when playing the
game with another child.

Author Keywords

Authors' choice; of terms; separated; by semi-colons

ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g.,
HCI)]: Miscellaneous. See:
http://www.acm.org/about/class/1998/

General Terms

Introduction

The educational psychologists Neumann Neumann (2014) write that touchscreen interfaces are increasingly being used in the home and educational settings by young children, and the finger-operated tactile affordances of tablets may support pre-schoolers educational development in domains such as literacy. They also note the need for more research into how to scaffold language learning in this new design space.

*W*ordcraft is an interactive tablet application that lets children build sentences and get immediate visual feedback. *W*ordcraft employs the constructionist approach to learning to encourage children to explore ideas while learning with the interface. It allows children to build a sentence incrementally, using immediate visual feedback of how their manipulations affect an animated scene to gain an understanding of how different parts of speech can impact overall sentence structure. Figure 1 shows an example in which the user is building a 5-word sentence and has to insert a preposition in order to activate the animation for the sentence: "A pig is hopping with a goat".

*W*ordcraft was assessed with 17 children aged 4 to 8 across 7 locations over a period of three weeks. Childrens fluency with language was classified as Beginner, Intermediate, and Advanced. Advanced children were able to decipher the meanings of previously unfamiliar words such as "amused" from the visual input and tried to make more complex sentence structures than what was
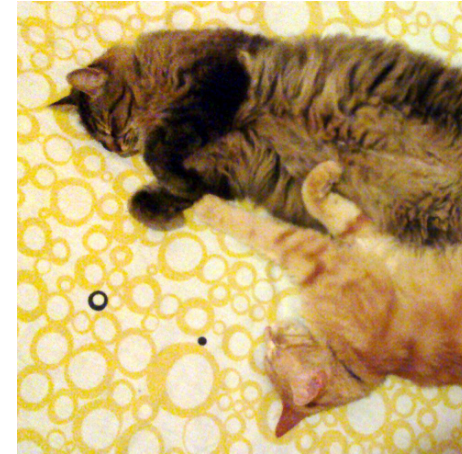
Figure 1: Insert a caption below each figure.

supported by the application. Intermediates were able to point out inconsistencies in the images generated by the tool. Beginners who were still learning to read began to notice the significance of colors, which corresponded to parts of speech. When children were paired with friends from similar age groups, they frequently discussed aspects of language, or metalinguistic discourse. These preliminary results suggest that the approach embodied in *W*ordcrafts design may be useful for improving a child's understanding of the relationship between syntax and meaning.

The remainder of this paper places this research in the context of related work, describes the design rationale and the technology behind the design of *W*ordcraft, presents the user study in more detail, and describes potential future directions.

Related Work

Games for Learning Language

The potential for using manipulative objects for play has led to the development of many physical, digital and virtual manipulative systems designed to help children explore different concepts. Most virtual manipulative systems are designed to teach children concepts in mathematics and programming, and have not been applied to language instruction. Wordcraft aims to retain the qualities of existing manipulative systems, while applying the principles to encourage play and linguistic learning.

Wordcraft is modeled in part on Scratch (Resnick et al., 2011), a visual programming language which is widely successful at teaching beginners to program. Scratch was built on ideas from Lego toys (Resnick, 1993) and is a modern descendant of LOGO, which was designed by Papert (1980) to support constructivist theories of the "child as an epistemologist" who builds knowledge by playing with programmable environments.

Most instructional games that have to do with learning language focus on teaching vocabulary and spelling. Chiong and Shuler (2010) report successful learning outcomes for mobile vocabulary tools for young children, and Kam et al. (2009) introduce games in which children must identify visual objects by name to develop their vocabulary or complete the spelling of a word given some of the letters. Yip and Kwan (2006) found that the vocabulary games they assessed tended to be successful learning tools (for college age learners). Somasundaran and Chodorow (2014) used pictures in a vocabulary assessment task as an alternative to multiple choice questions.

The DuoLingo second-language learning application (von Ahn, 2013) teaches syntax as well as vocabulary through a game-based interface, and also influenced the design of WordCraft. One of Duolingos games consists of a display of a sentence in one language, and a list of words in opposing language presented as cards to be dragged and dropped onto a tray in the correct order to form a sentence. In some cases the user must select between two confounding choices, such as the articles le or la to modify French nouns. If the correct choices are made, a green check mark or some other indicator of correctness is shown. If incorrect, a red X or other indicator of failure is displayed. WordCraft borrows DuoLingos card-based drag-and-drop interface for sentence formation, but greatly expands on it by visually displaying the meaning of a successfully generated sentence in an animated scene on a stage.

Generating Visual Scenes from Sentences

Recently, NLP research interest has grown in the problem of generating textual descriptions of the information viewable within images (e.g., Kulkarni et al., 2013), or conversely, given a sentence, generating a scene illustrating that text (Coyne and Sproat, 2001), or both (Farhadi et al., 2010). For generating descriptions, a popular application is news caption labeling, (e.g., Feng and Lapata, 2010). In most cases, the approach taken is to manually define the visual interpretation of the sentence (Coyne and Sproat, 2001; Kulkarni et al., 2011). Some very recent work attempts to automatically learn visual features that correspond to semantic phrases that are derived from sentence components (Zitnick et al., 2014; Sadeghi and Farhadi, 2011) and generate images from these features. This work does not work with full sentences, and is otherwise still too preliminary to build on for the purposes described here.

Wordcraft Design and Implementation

A major challenge in the design of *W*ordcraft is the mapping from syntax to semantics. The goal of this research was to test the efficacy of the ideas before implementing a full-fledged semantic analyzer and animation generator. Therefore, the sentence structure and vocabulary were restricted to simplify prototyping and evaluating the ideas.

A farm scene was chosen because of its familiarity to children, as seen in childrens books and games; similar kinds of scenarios should be easily substitutable using the same techniques.

The subsections below describe the design and operation of the apps user interface, the system architecture, the NLP component, and the visual framework for the animation component.

Interface Overview
The interface design is the result of three rounds of prototyping and testing with the target population of young children. The interface is divided into three areas the canvas, the *sentence builder* and the *word tray*.

A sentence is built by dragging words from the word tray to the sentence builder, which has a fixed set of slots corresponding to the length of sentence currently being built. The interface allows children to move fluidly between constructing 3-word, 5-word and 7-word sentences, which correspond to game levels. The levels allow children the ability to start simple and move to more difficult sentences at their own pace, and makes the tool appropriate for varying age groups.

When a noun is placed onto a legitimate slot on the sentence builder, an image is rendered on the canvas.

This image is updated with each new noun that is added to or removed from the sentence builder, thereby ensuring that there is immediate visual feedback. Other aspects of the animation are described below.

Words cannot be dragged onto a slot unless they form a grammatically correct sentence. If an incorrect word is dragged to a slot, it automatically falls back into the word area. This gives children feedback on the usage of words and how to create grammatically correct sentences.

The words are color-coded based on parts of speech. They are also grouped spatially in the word tray to help children develop a model of how the parts of speech work. To avoid overwhelming the children with too many words at once, not all candidate words are visible in the word tray at a time; instead, children can click on arrows to scroll through the available words. To increase interest, words are selected randomly from those available in each part-of-speech category to be shown initially.

The bottom of the screen shows a tool bar with three buttons Replay, Delete and Refresh. The Replay button is used to replay an animation, thereby allowing children to absorb and enjoy the visual feedback at their own pace. Dragging a word card onto the Delete button removes the word from the sentence. Advanced users can also replace words in the sentence area with a new word by dropping one word on top of another and seeing how it impacts the visual scene. The Refresh button clears the sentence builder and canvas.

Software Components
Computations are handled client-side, independent of a server, since a broad survey of U.S. parents of children aged 3-7 found that only a small fraction allow children access Internet-enabled mobile devices (Chiong and Shuler

2010). HTML5 is used for scene rendering since most of the objects in the game are pre-rendered hand-drawn vector graphics files. Several NLP platforms were considered but none met the requirements needed across mobile platforms. Instead, to create a self-sufficient, all-device deployable app, a custom grammar rule engine was written from scratch using PhoneGap, an open source toolkit that integrates web technologies portably (Ghatol and Patel, 2012).

The NLP components of WordCraft consist of an English vocabulary drawn from the Dolch word list designed for new readers (Johns, 1970; Jesness, 2004), a short list of valid sentence structures (see Table 1), and a JSON-based data structure that maps objects to the visual renderings that they can be subjected to (described below).

As mentioned above, the language game consists of 3 levels: 3-word, 5-word, and 7-word sentences, although word is used loosely here because in the lower levels, determiners are combined on cards with nouns so that children do not need to worry about agreement. Interestingly, in an earlier version of the design, determiners were capitalized in the word cards, but some children (reasonably) refused to move these into the object slot. In the final design, no word cards contain capitalization. Instead, when a card with a determiner is moved into the initial slot of a sentence, the first word is automatically capitalized.

In Level 1, children make 3 word sentences in a noun-be-verb combination, where the verb is a present participle. Level 2 consists of 5 word sentences in a noun-be-verb-preposition-noun combination. In Level 3, children have to assign the correct determiner for the first noun of the sentence but not the second one, to make 7 word sentences in a

det-noun-adjective-be-verb-preposition-noun combination. All verbs are shown in continuous present tense to reflect the fact that the completion of a sentence causes an animation to occur in the farm scene.

This simple grammar is similar to that of Yang et al. (2011), which was used for generating sentences from image content. It is of course a drastic simplification of possible sentence structure and is done in the interest of prototyping and testing. In some cases, children can form syntactically valid sentences that the system has no semantic equivalent for. In a fully deployed system this behavior would need to be corrected.

Visual Components
Constructing the canvas for the objects mentioned in the sentence involves three main tasks:

- *Rendering the object*: The noun(s) in the scene are compound objects created from individually drawn parts as shown in Figure 2.
- *Manipulating the object*: Animations are determined by the verbs and prepositions applied to the noun(s). Example animations are shown in Figure 3.
- *Placing the object*: The location of the object in the scene is determined by its current location, and in some cases prepositions, and other objects.

The current setting is an outdoor "farm" scene, which has a "vanishing plane" or the horizon, a "ground" plane and a "sky" plane. Each plane has 9 grid positions such as "ground-left-front", "sky-front-back", etc., as seen in Figure 4.

Associated with each word in the vocabulary is a Javascript Object Notation (JSON) data structure that contains information about how to render and animate
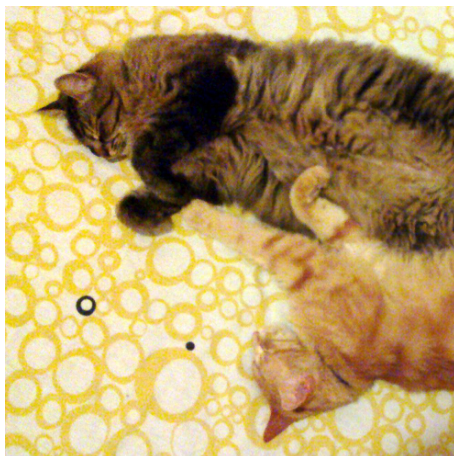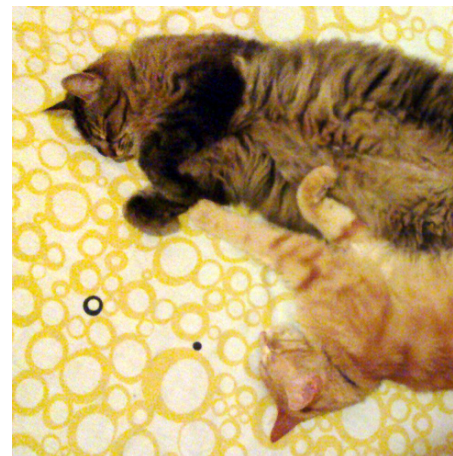
Figure 2: Composition of an object from its constituent parts. Emotions are added by changing the shape of the mouth and eyes.

Figure 3: Composition of an object from its constituent parts. Emotions are added by changing the shape of the mouth and eyes.

the objects when they appear in a sentence. Nouns contain references to:

Constructing the canvas for the objects mentioned in the sentence involves three main tasks:

- The image for the outer skin of the object (the sheep_skin in Figure 2), and whether there are one or two copies of that image for single or plural versions of the noun,
- The images for the current mouth and eyes for that object (happy, angry, etc.),
- The current dimensions and canvas position, including location on the plane as shown in Figure 4,
- The spatial relationship to other objects currently on the canvas,

The verb representations contain animation instructions: duration, speed (normal, very fast, slow, etc.), scale, and animation type (rotate, translateX, translateY). Additionally, each verb is restricted to taking on only certain prepositions, and the verbs definition stipulates how the preposition is interpreted, as described below

Adjectives representations indicate the color, body size (normal, small, large), and eye and mouth properties that noun objects can take on.

Sentence Processing Algorithm
As noted above, each word has a set of predefined properties associated with it. When a word is moved to its legitimate slot, a data structure containing the word and its properties is constructed. As more words are added to the sentence, the data structure becomes augmented
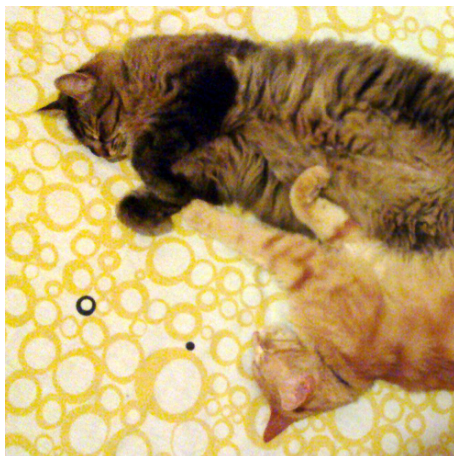
Figure 4: Composition of an object from its constituent parts. Emotions are added by changing the shape of the mouth and eyes.

dynamically with more information.

When the user moves a noun from the word tray to the sentence area, the object representing the noun appears on the stage. The initial state of the noun object is default, which is depicted by a combination of a happy mouth and happy eyes overlaid on the default skin appearance and placed in the default location for that noun. For example, the default location of "cat' is "`center_middle`" and that of "fence" is "`front_left`". In case of a plural noun, two copies of the object are rendered with their positions slightly displaced from one another.

Verbs control the animation as well as change the appearance features (eyes, mouth and skin). Adjectives change the appearance of noun objects.

The verb data structure contains instructions for a restricted set of prepositions, indicating where to move the subject of the verb relative to the object of the preposition. A Boolean indicator determines if the action applies to both the subject of the verb and the object of the preposition, or just the subject alone. For example, the indicator is set to True for the verb hopping and the preposition "with', with the result that "The cat is hopping with the pig." means that both hop together in unison. By contrast, "The cat is hopping near the pig." means that only the cat will hop because the indicator is set to False for "near' for "hop".

The grammar rules engine is a set of if-else conditions built in javascript. Since the sentence structure is fixed based on the length of the sentence, every slot is mapped to the part of speech that it can accept. Dragging words into slots can cause the slot assignment rules to adjust; for example, if the child places the article "a" as the first word in a 7-word sentence, the rules update to indicate that the word that follows must not be an adjective that starts with a vowel, and the auxiliary verb must be the singular is rather than the plural "are". Removing words from the sentence builder also causes reassignment of slot mappings. Nouns also have offsets associated with them, so that when a second noun is placed in a location that is already occupied by a first, it is moved over by that offset amount.

To illustrate the rendering sequence, consider the following sequence of drags from the word tray to the sentence builder to make the 5-word sentence the cat is running in front of the horse

- Step 1: "the horse"
- Step 2: "the cat"
- Step 3: "is"
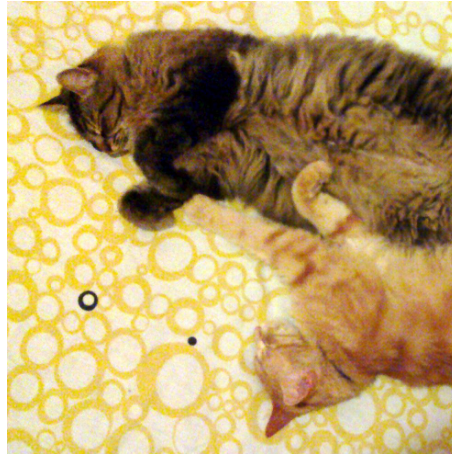
Figure 5: Final design of *W*ordcraft with a "five word" design, although it contains seven actual words

- Step 4: "in front of"
- Step 5: "running"

With step 1, the horse image is placed in its default location in $center_{m}iddle. With step 2, the cat object image appears, offset 2x positions to the left. The word discauses no changes in rendering. After step 4, the cat$

Assessment

The app was developed through three rounds of design assessment with the target population of children; the study results reported here pertain to only the final two rounds of testing. The first round was performed on a very early version of the interface; the second round was performed on the version of the interface shown in Figure 1. The third round was conducted using the final design, shown in Figure 5.

Method
A total of 17 children played with *W*ordcraft over the course of two weekends. The design was assessed using two different modes of evaluation.

The second round of testing was carried out with 7 children. A moderator explained the interface, after which they played with the game for 20 30 minutes, until they stated that they wanted to do something else, or displayed signs of fatigue. The moderator built one sentence as a demonstration. She did not describe the features of the game in depth, but instead let the children explore and find out how various features worked. As they played, the children were asked questions if they appeared to be struggling or if they did anything out of the expected behavior.

Research by Donker and Reitsma (2004) suggests that children do not talk as much during a think aloud session as adults and suggest as a remedy grouping children in pairs. This helps researchers observe childrens conversations and interactions with one another. Therefore, in the third round of testing, the 10 children were grouped in pairs with friends of similar ages. Otherwise, the procedure was the same as before.

Fluency Classification
Instead of a pre-test to gauge ability prior to playing with *W*ordcraft, we asked the children to read the words (combination of 2 nouns, 3 verbs) displayed on the screen when they first saw the app. Based on their ability to read these words, we classified them into 3 groups:

- *B*eginners: They were just beginning to read, and could either spell out words or sound them out phonetically. They needed help from the moderator to be able to read words, after which they selected

the ones they wanted to use in the sentence

- *I*ntermediate: These children could read most words, but had trouble with more complex words, like "depressed". Even if they did not know how to read a word, they were able to sound it out. They were not always aware of syntax they were prone to errors with syntactic agreement (verbs with object number, adjectives with determiner modifier "a" vs. "an")
- *A*dvanced: These children could read all words in the vocabulary, and had prior experience with making sentences. They tried variations of sentences that went beyond the current scope of the project. Some parents indicated that they were comfortable with concepts like sentence diagramming, which indicate that the sentence structures used in this app would be elementary for them. However, the novelty of seeing sentences animated was exciting for them.

These groups were determined based on the reading ability of the children, and not their age owing to the wide variation in reading ability that we observed in children within our target age range. For future studies, we want to calibrate reading levels prior to playing with the app, and also survey parents to get a better understanding of the childs existing exposure to sentence construction and understanding the nuances of language.

Observations

Children of all ages found the animations highly entertaining, and they elicited great attention and excitement. Playing in pairs also increased engagement and aided exploration of the interface.

Beginners

Four children (aged between 4 - 6 years) were classified as beginners. Each of these children had trouble reading words without help. The moderator helped them with difficult words. Beginners spent a lot of time with the 3 word sentences. The children who were part of the paired tests in round 3 were motivated to try 7 word sentences. The children who played by themselves in round 3 were not as keen to move forward, and needed to be encouraged by the moderator to move forward. Once they moved forward, they chose to move back from 5 and 7 word sentences to keep trying out the easier 3 word sentences.

- *Using sentences to reading Words*: For a child who is still beginning to read, the interface allows exploration to understand which letters correspond to which word. For instance, Sarah[1] was able to identify that "p I g" was "pig" after seeing the resulting image on the screen. After playing with the app for 15 minutes, she was also inspired to state, "I can make 10 sentences", and she came up with 5 sentences that followed the sentence structure in the app ("The cat is fighting with the mouse", "The cow is fighting with the robot" etc.)ce
- *Learning new words*: Madison was able to learn a new word. She wanted to know what the word "amused" meant, and so she used it in a sentence. After seeing the image, when asked by the moderator, she was able to state that amused meant "happy".
- *Understanding of Determiner Modifiers*: None of the beginners had prior exposure to the context of words used after vowels. When they tried 7-word sentences, they often got stuck while trying to use words like "excited" after "a". In two of these

cases, the moderator explained that excited would not work with "a", after multiple tries to use the word, and when they finally asked for help. Once they were told about this, they were careful to avoid repeating that behavior. This is an interesting area to explore in future research even if a child is unaware of vowels or how they work, the feedback from the interface could move them toward creating a correct sentence.

- *Awareness of Color Patterns*: After a few rounds of the game, beginners realized there was a color pattern and began moving words using the colors. They were completely unaware of parts of speech, but were able to see patterns in how colors were being used in the interface. For instance, one of them said, "in 3 words [sentences], you use one of each color to make the sentence".

Intermediates
Seven children were classified as intermediates (aged between 5.5 8 years). These children could read most of the words and were comfortable with making sentences. They moved forward from 3 word sentences quickly, and seemed to be interested in trying 5 and 7-word sentences. Some of them clearly expressed the interest to make "bigger" sentences when they were playing with 3 word sentences, suggesting that they needed a challenge.

- *Awareness of Locational Contexts*: Intermediates were able to point out when the images were not generated as expected. For instance, when Brad made the sentence the cows are crying with the pigs he pointed out that the image was inaccurate because only the cows are crying, but even the pig should be crying. The beginners when presented with a similar context said that the image generated was as per their expectation.

- *Learning new words*: Madison was able to learn a new word. She wanted to know what the word "amused" meant, and so she used it in a sentence. After seeing the image, when asked by the moderator, she was able to state that amused meant "happy".

- *Explaining Verb-Adjective Inconsistencies*: The current interface allows children to make sentences that have conflicting emotions in a 7-word sentence, e.g., "the fierce goat is smiling near a fence". The intermediates who produced some of these cases were able to explain the perceived inconsistencies in the resulting image (which only depicted one of the two emotions in the sentence) based on their understanding of language and emotions. For instance, Serena explained, "how can a fierce goat smile? That doesnt make sense. If its fierce, it means it will be angry." While it is possible to be both fierce and smile, the children came to the reasonable conclusion that only one emotion was possible and explained the behavior of the interface as an inconsistency. This could be indicative of them trying to make sense of why the picture didnt change, and that repeated instances could help them develop their metalinguistic ability in terms of reasoning through how emotions are conveyed (in a simplistic manner).

- *Understanding "funny" sentences*: Wordcraft offers the flexibility to make funny sentences, where even inanimate objects can move, talk etc. The idea behind this design decision was to allow for the creation of sentences that are grammatically correct, even if the ideas expressed in these sentences tend to be illogical. These children were able to clearly

verbalize why they found the sentences funny, when they were asked. Alice said "barns dont roll in real life, but in this game they can roll. Thats because its make believe." It will be interesting to observe if over a longer period, children move away from making silly sentences to making more logical ones.

- *Connect between colors and parts of speech*: Many of the intermediates were not aware of the parts of speech, but they were able to verbalize what the different color codes could mean. Their responses ranged from "the purple words are the actions", to "the red words are nouns and purple words are verbs".

Advanced

Five children (aged between 7.5 8 years) were advanced. They could read all the words and had some degree of comfort with making sentences. Like the intermediates, they skipped through 3 word sentences and went to 5 and 7 word sentences. Even though they were advanced, they still spent about 20 minutes or more exploring the interface and playing with it. The novelty of watching the images appear when a sentence was made, was a driving force for this engagement.

- *Learning New Words*: Even though they could read all the words, the advanced children were not always aware of the meanings of the words they saw in the interface. For instance, Ella said "wailing, waving, I dont know what that means". When she saw the image she said, "oh, wailing means crying!" showing that making sentences that effect a visual outcome is an effective way to learn the meaning of a word.
- *Trying out Different Constructs*:Since they had prior exposure to working with sentences, they were also more inclined to try out sentence structures that the

app did not support. In 7 word sentences, many of them tried to move words like weeping into the spot for the adjective an accurate way to use the word in its adjective form, but the interface had the word tagged as a verb and hence did not allow this. For future work, we will need to explore the concept of allowing more complex sentence structures and then tag each of these as lessons to observe if experts are able to use the interface to learn the more complex sentence structures.

- *Connect between colors and parts of speech*: The advanced children were able to clearly articulate what each color meant, though even they could not always name the parts of speech. This suggests that the color codes could be useful in helping children build this understanding.
- *Unwillingness to make "silly" sentences*: The advanced children appeared to have a pre-existing mental model of how sentences should work, and what makes a valid sentence. They avoided making sentences like "the fences are rolling" on their own. Nadia went looking for an animal noun while making the sentence "The cat is laughing with ____". When she was probed about this she said, "the word in the sentence is with. That means there should be another animal." She was unwilling to try making the sentence with an inanimate object. This shows a clear understanding of not just the grammatical correctness, but also logic. For future work, it would be interesting to observe if repeated use of Wordcraft can move beginners and intermediates to the expert stage

Column	1	2	3
Measure	22.52	12.16	10.75
Prediction	22.72	12.26	10.60
Error %	0.009	0.008	0.014

Table 1: This sample table has the caption appearing below. Please use 0.75 rules/borders for your tables, align decimals or center text in the cells.

Conclusions and Future Work

We have presented a novel game application that allows children to explore language structure and see its effects interactively. Initial results from this research suggest that this approach, which transfers some of the benefits of childrens block toys and takes advantage of the dynamic affordances of software tools, allows children to observe how different constructs result in different meanings. For instance, as they played with the interface, children were able to talk about the difference between "the cow is hopping with the goat", and "the cow is hopping away from the goat."

Children at different reading levels played differently with Wordcraft. Beginners liked the familiarity of 3-word sentences and experimented with changing one word at a time, to see how it impacted the scene. Intermediates were more interested in explaining why things worked the way they did. Since they were not yet confident in their sentence building abilities, they applied their knowledge of language and the world to explain inconsistencies that they spotted in the app. Experts were more confident in their knowledge and they called out the same inconsistencies as "mistakes" and talked about what constituted a "logical" sentence.

Through these observations, we noted that the storybook animation format encouraged children to talk about what they were seeing, especially when they were engaged in play with a friend. In the paired sessions, children discussed the implications of using a word in a given space with each other before they made the sentence and displayed eagerness to see if their intuition would be correct. Some of them took turns at making sentences, and they often prompted the active player to try out new words.

The interface thus engaged children in metalinguistic discourses. Wordcrafts visual approach appears to foster language skills by allowing children to discuss the implications of word usage and sentence construction. It also allows them to observe how different words can impact meaning and discuss why this is so.

Future work should investigate more rigorously if children are able to make the connection between what they observe about the structure and meaning of language in this application to formal notions of syntax, to parts of speech, and writing and other concepts in school curriculum. A future version should also incorporate spoken output to aid pre-readers further.

Acknowledgements

References and Citations

Use a numbered list of references at the end of the article, ordered alphabetically by first author, and referenced by numbers in brackets [**?**, **?**, **?**, **?**] For papers from conference proceedings, include the title of the paper and an abbreviated name of the conference (e.g., for Interact 2003 proceedings, use *Proc. Interact 2003*). Do not include the location of the conference or the exact date;

do include the page numbers if available. See the examples of citations at the end of this document.

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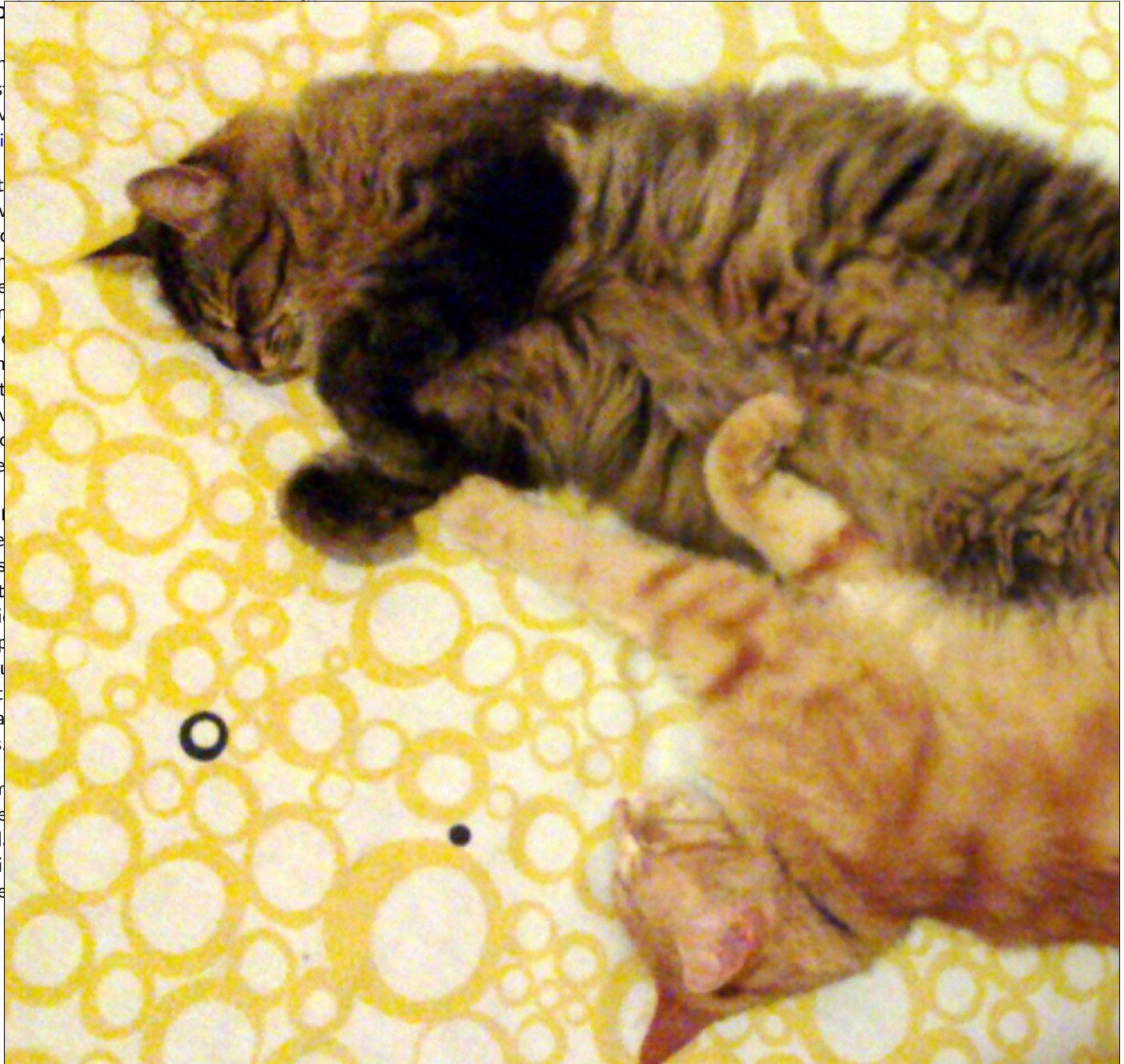
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