Thinking Through Text Comprehension III: The Programing of Verbal and Investigative Repertoires

Marta Leon, T. V. Joe Layng, and Melinda Sota
DYMO / Mimio – Headsprout

Abstract

Reading comprehension can be considered a complex human performance involving two integrated repertoires: a verbal repertoire and an investigative (generative) repertoire. The analytical and reasoning skills necessary to demonstrate reading comprehension can be systematically taught by analyzing the verbal and investigative repertoires involved and then arranging instructional contingencies designed to build and extend those repertoires. This paper describes the programing of such contingencies, drawing from the conceptual foundation outlined for reading comprehension (Layng, Sota, & Leon, 2011) and the analysis of the repertoires involved (Sota, Leon, & Layng, 2011).

Keywords

comprehension, inferential, derived word meaning, vocabulary, fast mapping, programing, investigative

In discussing reading comprehension and introducing a theoretical framework that guided the development of Headsprout *Reading Comprehension*, Layng, Sota, and Leon (2011) described a fictional scenario in which Jeffrey and John each answer a reading comprehension question. Jeffrey, who answers the question correctly, experiences private events that are different from John's. First, Jeffrey reads the passage, the question, and the possible answers. Next, he determines what the question is asking him to do: "It wants me to find how Sam feels. I'll look back in the passage to see if I can find 'sad,' 'happy,' or 'funny.'" Then he looks back in the passage: "No… no… I can't find any of those words in the passage. I'll have to look for clue words that help me think about how Sam was feeling. Here it says, 'When Sam saw his new bike, he grinned.'" Finally, Jeffrey answers the question: "Hmm… 'grinned.' That makes me think Sam was feeling happy, and 'happy' is one of the possible answers. I'll put a mark next to 'happy.'"

This scenario illustrates an instance of inferential comprehension: part of the terminal repertoire that Headsprout® *Reading Comprehension* was designed to build. Layng et al. (2011) argue that reading comprehension can be considered a complex human performance involving two integrated repertoires: a verbal repertoire and an investigative repertoire. The above scenario illustrates two parts of an investigative repertoire applied to answering an inferential reading comprehension question: (1) an overall strategy applied to answering multiple-choice reading comprehension questions and (2) a more specific strategy applied to answering inferential comprehension questions. It is important to note that different specific strategies are required for each comprehension type— literal, inferential, summative (main idea), and derived-word-meaning (vocabulary in context) comprehension. Together, these general and specific strategies make up the investigative repertoires taught in Headsprout *Reading Comprehension*.

In addition to an investigative repertoire, a learner's verbal repertoire must be taken into consideration in the design of any program of reading comprehension. The verbal repertoire is closely linked to the textual, intraverbal, autoclitic, and tacting repertoires (see Skinner, 1957) needed to come into contact with key features of written text and is built over the course of a lifetime. A verbal repertoire can take much longer to establish than an investigative (strategy) repertoire. Nevertheless, it is an important part of reading comprehension; therefore, instructional activities designed to facilitate rapid acquisition of new vocabulary were built into the design of Headsprout *Reading Comprehension* (see Sota, Leon, & Layng, 2011, for a more detailed discussion of factors considered in determining the targeted terminal repertoire of the program).

The current paper is the third in a series of three articles addressing the problem of teaching young learners how to comprehend written text. The three papers together provide a somewhat detailed description of the design and development of Headsprout *Reading Comprehension*. The program comprises 50 online lessons lasting about 20 to 30 minutes each. Once finished with the program, learners have a repertoire that enables them to comprehend written text, as indicated by their ability to answer questions about the text. The passages feature narrative, expository,

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and poetic text. Science concepts, biography, measurement, using a table of contents, reading maps, following directions, and analyzing text using Venn and other types of diagrams are all incorporated into the program.

The first article (Layng et al., 2011) described the theoretical and procedural underpinnings of the effort. In that paper, the authors describe how thinking about text—and the private events that accompany thinking about text—may be approached within a contingency analytic framework and how that approach to private events informs the design of instruction. The heart of the approach requires the characterization of stimulus control topographies to include both dimensional aspects—what is responded to— and instructional/abstractional aspects—how one responds (see Goldiamond, 1966; Goldiamond & Thompson, 1967/2004). Accordingly, critical to the approach is defining the dimensional and instructional/abstractional relations important to both verbal and investigative repertoires to be programed. That process is the topic of the second paper in the series (Sota et al., 2011).

That task is not an easy one, as Sota et al. (2011) note:

> *Comprehension is not a monolithic concept. It is not something that someone either has or does not have. It is not something that someone either can do or cannot do. Reading comprehension is what we call it when particular responses are made in the presence of particular textual stimuli. Often, it refers to public events as well as private events which we would typically call thinking or reasoning (see Layng, Sota, & Leon, 2011). When we say that a learner can comprehend what he or she has read, we are making a generalization statement based on a large pattern of stimulus-control topographies (Ray & Sidman, 1970). These topographies vary across passages, questions, and responses. For example, reading material may vary in terms of the passage's length, the reading level at which it is written, and its subject matter, as well as its style, sentence structure, vocabulary, and so on. A question about the passage read may vary in terms of length, structure, and vocabulary, as well as the response required. Questions may be multiple-choice or open-ended. They may require a spoken response or a written one. These differences represent differences in stimulus-response relations and, ultimately, in the programing involved in building a reading comprehension repertoire. (p. 11)*

Each element has to be analyzed and the dimensional and instructional relations specified through a rigorous content analysis. Further, a hierarchy of relations must be defined and the constituent repertoires identified. Once the target relations are identified and, as a result, the criteria for assessing their occurrence determined, a program needs to be designed and tested that takes a learner from basic decoding of text to comprehending that text as defined by the content analysis.

The current paper describes the programing process involved for establishing reading comprehension. This instructional design process is informed by the approach described by Layng et al. (2011) and based on the analysis described by Sota et al. (2011). The following sections describe how Headsprout *Reading Comprehension* was designed to build learners' verbal repertoires and teach both general and specific investigative repertoires. Whereas an exhaustive account of the process would likely require a textbook, we will attempt to illustrate the process by describing the program design and development specific to ensuring that learners' verbal repertoires meet the program's vocabulary requirements (from context and directly taught), as well as the design specific to teaching inferential comprehension.

THE PROGRAM

A program is a sequence of contingencies with changing criteria that leads to a replicable outcome. This outcome is (1) specified in advance, including both the repertoire that learners are expected to demonstrate and the level of mastery they are expected to reach, and (2) replicable, in that all learners who complete the program show similar terminal repertoires as evaluated by measures embedded within the program itself or administered after completion of the program.

The outcome is achieved through a series of contingencies presented to the learner, each of which is changed slightly from the one before. Changes may span the three contingency terms, as previously neutral stimuli come to guide behavior, new responses are shaped, and previously irrelevant consequences are potentiated. As the program advances, the requirements for reinforcement and progress are gradually raised. The first response requirement is preferably already part of the learner's repertoire, while the last response requirement is the terminal repertoire (see Twyman, Layng, Stikeleather, & Hobbins, 2004).

PROGRAMING A VERBAL REPERTOIRE

If what we call reading comprehension is to occur, there first needs to be a sufficient amount of overlap between the learners' verbal repertoire and the text of the passage, questions, and answers that learners read. The extent of this overlap may vary. If there is no overlap, the textual stimuli will fail to guide any verbal behavior on the part of the learner. If there is total overlap, the writer is simply restating what is already in the reader's repertoire. There must be enough overlap such that the learner's verbal responses to a text may be guided by stimulus-control relations similar to those that guide the writer or other members of the relevant verbal community, but there must be enough of a discrepancy such that new responses are encouraged. Accordingly, the program must provide instruction that increases the likelihood of such overlap, which can be illustrated by an example from our learning laboratory.

ENSURING OVERLAP WITH LEARNERS' VERBAL REPERTOIRES

In initial iterations of the program, learners read a passage and saw a poster (shown in Figure 1) as part of their instruction on interpreting illustrations. Then, they answered questions about when the exhibit would be open. The questions were answered incorrectly by 4 out of 5 learners in our laboratory. Further, correction procedures occasioned by an incorrect response had little corrective effect.

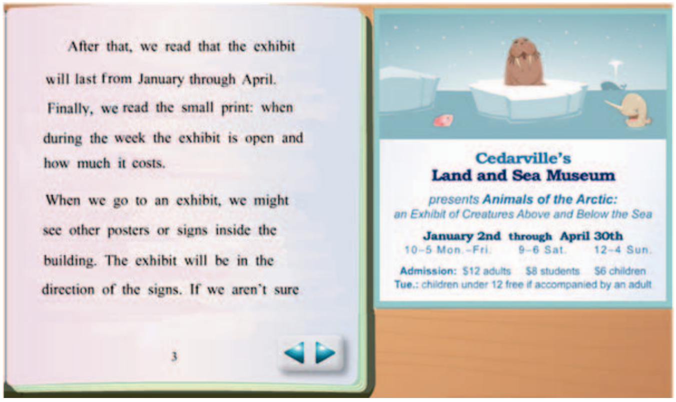

Figure 1. Original text used in the passage.

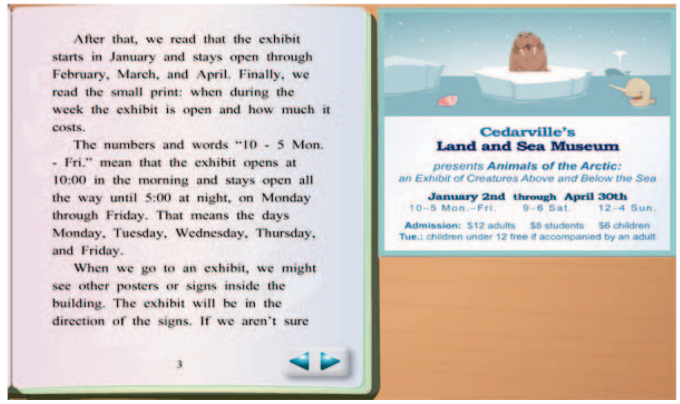

Figure 2. Revised text used in the passage.

Interviews conducted with those learners at the end of the session revealed that they did not know that "Mon.–Fri." meant "Monday through Friday" or that it included the days Monday, Tuesday, Wednesday, Thursday, and Friday. This was true even for some learners who read "Mon.–Fri." as "Monday through Friday." In this case, learners were answering the question incorrectly due to an apparent lack of overlap between their existing verbal repertoires and the stimuli supplied in the poster. We then modified the textual stimuli in the passage, as illustrated in Figure 2, and correct responding to the questions increased, as shown in Figure 3. The modifications to the text in the passage were designed to increase the overlap between the learners' intraverbal repertoires and the contents of the poster. After these modifications were implemented, 4 out of 5 naïve learners in our laboratory responded correctly to the same questions to which previously 4 out of 5 learners had responded incorrectly.

Figure 3 shows a sample of the data collected in our laboratory for this segment. The data collection and display is based upon a control/analysis programing model first described by Sidman and Stoddard (1967). Columns "a" through "f" represent different passage–question–answer sets. The sample in column "a" is the set under discussion. A horizontal line indicates a response request. An initial uptick indicates the question was answered correctly on the first attempt. A down tick indicates an incorrect response, which occasioned a correction procedure (horizontal line). A subsequent incorrect response produces a down tick and occasioned another correction procedure. A correct response to the correction produces another set, column "b." Initials in each row indicate different learners. The data are from the initial five learners, tested before the described change was made, and the five learners tested after the change in the program.

The revised version of the passage (in Figure 2) overlaps with learners' verbal repertoires and extends the instructional guidance exerted by the stimuli "Monday, Tuesday, Wednesday, Thursday, and Friday" to the stimulus "Mon.–Fri." The autoclitic frames added to the text are ones that already exist in learners' repertoires and possibly already control other, similar responses. The importance of overlapping writer and learner verbal repertoires cannot be overstated, but it is only part of what it takes to teach reading comprehension.

Another part of this overlap between the learners' verbal repertoires and the text is afforded by what is commonly referred to as the learners' vocabulary (Layng et al., 2011; Sota et al., 2011). The literature on reading comprehension has identified building a core vocabulary as essential for reading comprehension (e.g., Tannenbaum, Torgesen, & Wagner, 2006). However, designing programs that effectively and efficiently build vocabulary can be challenging. Several issues seem to be at the center of this challenge.

First, what is meant by vocabulary? "Vocabulary" does not simply refer to words or even to words and their definitions. When we speak of vocabulary, we are typically referring to words in combination with the many relations those words enter into. These relations can be between the vocabulary word and other words (intraverbal relations) and/or nonverbal stimuli (tactual relations). An effective vocabulary program, therefore, must be designed specifically to establish these relations, with instructional strategies and methods chosen based on the type of relation to be established.

Second, how can vocabulary be taught efficiently? Some estimates of vocabulary learning assert that average elementary school students learn approximately 12 new words per day (Anglin, 1993, cited in Bloom, 2002), but programs that explicitly teach vocabulary may do so relatively slowly. For example, McKeown, Beck, Omanson, and Perfetti (1983) estimate that it typically takes about 20 minutes of instruction to explicitly teach a single new vocabulary word.

EXPLICIT VOCABULARY INSTRUCTION

In programing vocabulary instruction in Headsprout *Reading Comprehension*, we focused on two central issues: (1) to effectively teach vocabulary by teaching the relations that the target words enter into and (2) to do so as efficiently as possible. The instructional sequence that we programed to teach vocabulary words was based on procedures commonly used to teach stimulus equivalence, but with some important differences. Our objective was not to demonstrate that novel, arbitrarily selected stimuli can become members of the same class through exposure to matching-to-sample contingencies. Instead, the goal was twofold. First, we wanted to quickly establish a vocabulary word, its definition, and a corresponding picture as members of the same stimulus class. Second, we wanted to use the definition of each word as the stimulus in the class that would "bridge" the stimulus class with the learners' existing verbal repertoires—therefore rapidly expanding a learner's verbal repertoire by taking advantage of the learner's existing repertoire. Below, we

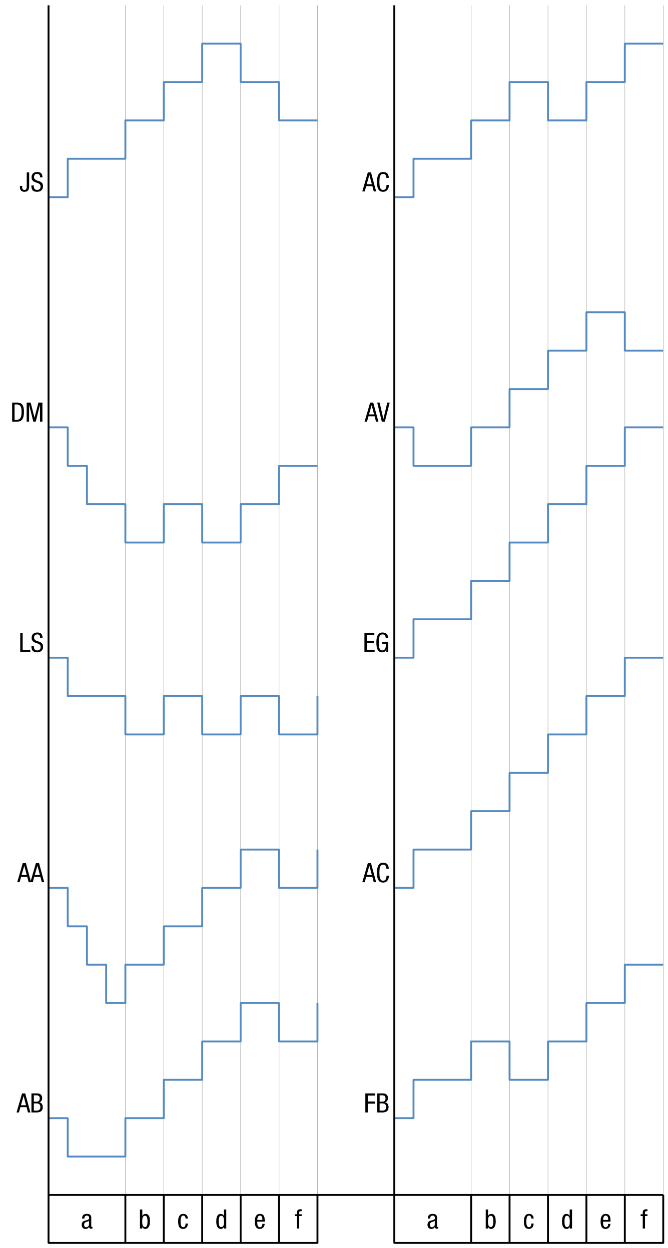

Figure 3. Sample of data collected in our laboratory.

describe the program built to establish 24 relations (four vocabulary words with six relations each) in approximately five minutes of interactive instruction.

Simultaneous presentation and linkage by autoclitic frames. In an introductory sequence, learners are presented with the target vocabulary word, to which they have to emit an observing response (clicking on the word). After the click, learners hear a definition of the word, hear a sentence that uses the word, and then see a picture illustrating the word. This sequence of events is presented in Figure 4.

As shown in Figure 4, we depart from typical stimulus-equivalence approaches by providing learners with the three nodes of the stimulus class from the outset. That is, the program attempts to establish instructional (S^Di) guidance (see Layng et al., 2011) of the words, definitions, and pictures from the outset by presenting the stimuli simultaneously and using autoclitic frames

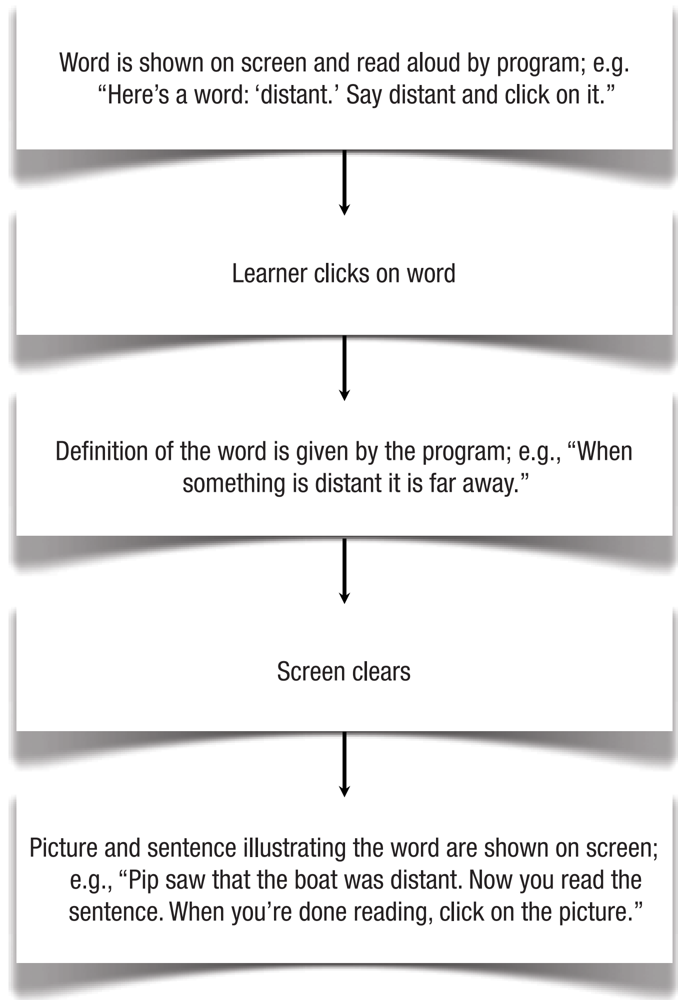

Figure 4. Instructional sequence to introduce vocabulary words.

(Skinner, 1957) to establish the relations between them. In typical stimulus-equivalence procedures, learners are not exposed to the programed stimulus classes in advance, but instead must go through a sequence of multiple trials in order to learn those classes through direct exposure to the contingencies. Because our goal was to establish these stimulus classes as quickly and efficiently as possible (as opposed to demonstrating the properties of typical matching-to-sample training), we were free to provide the three nodes of the relation through simultaneous presentation and linkage by autoclitic frames. The procedure used could be considered one of one-to-many or sample-as-node, where all the comparison stimuli that are part of the class are associated by virtue of their relation to a single sample. We repeat this process for two additional words in order to create the first group of three stimulus classes.

Stimulus equivalence. Once the three words have been introduced, the words, the three definitions, and the three pictures are arranged in a typical stimulus-equivalence paradigm where learners see a sample and an array of three comparisons and must select the comparison that belongs in the same stimulus class as the sample. Figure 5 shows an example of this procedure.

Another departure from the typical stimulus-equivalence paradigm is illustrated by the potential familiarity to learners of the stimuli used. In typical stimulus-equivalence procedures,

Figure 5. Example of stimulus-equivalence procedure. The definition is presented as the sample, and three pictures are presented as the comparisons.

investigators take pains to ensure that the stimuli used in the classes are novel to learners (Sidman, 1994). In our program, such concern with novelty is nonexistent. The pictures used to illustrate the words are novel to the learners, but they represent objects that are likely to be familiar to most learners. The definitions for each word were written to maximize the likelihood that they would overlap with the learners' existing verbal repertoires. We avoided definitions from dictionaries because they seldom allow for such overlap, especially when it comes to learners in elementary grades. We created our definitions by first carefully examining the different contexts in which each target word is likely to appear and by examining the word's most common meanings and usages, and then writing a definition consistent with such examination. Thus, the vocabulary words themselves may be the only stimuli in the classes that are novel to learners.

Fast mapping with contingency adduction. While learners are engaged in this matching-to-sample activity, the program introduces a fourth (not previously seen) word that learners have to match to a fourth (not previously seen) definition and then to a fourth (not previously seen) picture. In our learning laboratory, the introduction of these novel stimuli resulted in learners responding correctly to the new word introduced, almost without exception. The practice of embedding trials showing a novel sample and a novel comparison stimulus in matching-to-sample tasks, while keeping the other comparison stimuli as before, is sometimes referred to as "exclusion learning" or "fast mapping" in the cognitive psychology literature (see Bloom, 2002, for a discussion of fast mapping). "Exclusion learning" refers to the notion that when the novel sample and novel comparison are presented, learners select the novel comparison because all other comparisons are already matched to their respective samples. Learners, then, are thought to select the correct comparison by a process similar to that of elimination, i.e., by exclusion. The label "fast mapping" suggests that learners are mapping the relations among stimuli. Both labels point to what the programer designs rather than to what variables can account for learners' behavior. The programer knows which stimuli to put in the "excluded" class that is introduced after the original classes are formed, as well as how the new stimuli are "mapped" within a class.

We approach this somewhat differently. Learners are naïve with regard to which stimuli are in the excluded class or are to be fast mapped. Their behavior is under the instructional (S^Di) guidance of selecting the comparison stimulus that goes with the sample and under the dimensional (S^Dd) guidance of the specific sample-comparisons array presented in each trial. Responding in accordance with the three stimulus classes formed (the first three words and their respective definitions and pictures) is potentiated by the initial instruction and the subsequent contingencies set up by the matching-to-sample trials. In each trial after the initial training, response alternatives are effectually reduced to one sample among the three in the array because of previous reinforcement and instruction for responding within the class. When a novel sample and a novel comparison are presented, learners consistently select the "correct" comparison (the one associated with the new sample) because all the remaining samples present have been previously included in their respective stimulus classes. The new comparison is the only one that has not been previously matched with a sample. Thus, response alternatives are effectually reduced to the new comparison. Dimensional guidance is varied because of the presentation of a novel stimulus, but abstractional control (selecting the comparison stimulus that goes with the sample) is adduced (after Andronis, Layng, & Goldiamond, 1997; Layng, Twyman, & Stikeleather, 2004) and maintained.

The purpose of using this particular matching-to-sample procedure (in which we introduce a whole new class of stimuli without previous instruction and learners' responses consistently conform to the new stimulus class) is efficiency of instruction. Once this instructional sequence ends, learners have practiced each of the relations between words, definitions, and pictures, in all possible directions, for four vocabulary words. This entire instructional sequence takes approximately five minutes. As of this writing, our online data from over 35,000 learners indicate that the learners achieve about 96% correct throughout the instructional segment.

Extension Across Contexts. This activity, however, is not the complete extent of their practice with vocabulary words. Proper S^Di guidance must occur across a range of stimuli before learners can be considered to "truly know" the meaning of a word. That is, learners must tact the relation between a word and its meaning in novel verbal contexts different from those in which the relation was originally trained —that is, different from the stimulus-equivalence procedure described above. Thus, vocabulary words taught through this stimulus-equivalence procedure appear again in subsequent passages that learners must read and about which they must answer reading comprehension questions. Often, learners must tact the relation between the word and its meaning in a novel context provided by different stimulus prompts and by variation of the variable attributes of the word meaning, if they are to correctly answer the questions.

PROGRAMING AN INVESTIGATIVE REPERTOIRE

Because it is impossible to teach each reading comprehension question that learners will encounter, it becomes necessary to teach a *strategy* that can be transferred across a range of reading comprehension questions. A strategy is a generative repertoire whereby learners engage in supplementary verbal stimulation to solve a particular problem (Layng, 2005; Palmer, 1991; Robbins, 2004, 2011). Strategies are defined as a systematic attack on problems for which algorithmic (successive conditional discriminations) and principle application are insufficient to result in a response that would be reinforced (Tiemann & Markle, 1990). Strategies require the production, on the individual's part, of supplementary verbal stimulation that potentiates responding consistent with the S^Di guidance exerted by the contingencies implied in the problem at hand (Layng et al., 2011). Furthermore, a strategy requires application to novel conditions in order to be considered as such.

As noted by Sota et al. (2011), reading comprehension is not a monolithic skill; it rests on different strategies that are relevant to different reading comprehension questions. We prefer the term "investigative repertoire" (Layng et al., 2011) to refer to the overarching repertoire of inspecting the contingency requirements (see Skinner, 1966) of any reading comprehension question presented, be it a literal, inferential, summative, or derived-meaning question. Based on an inspection of the contingencies, learners can then apply the strategy that is relevant to the specific question at hand (see Robbins, 2004).

EXPANDING A VERBAL REPERTOIRE THROUGH BUILDING A DERIVED-MEANING INVESTIGATIVE REPERTOIRE

Verbal and investigative repertoires overlap; they are not completely separate. One place where they overlap is in derived-meaning (vocabulary) comprehension. As noted elsewhere (Layng et al., 2011; Sota et al., 2011), vocabulary is critical to a verbal repertoire. Though some vocabulary is directly taught, many words are learned through reading text (Bloom, 2002). Accordingly, a strategy for acquiring this type of vocabulary is critical to extending a learner's verbal repertoire.

In Headsprout *Reading Comprehension*, the strategy that learners are taught for determining the meaning of a word in context begins by having learners replace the unknown word with the first possible answer, read the sentence formed thereby, and then repeat this same task with the remaining possible answers. Take the following as an example:

> Once there were two countries that did not like each other. There was so much <u>strife</u> between them that they were always at war. Finally, most of the people decided to try to make peace.
>
> What does "strife" most likely mean?
>
> ○ fighting
>
> ○ peace
>
> ○ space

Learners are taught to replace the word "strife" with each of the possible answers, as follows:

- *There was so much <u>fighting</u> between them that they were always at war.*
- *There was so much <u>peace</u> between them that they were always at war.*
- *There was so much <u>space</u> between them that they were always at war.*

The next step in the strategy is to evaluate which of the three sentences above makes the most sense. For many of our target learners, however, the responses required by such instruction may not be in place. For example, what does "makes the most sense" mean in this context? As noted above, tacting which sentence makes the most sense equates to tacting which string of verbal stimuli includes thematic categories that are mutually congruent. For example, "peace" and "war" and "space" and "war" (the categories present in the second and third sentences above) create thematic discrepancies that are readily apparent. On the other hand, "fighting" and "war" are in the same thematic category. The S^Di guidance exerted by "war" is similar to that exerted by "fighting," given the relational autoclitics of the sentence. Tacting thematic congruencies and discrepancies is not simple to teach, given the wide variety of derived-meaning questions that learners will encounter within the program and outside of it (e.g., in reading comprehension exercises or tests in the classroom). Thus, we took an "EGRUL" approach to this task. EGRUL approaches use different examples and non-examples in order to guide learners to "discovering" the rule, as opposed to "RULEG" approaches, in which the rule is provided first and followed by examples and non-examples (Markle, 1969; 1981; 1991).

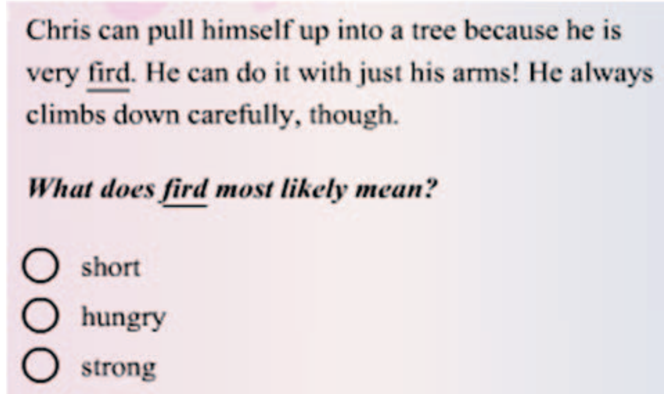

Figure 6. Example of question asking learners to derive the meaning of a word from context.

For this instructional sequence, the program goes through several sentences that either "make sense" or don't, thus demonstrating what the term means via carefully designed examples and non-examples. Specifically, learners first read the passage, question, and possible answers, examples of which are presented in Figure 6. Note that the target word is a non-word. This deliberate choice forces learners to use the process taught rather than rely on already established occasion-behavior pairs (see Sota et al., 2011).

After reading the content shown in Figure 6, learners hear, "Let's see how each answer fits in the sentence." The program then substitutes each possible answer for the target word in the passage, one at a time, as shown in Figure 7.

While learners see the content shown in Figure 7, the narrator reads aloud the sentences formed by inserting each possible answer. After each sentence is read, learners hear either "That makes sense!" or "That doesn't make the most sense here." For the top panel of the figure above, learners would hear, "'Chris can pull himself up into a tree because he is very short. He can do it with just his arms!' That doesn't make the most sense here."

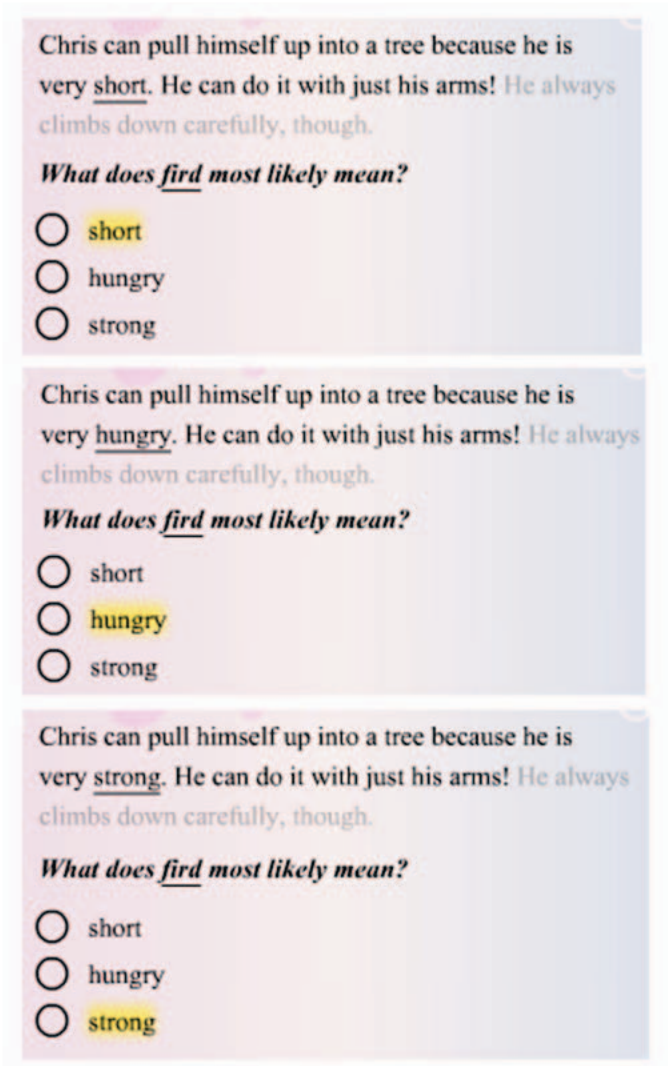

Figure 7. Example of sequence to teach learners to derive the meaning of a word from context.

The verbal stimuli from the screen and the audio are designed to overlap with learners' verbal repertoires. After one iteration of this sequence, the program no longer evaluates whether each sentence formed makes sense. That is left to learners, with the narrator asking, "Does that make sense?" after each sentence is read. This sequence repeats with a range of questions that ask for the meaning of a variety of words (nonsense words, as well as actual words that include nouns, adjectives, verbs, and adverbs) across a variety of passages. Learners are thus taught an investigative repertoire to apply across questions related to deriving the meaning of words from context.

The description above is a summarized account of the investigative repertoire put in place by the program to teach how to derive the meaning of words from context. Similar investigative repertoires are programed for literal, inferential, and summative reading comprehension, but space precludes a detailed account of each. The next section focuses on the programing of an investigative repertoire to answer inferential comprehension questions.

PROGRAMING AN INFERENTIAL INVESTIGATIVE REPERTOIRE

Inferential reading comprehension can be defined as the process of answering a question that is related to a passage, but the answer to which does not have a one-to-one topographic correspondence with the passage (Sota et al., 2011). The learner, for example, may be asked to predict, based on current information, a future event in a story, to estimate how a character is feeling, or to deduce the probable cause of an event, to name a few. How does one program a repertoire that encompasses such seemingly disconnected responses?

As with other complex repertoires, there may be multiple ways to program for the same terminal repertoires. Below, we describe one program that has proven effective in our learning laboratory.

Our first step in designing a strategy for answering inferential comprehension questions was to analyze the concept of inferential questions (see Sota et al., 2011). Questions that are designated as inferential have the following critical attributes:

1. The answer category appears in the passage.
2. The answer meets the criteria specified in the question.
3. The answer does not have a topographic correspondence with the words in the passage.

This concept analysis of inferential comprehension simplifies programing in several ways. First, it makes the programing of coordinated concepts clearer and more efficient. In the case of an inferential question, its coordinate concept is a factual or literal question, described by Sota et al. (2011). Literal and inferential questions are coordinate concepts. That is, they only differ in the specific value of one of their critical attributes. While factual questions require topographic correspondence between the answer and the words in the passage, inferential questions require the lack of such topographic correspondence. This sharing of all but one critical attribute allows programers to find commonalities in the strategies and leverage those commonalities to minimize the number of "rules" that learners have to remember.

The second contribution of a concept analysis to programing lies in its delineation of what constitutes a correct answer to an inferential comprehension question. The characteristics of a correct answer (i.e., one that has the three critical attributes outlined above) can then be taught to learners explicitly. We will describe how we programed for this attribute-based instructional system in greater detail below.

Third, the concept analysis sets the ground for programs that facilitate transfer across a wide variety of stimuli (in this case, a wide range of inferential questions). The concept analysis indicates the range of variable attributes that must be systematically varied across inferential comprehension questions in order to vary the dimensional guidance or S^Dd, in this case represented by the particular question and passage characteristics, while keeping the instructional guidance or S^Di constant (see Layng et al., 2011).

The first critical attribute (the answer must appear in the passage) was addressed by inserting a step designed to evoke responses that increase the likelihood that learners' responses are guided by the passage. The program directs learners to "click the part of the passage that helps [them] answer the question" before they can select an answer. By attending to and actively responding to the portion of the passage that is thematically related to the question, that is, matching S^Di guidance, the likelihood

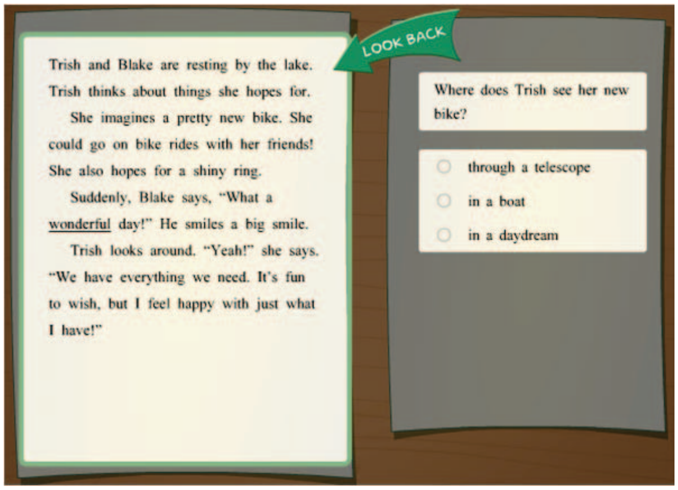

Figure 8. Example of sequence to teach learners to look for the answer in the passage before answering the question.

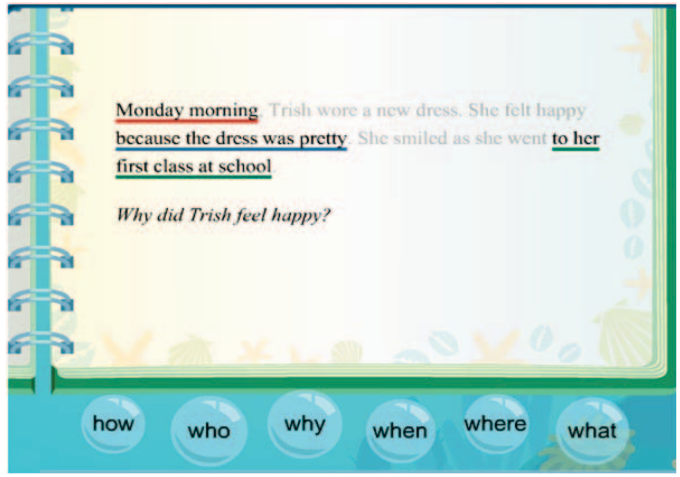

Figure 9. Example of instruction common to literal and inferential comprehension.

of a correct response is further increased (Layng et al., 2011). An example of what learners see during this sequence is shown in Figure 8. Learners first read the passage, question, and possible answers, but cannot select an answer at this point. Instead, they are directed to click on the part of the passage that will help them answer the question. The passage comprises several clickable spots, and learners receive confirmatory or corrective feedback depending on which part of the passage they click (in the figure above, the correct part of the passage is "She imagines a pretty new bike"). After selecting the part of the passage that helps them answer the question, learners move on to selecting one of the three possible answers presented.

The second critical attribute of inferential questions (the answer meets the criteria specified in the question) is shared by at least two types of comprehension questions (literal and inferential), and thus is taught as a skill common to both types of questions. Figure 9 shows an example of what learners see while going through this prerequisite skill instruction. Learners are presented with short passages followed by a question about the passage. Three different sections of the passage (sentences or phrases) are underlined in different colors to potentiate discrimination. Learners have to click on the underlined part that shows the answer to the question. The questions presented vary systematically in the type of characteristic asked about and cover the question words *when*, *where*, *how*, *who*, *what*, and *why*. As mentioned above, learners are required only to click on the part of the passage that contains the answer to the question, not yet to answer the question in its entirety. The purpose of this preparatory instruction is to provide learners with a uniform repertoire of tacting the contingency requirements of each question based on the question words.

The third critical attribute (the answer does not have a topographic correspondence with the words in the passage) differentiates inferential comprehension from literal comprehension. If the answer to the question does *not* have a topographic correspondence with words in the passage, then topographic correspondence cannot be a source of stimulus control when selecting the correct answer. Learners' behavior when answering inferential questions must rely on thematic or category correspondences present in the passage, question, and answers.

Skinner (1957) used the term *thematic prompt* to refer to a verbal stimulus that increases the likelihood of a target response. Key words in the passage can be considered thematic prompts inasmuch as they are instructional stimuli ($S^{D}i$) that restrict response alternatives to the category that matches the instructional stimuli in the inferential question (see Layng et al., 2011). The problem is that often these thematic prompts are ineffective at evoking the target response by their mere presence. The task, then, is to get learners to respond to those thematic elements.

What do people who are adept at inferential comprehension do in order to find thematic correspondences between words in the passage and words in one of the possible answers (the "correct" answer)? According to cognitive psychology, they activate and use their background knowledge. This explanation, however, is insufficient to design a program that systematically and explicitly teaches learners to make inferences; it does not provide any indication of the operations that need to take place in order to activate background knowledge. For example, what are learners actually doing when they are "activating their background knowledge?" And how can a program explicitly and systematically teach that behavior?

When learners are drawing on their background knowledge, they are engaging in intraverbal responses that are thematically related to the question at hand. If we want to teach learners to systematically produce intraverbal responses that are thematically related to the question, then we have to provide explicit instruction on this sort of response generation. The reader will recall the steps that Jeffrey, a child in our early example, takes to find the inferred answer. When he cannot find the exact answer in the passage, he says, "I'll have to look for clue words that help me *think about* how Sam was feeling." But to teach that behavior, we need to establish the repertoire described by "think about," as learners cannot simply be asked to "think about."

Instead, they are provided with examples of what they are doing when they are "thinking about" something. We begin by having the learners read the question about the passage. This is critical, since the criteria for selecting the correct answer are specified by the question, and the answer must fall in the same thematic category as a category that appears in the passage. Then, the narrator rereads the question and tells the learner,

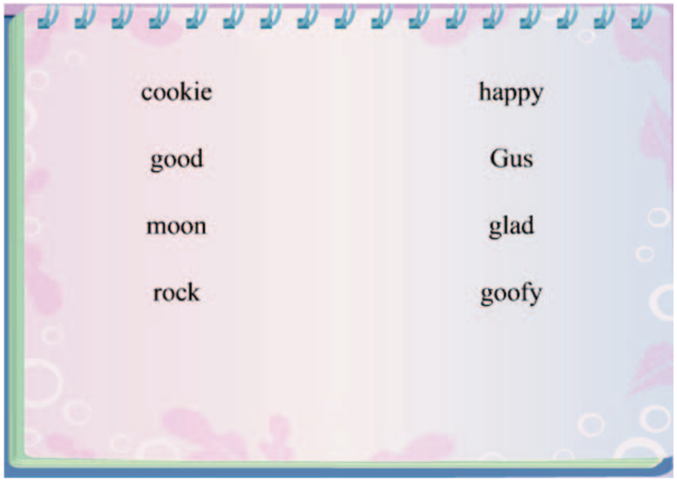

Figure 10. Example of early sequence designed to activate background knowledge.

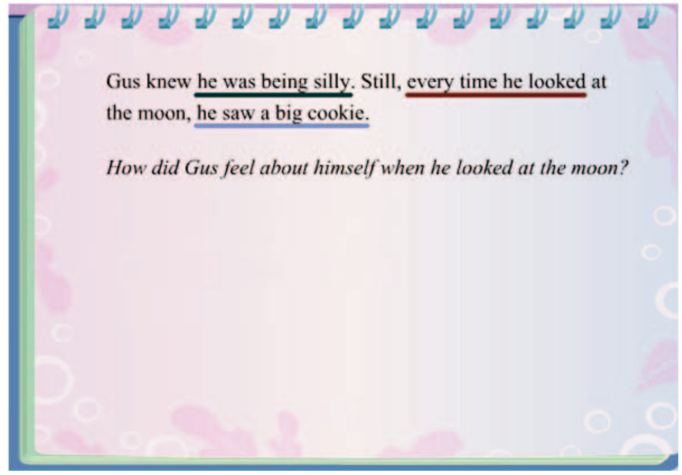

Figure 11. Example of frame where learners find clue words in the passage.

"We need to look for clue words that make us think about ___." For example, if the question is asking about how a character feels, then learners are told, "We need to look for clue words that make us think about feelings." Here, again, we designed an EGRUL approach in which learners are guided through a series of examples and non-examples (Tiemann & Markle, 1990). Learners select from a list of items that may make the learner think about what the question is asking (for example, items that may make the learner think about feelings). Figure 10 shows a list of examples and non-examples of items that make learners think about feelings.

When presented with a frame like the one in Figure 10, learners hear the instruction "Click on the words that make you think about feelings" and have to select all the examples among an array of examples and non-examples. Confirmatory or corrective feedback follows each learner response. The objective of this step is restriction of response alternatives to those that are thematically related to the question (in this case, a question about feelings). The responses evoked during this instructional sequence do not need to be exhaustive. They simply need to be in the same thematic category as the target response. When these responses are made more likely, the probability of a correct answer to the question is also made more likely, because the correct answer is in the same class.

Next, we have learners go back to the passage and examine a selected set of phrases underlined in different colors (see Figure 11 for an example). Learners have to find clue words that fall in the same thematic category as the items they just selected when they were "thinking about."

Now that responses thematically related to the question have been made more likely, three possible answers are presented, and the learner is instructed to select the one that answers the question (see Figure 12). Typically, one of the possible answers meets all of the critical attributes listed above except for the first one. Another possible answer meets all of the critical attributes except for the second one. The third possible answer meets all of the critical attributes. If learners select an incorrect answer (one lacking one critical attribute), the program provides specific feedback about the attribute that is missing.

Naturally, the extensive support involved in presenting lists of examples and non-examples for each question cannot and should not be maintained throughout, as the ultimate goal is that learners will be able to do this independently. After the criterion is met for this stage of instruction, the support is withdrawn and learners are encouraged to "think about clue words" independently, without the program supplying examples or non-examples. This encouragement is later removed completely.

Earlier in this discussion, we mentioned that learners can be taught explicitly to respond across the critical attributes of an inferential question (i.e., the answer category appears in the passage, although the answer does not have a point-to-point topographic correspondence with it, and it meets the criteria specified in the question). This is done partially by restricting response alternatives that are already at some strength in learners' repertoires in order to make the target response more likely (see Goldiamond & Thompson, 1967/2004). Let's consider one example.

The school bus pulled up to the bus stop. It waited there for five minutes. Finally, all the children came and got on. Then the school bus went on down the street.

Why did the school bus wait at the bus stop?

- It waited there for five minutes.
- The bus driver was late.
- Some children were late.

Unless response alternatives are restricted, learners' responding is under the guidance of competing S^Di. On one hand, their existing repertoires may make the response "the bus driver was late" likely, because that is a valid reason for a bus to have to wait. This response is probably at some strength for many learners without their needing to attend to the textual stimuli in the passage. For each question presented in the program, there is at least one possible answer that is a likely response if one considers exclusively the learners' verbal repertoires. We selected these possible answers, or distracters, by design, in order to teach learners to use the strategies taught in the program and not rely exclusively on their past verbal repertoires. The other distracter, "it waited there for five minutes," is probably unlikely to exist in learners' intraverbal repertoires in any meaningful strength before this exercise. The passage, however, contains the

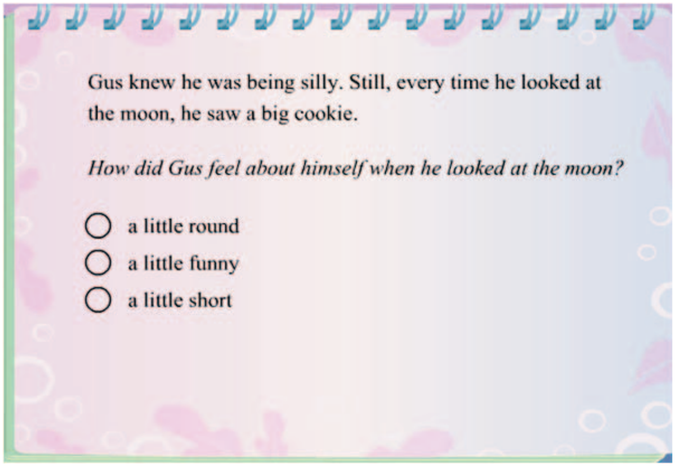

Figure 12. Example of frame where learners select answer after having identified clue words in the passage.

words "it waited there for five minutes," and that response may momentarily increase in probability because of the textual and echoic components that evoke it. Again, this type of distracter (a possible answer with words that appear in the passage but that do not answer the question) is used frequently in the program by design.

When learners select one of these distracters, the feedback they receive indicates why the distracter is not a correct answer. For example, the program's auditory feedback may inform learners that "we see some of those words in the passage, but they don't answer the question." Similar feedback, specific to the critical attribute missed, is provided if learners select the distracter that is strong in their existing repertoires but that does not have a thematic correspondence with the textual stimuli in the passage. Thus, this sequence shapes learners' responding along the critical attributes of inferential questions. This strategy is used throughout the program, with some modifications as the program advances in order to withdraw program support and encourage learner independence. What varies throughout the program is the passages from which questions are drawn, the reading level of the passages, and each of the variable attributes of the questions, as in the concept analysis described by Sota et al. (2011).

PROGRAMING A GENERAL INVESTIGATIVE REPERTOIRE

As noted above, the program teaches specific strategies, or investigative repertoires, for each comprehension type. Each use of a particular strategy is in turn occasioned by a more general strategy that helps the learner identify which specific strategy is required. To accomplish this, the learner must categorize the question with regard to the type of comprehension strategy that will be required to answer it. To accomplish this, an icon is paired with each specific strategy. The icons are depicted in Figure 13.

When presented with a passage–question–answers set, the learner is taught to select an icon that represents the strategy required by the question. A "fish race" game is used to practice identifying the strategy needed to answer a question. Distinguishing between literal and inferential questions, however, requires an examination of the possible answers in relation to the passage to determine if a literal match or a categorization

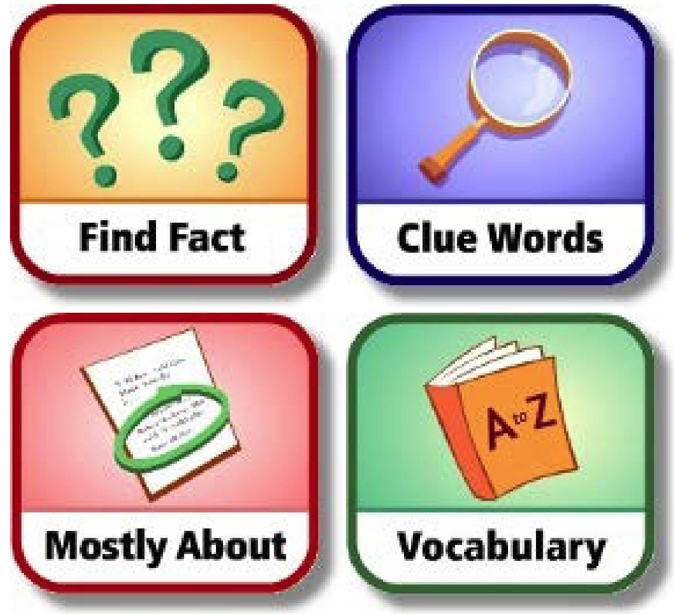

Figure 13. A specific icon is paired with each specific type of comprehension strategy.

match is required.

When first presented with a passage that has multiple question-and-answer sets, the learner is required to first read the passage, then read the question, and then click on the icon representing what the question is asking the learner to do. This increases the likelihood that the learner will ask him – or herself, "What is this question asking me to do?" Next, the learner reads the answers and is required to click on the area of the passage that answers the question. The learner then selects the answer to the question using the strategy particular to that question type. Over the course of many lessons, the individual steps are removed until the learner completes the sequence independently.

Space precludes a discussion of all the steps that are required to establish this repertoire, but the terminal repertoire is described for Jeffrey at the beginning of this article and follows this sequence:

Step 1. Determine what the question is asking. In this case, it is either a Find the Fact or a Clue Words question. First, Jeffrey reads the passage, the question, and the possible answers. Next, he determines what the question is asking him to do.

Step 2. The learner determines if there is a 1:1 match between the possible answers and the text, which would make this a Find the Fact question. "It wants me to find how Sam feels. I'll look back in the passage to see if I can find 'sad,' 'happy,' or 'funny.'"

Step 3. The learner does not find a 1:1 correspondence, which occasions the Clue Words strategy. "Then he looks back in the passage: 'No… no… I can't find any of those words in the passage.'" (If there were a 1:1 correspondence, the learner would use the Find the Fact strategy to select the answer that matched the words found in the passage.)

Step 4. The learner begins to use the strategy specific to answering inferential questions. "I'll have to look for clue words that help me think about how Sam was feeling."

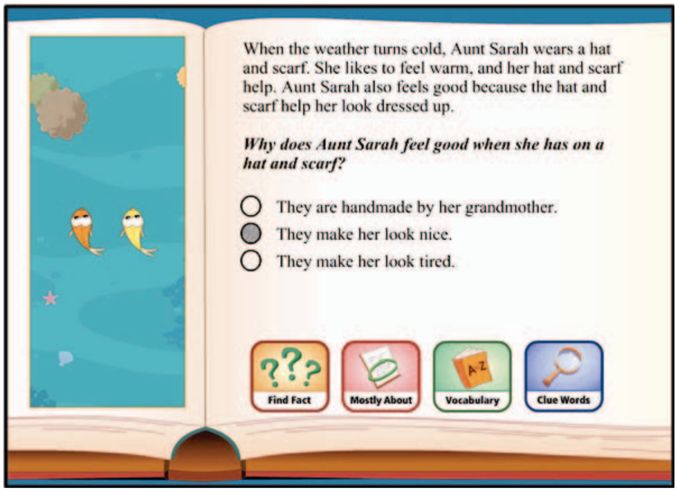

Figure 14. The "fish race" game. Learners must click on the icon that represents the type of comprehension strategy required. For the passage–question–answer set depicted, the learner must see that there is no 1:1 correspondence between the words in the answer and the words in the passage and, therefore, choose the Clue Words icon.

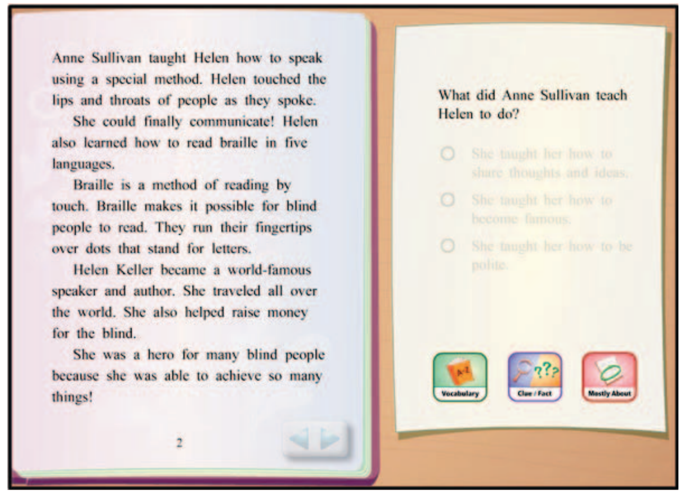

Figure 15. An example of an early passage–question–answers set. The learner must select the icon that matches the question. The Clue Words and Find the Fact icons are combined, since the matching is required before the learner examines the passage.

CONCLUSION

What we have described here is portions of a program that teaches learners how to comprehend text. Headsprout *Reading Comprehension* is a product of a concerted team effort that involved graphic artists, animators, audio engineers, software engineers, database specialists, network engineers, user test specialists, program editors, instructional designers and learning scientists. It took over three years and more than $2 million to produce. We began with the foundation described by Layng et al. (2011), performed the analyses detailed by Sota et al. (2011), and through continuous testing, revising, and retesting produced the program which is the topic of this paper.

Other programs may be developed that achieve similar outcomes through different procedures. Nevertheless, insofar as the program described here is being used successfully to teach learners how to comprehend text, we have at least a reasonable basis to conclude that the thinking and analytical skills involved in comprehension can be explicitly taught (Layng et al., 2011; Sota et al., 2011). Furthermore, the consistency in applying the complex patterns taught in our program by more than 150 individual learners who participated in developmental testing and more than 35,000 school users leaves us encouraged that we accomplished what we set out to do. It has not escaped our attention that this consistent performance—in answering questions correctly and in what learners seem to be "thinking" while doing so—is a function of our program, and that programs such as ours may provide a framework for effectively teaching thinking of all kinds.

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AUTHOR CONTACT INFORMATION

MARTA LEON

DYMOIMimio – Headsprout
127 Broadway E.
Suite 300
Seattle, WA 98102
email: marta.leon@headsprout.com

T. V. JOE LAYNG

DYMOIMimio – Headsprout
127 Broadway E.
Suite 300
Seattle, WA 98102
email: joe.laying@headsprout.com

MELINDA SOTA

DYMOIMimio – Headsprout
127 Broadway E.
Suite 300
Seattle, WA 98102
email: melinda.sota@headsprout.com