Journal of Autism and Developmental Disorders, Vol. 33, No. 6, December 2003 (© 2003)

Development and Evaluation of a Computer-Animated Tutor for Vocabulary and Language Learning in Children with Autism

Alexis Bosseler[1,2] and Dominic W. Massaro[1]

Using our theoretical framework of multimodal processing, we developed and evaluated a computer-animated tutor, Baldi, to teach vocabulary and grammar for children with autism. Baldi was implemented in a Language Wizard/Player, which allows easy creation and presentation of a language lesson involving the association of pictures and spoken words. The lesson plan includes both the identification of pictures and the production of spoken words. In Experiment 1, eight children were given initial assessment tests, tutorials, and reassessment tests 30 days following mastery of the vocabulary items. All of the students learned a significant number of new words and grammar. A second within-subject design with six children followed a multiple baseline design and documented that the program was responsible for the learning and generalization of new words. The research indicates that children with autism are capable of learning new language within an automated program centered around a computer-animated agent, multimedia, and active participation and can transfer and use the language in a natural, untrained environment.

KEY WORDS: Vocabulary learning; animated tutor; multimedia; language learning; animated speech; tutoring children with autism; computer.

INTRODUCTION

The goal of this research is to use recent advances in research, theory, and technology to develop, implement, and evaluate a tutor for language learning in children with autism. Autism is a spectrum disorder, identified by a variety of characteristics, which usually include perceptual, cognitive, and social differences. Among the defining characteristics, the limited ability to produce and comprehend spoken language is the most common factor leading to diagnosis (American Psychiatric Association, 1994). The language and communicative deficits extend across a broad range of expression, with large individual variations in the degree to which these children develop the fundamental lexical, semantic, syntactic, phonological, and pragmatic components of language (Tager-Flusberg, 1999).

Approximately one-half of the autistic population fails to develop any form of functional language (Lord, Rutter, & Le Couteur, 1994; Prizant, 1983; Tager-Flusberg, 2000). Within the population that does develop language, the onset and rate at which the children pass through linguistic milestones are often delayed compared with nonautistic children (e.g., no single words by age 2 years, no communicative phrases by age 3 years; American Psychiatric Association, 1994). The ability to label objects is often severely delayed in this population, as is the inappropriate use of verbs and adjectives. Van Lancker, Cornelius & Needleman (1991), for example, found that autistic children were below controls in their ability to identify concrete nouns, nonemotional adjectives, and emotional adjectives.

[1] Department of Psychology, University of California, Santa Cruz, California.
[2] Correspondence should be addressed to Dominic W. Massaro, Department of Psychology, University of California, Santa Cruz, CA 95064; e-mail: massaro@fuzzy.ucsc.edu

0162-3257/03/1200-0653/0

Unfortunately, even after acquired, applying language skills more generally poses an additional obstacle for those with autism. Difficulties arise in their ability to generalize acquired skills to new settings (Handleman, 1979), stimuli (Carr, 1980), and individuals not associated with the initial training (Carr & Kologinsky, 1983). However, the ability to generalize and transfer acquired skills can be taught with intensive training (Carr & Kologinsly, 1983; Jahr, 2001; Stokes, Baer, & Jackson, 1974). Thus, strategies to promote generality across settings, people, and situations are necessary components of treatment programs for those with autism.

Vocabulary acquisition and knowledge is an important component of language competency (Gupta & MacWhinney, 1997), constituting both proficiency in oral communication and reading comprehension (Wood, 2001). Recent studies illustrate that the breadth and depth of vocabulary affects not only reading success (Stanovich, 1986; Wood, 2001) but also overall success in school (Vermeer, 2001). Accordingly, the need to develop and strengthen vocabulary is an essential element of intervention programs for many children with autism; therefore, prevention programs to narrow the gap of at-risk populations should begin as soon as possible after diagnosis. Unfortunately, these motivational environments necessary to develop language skills must overcome many inherent obstacles (Tager-Flusberg, 2000). The behavioral difficulties that speech therapists and instructors encounter, such as lack of cooperation, aggression, and lack of motivation to communicate, create difficult situations that are not optimal for learning (Carr, 1982; Koegel, 2000; Koegel, Koegel, & Surratt, 1992).

Computer-based instruction is emerging as a prevalent method to train and develop vocabulary knowledge for both native and second-language learners (Wood, 2001) and for individuals with special needs (Barker, 2003; Heimann, Nelson, Tjus & Gilberg, 1995; Moore & Calvert, 2000; Yamamoto & Miya, 1999). An incentive to employing computer-controlled applications for training is the ease with which automated practice, feedback, and branching can be programmed. Another valuable component is the potential to present multiple sources of information, such as text, sound, and images, in parallel (Chun & Plass, 1996; Dubois & Vial, 2000). Incorporating text and visual images of the vocabulary to be learned along with the actual definitions and sound of the vocabulary facilitates learning and improves memory for the target vocabulary. Dubois and Vial (2000), for example, found an increase in recall of second-language vocabulary when training consisted of combined presentations of spoken words, images, written words, and text relative to only a subset of these.

Computer-based instruction makes it possible to include talking heads rather than simply disembodied voices in lessons. There are several reasons why the use of auditory and visual information from a talking head is so successful and why it holds so much promise for language tutoring. These include robustness of visual speech, complementarity of auditory and visual speech, and optimal integration of these two sources of information. Speech reading, or the ability to obtain speech information from the face, is robust in that perceivers are fairly good at speech reading even when they are not looking directly at the talker's lips. Complementarity of auditory and visual information simply means that one of the sources is most informative in those cases in which the other is weakest. Because of this, a speech distinction can be differentially supported by the two sources of information. That is, two segments that are robustly conveyed in one modality would be relatively ambiguous in the other modality. For example, the difference between /ba/ and /da/ is easy to see but relatively difficult to hear. In contrast, the difference between /ba/ and /pa/ is relatively easy to hear but very difficult to discriminate visually. The final characteristic is that perceivers combine or integrate the auditory and visual sources of information in an optimally efficient manner.

We expect that the student's engagement will be enhanced by face-to-face interaction with a computer-animated agent. The value of visible speech, emotion, and intention in face-to-face communication was the primary motivation for the development of Baldi, a three-dimensional computer-animated talking head. Baldi provides realistic visible speech that is almost as accurate as a natural speaker (Cohen, Walker, & Massaro, 1996; Massaro, 1998, chapter 13). The quality and intelligibility of Baldi's visible speech has been repeatedly modified and evaluated to accurately simulate naturally talking humans (Massaro, 1998). Baldi's visible speech can be appropriately aligned with either synthesized or natural auditory speech. Baldi also has teeth, tongue, and palate to simulate the inside of the mouth, and the tongue movements have been trained to mimic natural tongue movements (Cohen, Beskow, & Massaro, 1998). This technology has the potential to help individuals with language delays and deficits, and we report in this article two experiments using Baldi to carry out language tutoring for children with autism.

Computers are also being used in educational settings as a new method of teaching for children with autism (Calvert, 1999; Moore & Calvert, 2000;

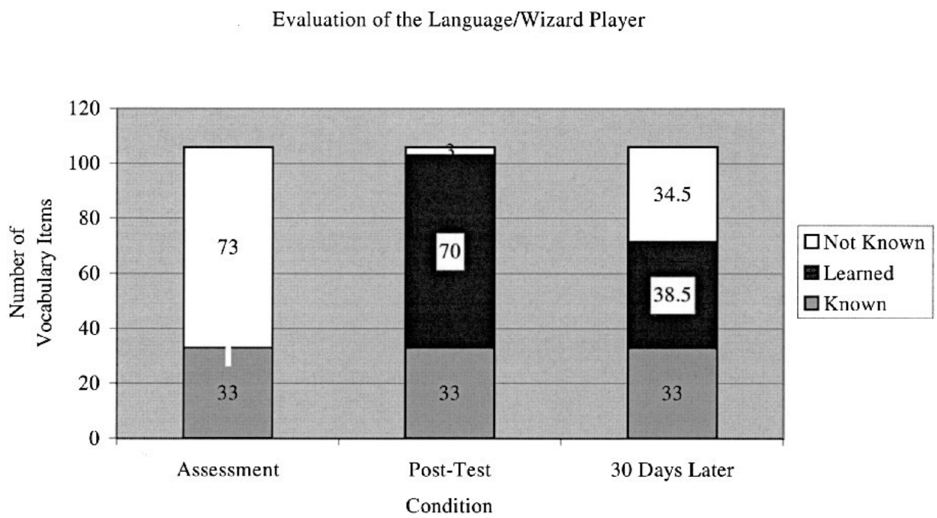

Fig. 1. Results of word learning at the Tucker-Maxon Oral School using the Language Wizard/Player. The results give the average number of words that were already known, the average number learned using the program, and the average number retained after 30 days. This outcome indicates significant vocabulary learning, with about 55% retention of new words after 30 days.

Yamamoto & Miya, 1999). Moore and Calvert (2000) investigated the effectiveness of a computer program to teach vocabulary. The children learned significantly more vocabulary items in the computer condition (74%) relative to the teacher condition (41%). The children also attended appropriately more often in the computer than in the teacher condition (75% vs. 65%), with a significant correlation between attention during training and accurate memory for the vocabulary items.

We anticipate that using Baldi as a tutor in an effective computer-based language-training program will facilitate language learning in children with autism. Effective programs for this population share the following elements: curriculum addressing the ability to use and comprehend language and interact socially, highly supportive teaching environments and generalization strategies, and learning environments that are predictable and routine. The advantages of the program include the unique ability to control and manipulate the visual and auditory components of spoken language automatically, visual images and text in the lessons to provide additional cues for word and concept learning, enough variation in the learning environment to facilitate generalization of what is learned, and a one-on-one format between the child and the computer. Presenting materials via computers can also potentially diminish the social difficulties some children with autism experience when interacting with a teacher or researcher.

Baldi is featured in a language-tutorial application to train and develop vocabulary, language, and listening skills. This Language Wizard/Player allows easy creation and presentation of a language lesson involving the association of pictures and spoken words. The lesson plan includes both the identification of pictures and the production of spoken words. This pedagogy is currently integrated into the curriculum of Tucker-Maxon Oral School (TMOS) for hard of hearing children. An independent assessment (Barker, 2003) of the student's vocabulary growth indicated that the students instructed by the Language Wizard/Player for word learning showed a significant gain in vocabulary during training. Moreover, the students were able to recall about 55% of these words when reassessed 30 days later (see Fig. 1).

METHOD

The goal of our investigation was to examine the effectiveness of the Language Wizard/Player in two schools with day programs for children with autism. We first examined whether children with autism could learn new vocabulary and grammatical usage and how they behaved to ensure compatibility of the program with this population. There were three stages in the study: an initial assessment test, training and testing, and a reassessment test after 30 days. Given the success of this initial study, it was important to address several issues: whether the Language Wizard/Player was responsible for the learning (e.g., students might have been receiving training on the words outside of our training program), whether the children would be able to generalize the learned vocabulary to new instances, and whether the students would transfer what they learned to an environment outside of the computer application when assessed by his or her instructor. The design of the second experiment was based on a single-subject multiple-baseline design (Baer, Wolf, & Risley, 1968) in which some words were continuously being tested while other words were being tested and trained. The student's instructors and speech therapists agreed not to teach or use these words during our investigation. Even if this were not the case, any significant difference between these two conditions is necessarily the result of the training program rather than some other factor.

EXPERIMENT 1

Method

Participants

Nine children diagnosed with autism, one girl and eight boys, ranging in age from 7 to 12 years were recruited from two day programs for children with autism in Santa Cruz County. Before the start of our investigation, we requested parent permission from all of the children enrolled in the two school programs. Out of 13 children, nine were permitted to participate. These students manifest a wide range of symptoms and abilities. Appendix 1 gives a brief description of each student's academic and adaptive functioning abilities as well as the diagnostic information provided by the school, parent, and teacher reports. All of the students exhibit delays in all areas of academics, particularly in the areas of language and adaptive functioning. During the investigation, one child left the school program, and therefore his participation in the study ended and his data were not used. Seven of the remaining eight children were capable of speech.

Stimuli

The vocabulary lessons were created using a Language Wizard. The lessons used Baldi, synthesized speech, and images of the vocabulary items. Appendix 2 gives a list of some of the items that were used in the lessons. The visual images were imported by the experimenter, who determined which parts of the visual image were associated with the spoken words or phrases. The Wizard was equipped with default settings that determine what Baldi said and how he said it, the feedback given for responses, the number of attempts permitted for the student per question, and the number of times each item was presented.

Figure 2 shows a view of the screen in a prototypical application in which the students learned to identify shapes. The outlined region designates the selected region. The faces in the left-hand corner of the figure are the "stickers," which show a happy or a sad face as feedback for correct and incorrect responses. Processing information that is presented via the visual modality reinforces learning (Courchesne *et al.* 1994; Dubois & Vail, 2001) and is consistent with the suggestion that visually presented material be used for educating children with autism (Schopler, Mesibov, & Hearsey, 1995). All of the exercises required the children to respond to spoken directives such as "click the little star" or "find the red fox." The items became highlighted whenever the child moved the mouse over that region. The students responded by clicking on one of the designated areas or by touching the monitor when a touch screen was being used.

There were five application exercises: pretest, presentation, recognition, production, and posttest (see Table I). The program stored the student's performance in a log file.

As described in Table II, each curriculum was designed for the student to progress through a series of four stages: assessment without feedback, training with written captioning of Baldi's speech as well as written labels for each vocabulary item, training in which the position of each vocabulary item was changed from the previous stage and without written labels, and training in which the position of each vocabulary item was changed from the previous stage and without captioning. The students gave an oral response during the production exercise, which was immediately replayed to the student to hear his or her response. The students were administered the lessons in progressive fashion through the three stages of the curriculum until 100% identification accuracy was attained on the posttest during the last stage of training. A reassessment occurred approximately 30 days after the final posttest.

Procedure

Before beginning our formal investigation, we conducted a series of training sessions over the course of several months to introduce the children to the experimenter, Baldi, and the format of the lessons. The students learned to sit at the computer, to put on headphones, to listen and respond to Baldi, and to use the mouse or to touch the screen. Each student had the option to respond with either an external mouse

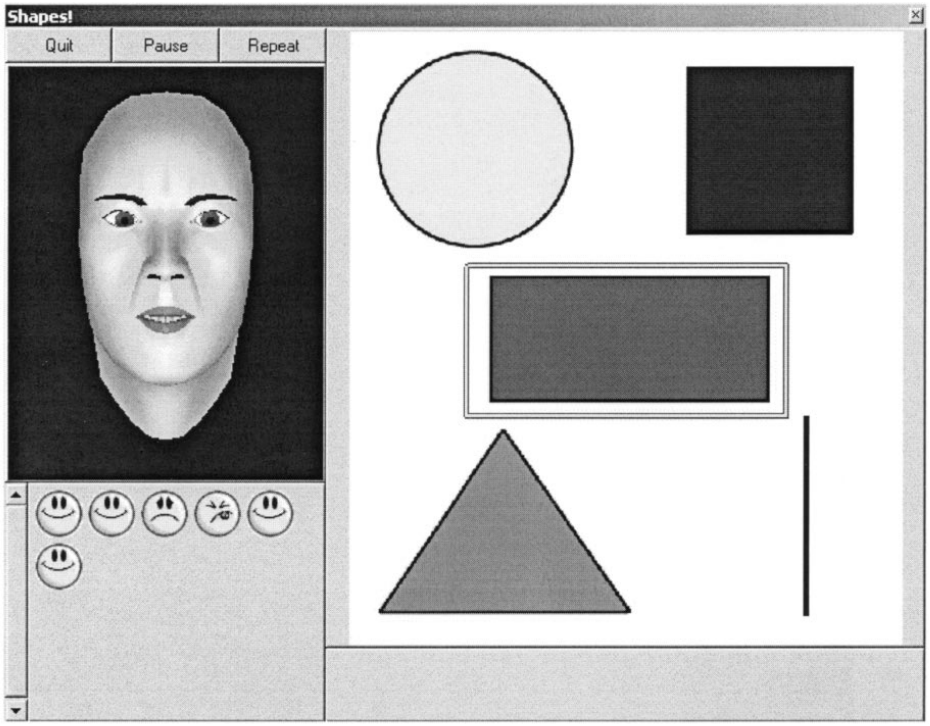

Fig. 2. A prototypical computer screen from the Language Wizard/Player illustrating the format of the tutors. Each application contains Baldi, the vocabulary items and written text and captioning (optional), and "stickers." In this application the students learn to identify shapes. For example, Baldi says "Click on the rectangle." The student clicks on the appropriate region, and visual feedback in the form of stickers (the happy and sad faces) are given for each response. The outlined region around the rectangle indicates the student's selection.

(Logitech M-CAA42, Fremont, CA) or a touch screen (KEYTEC Magic Touch, Richardson, TX). The students were reinforced for correct behaviors and were presented with several lessons containing vocabulary that the children had already mastered. Students also required some monitoring and direction during the lessons, but eventually all of the students learned to work independently.

The tutors were constructed and run on a 600-MHz PC with a 128-MB RAM hard drive running Microsoft Windows NT 4 with a Gforce 256 AGP-V6800 DDR graphics board. Baldi and the images were presented on a Graphic Series view Sonic 20-in. monitor. The auditory speech was delivered at a comfortable listening intensity via a Plantronics PC Headset model SR1 (Santa Cruz, CA). Students completed two sessions a week, a minimum of two lessons per session, with an average of three, and sometimes as many as eight. The sessions lasted between 10 and 40 minutes. A total of 559 different vocabulary items were selected from the school curriculum, magazines, books, and image banks, generating a total of over 84 unique vocabulary lessons. Each student was given a unique curriculum dependent on his or her abilities. The students worked with the program a few times a week over the course of six months (see Table III).

Results

Our evaluation determines the degree to which the Language Wizard/Player contributes to the acquisition and retention of vocabulary and grammar as well as a subjective measure of each student's response to the program. The data were captured and calculated at three separate points of our investigation: the initial assessment, the training sessions, and the final reassessment. Figure 3 gives the average number of words that were already known, the average number learned using the program, and the average number retained after 30 days. The results showed significant vocabulary learning, with about 91% retention of new words after 30 days.

Table III provides the individual performance of each student. As can be seen in the table, new

Table I. Description of the Language Wizard/Player Exercises; Each Exercise Is Optional and May Be Modified during Construction of the Application

Exercise	Description	Example
Pretest	To determine preexisting knowledge of the vocabulary items prior to tutoring. Records the correct and incorrect responses.	Student was prompted to select their name from a list. Baldi asked the student to find the named vocabulary item by clicking on the presented vocabulary items on the screen. Each response was recorded in a log file.
Presentation	To teach the associated visual images of the word with the vocabulary item.	Baldi begun this component saying, "Okay (user), now I will name these items for you." As each item was named, the associated region was highlighted. Baldi then said, "Show me the (item)." The student was required to click on the region highlighted to acknowledge the association of the visual image and the vocabulary item.
Recognition	To provide the student an opportunity to learn to recognize the items	Baldi begun by saying "Now let's practice (user)!" Baldi then prompted the student to identify each item by clicking on the visual image. After the student responded, another item was presented until all items had been practiced. Vocabulary items counted wrong during the pretest were presented at least twice. The number of recognition trials continued until the student was able to identify all items correctly or until a specified number of trials were reached. The experimenter set this variable during the construction of the lesson. Feedback for correct and incorrect responses was given by Baldi and in the form of stickers. Each response was recorded in the log file.
Production	To provide the student an opportunity to practice saying the name of each vocabulary item. Each response is recorded and stored in separate wave files for later evaluation.	Baldi begun by saying, "Now let's practice saying these words." Each vocabulary item was highlighted individually, and Baldi prompted the student to name the vocabulary item. The student's speech was recorded in wave files and immediately played back for the student. This sequence was repeated for all of the vocabulary items.
Posttest	Instructor can compare the scores between this exercise and the pretest to determine the number of vocabulary items learned.	Baldi said, "Now you're ready for the final test!" Baldi then asked the student to click on the specified vocabulary item. Feedback was given by Baldi and in the form of stickers.

vocabulary was learned by each of the students. The initial assessment test produced an average proportion of .44 correct identifications. During training, each lesson contained a pretest and a posttest. Across all lessons, the students identified significantly more words during the posttest ($M = .84$, $SD = .08$) than the pretest [$M = .67$, $SD = .31$; $t(7) = 2.99$, $p < .001$]. In addition, the students identified significantly more words on the reassessment after 30 days ($M = .91$, $SD = .02$) than on the initial assessment [$M = .45$, $SD = .07$; $t(7) = 1.89$, $p < .001$], indicating that the children not only learned new language but retained the material for at least 30 days after training was completed (Fig. 3).

Seven of the eight students appeared to enjoy working with Baldi. The children made statements like "Hi Baldi" and "I love you Baldi." The stickers generated for correct (happy face) and incorrect (sad face) responses proved to be an effective way to provide feedback for the children. Some students displayed frustration when they received more than one sad face and responded positively to the happy faces, too, saying "Look," pointing, or laughing when a happy face appeared. We also observed the students providing themselves verbal praise such as "Good job," or prompting the experimenter to say "Good job." One student did not enjoy working with our program (Student 8). Although this student did demonstrate learning during both the training sessions and the reassessment, his refusal to cooperate led to his withdrawal by parent request after the experiment was completed.

Discussion

The goal of our investigation was to evaluate the effectiveness of the Language Wizard/Player to train and develop vocabulary and grammar and to see whether the students could recall the vocabulary 30 days following mastery. Our data show that the students were able to identify significantly more items during the (Stage 3) posttest relative to the initial

Table II. Detailed Description of the Assessment and the Three Stages of Training Presented to the Children

Lesson	Description
Assessment	Contained pretest exercise only. Did not contain orthographic labels of vocabulary items or captioning of speech. Child was asked to identify each item by clicking on the appropriate region. Designed to assess the child's knowledge of vocabulary items. If 100% identification accuracy was not reached during this assessment, then the student was administered the tutorials.
Stage 1	Tutorial. This tutorial consisted of pretest, presentation, recognition, production, and posttest. During the pretest, production, and posttest, the vocabulary items were presented once, whereas both the presentation and recognition exercises were presented twice. Captioning and orthographic cues were provided to facilitate association between the presented visual images and the word. The captioning tracked Baldi's speech with the target word highlighted in bold.
Stage 2	Tutorial. Contained all five exercises listed above, each exercise presented once. Orthographic cues were removed, however, the lessons did contain captioning. These lessons were designed to strengthen the student's visual and auditory association of the vocabulary items.
Stage 3	Tutorial. Contained all five exercises each presented once. Student was presented only with the vocabulary items and auditory speech. Did not contain captioning. Required the child to rely on speech input only. Designed to strengthen spoken language processing by associating the visual image with the spoken word.

Note: For each lesson, the child must attain 100% accuracy during the posttest exercise before moving to the next tutorial. The order of presentation and relative position of each vocabulary item is altered for each lesson.

assessment, indicating that the Language Wizard/Player was effective at training vocabulary. Furthermore, the students were able to recall 85% of the newly learned items at least 30 days after training was completed (see Fig. 3).

EXPERIMENT 2

Although all of the children demonstrated learning from initial assessment to final reassessment, the children might have been learning the words outside of our program; for example, from speech therapists, at home or in their school curriculum. Furthermore, we questioned whether the vocabulary knowledge would generalize to new pictorial instances of the words. In addition, we asked whether the children would transfer what they learned to an environment outside of the computer application when assessed by his or her instructor. To address these issues we conducted a second experiment. Collaborating with the children's instructors and speech therapists, we gathered an assortment of vocabulary words that the children supposedly did not know. We used these words based on the Baer *et al.* (1968) single-subject multiple-baseline design (see also Horner & Baer, 1978). We randomly separated the words to be trained into three sets, established individual pretraining performance for each set of vocabulary items, and trained on one set of words while probing performance for both the trained and untrained word sets. Once the student was able to attain 100% identification accuracy during a training session in a Stage 3 posttest, a generalization probe to new instances of the vocabulary images was initiated. If the child did not meet the criterion, he or she was trained on these new images. Generalization training continued until the criterion was met, at which time training began on the next set of words. Probe tests continued on the original set of words and images until the end of the study. We continued this procedure until the student completed training on all three sets of words. To determine whether the students would transfer what they learned to an environment outside of the computer application, an additional probe was carried out with the student's instructor in a natural setting. Our goal was to observe a significant increase in identification accuracy during the posttraining sessions relative to the pretraining sessions, generalization to new instances, and transfer to a different environment.

Method

Participants

Six of the children (Students 1–6 in Appendix 1) who participated in the first experiment were tested. Student 7 was not present in school when the study was initiated.

Stimuli

As in Experiment 1, the vocabulary lessons were created using the Language Wizard. The lessons for each word set were designed for the student to progress through a series of five stages, our standard curriculum (assessment and training 1–3), and a generalization

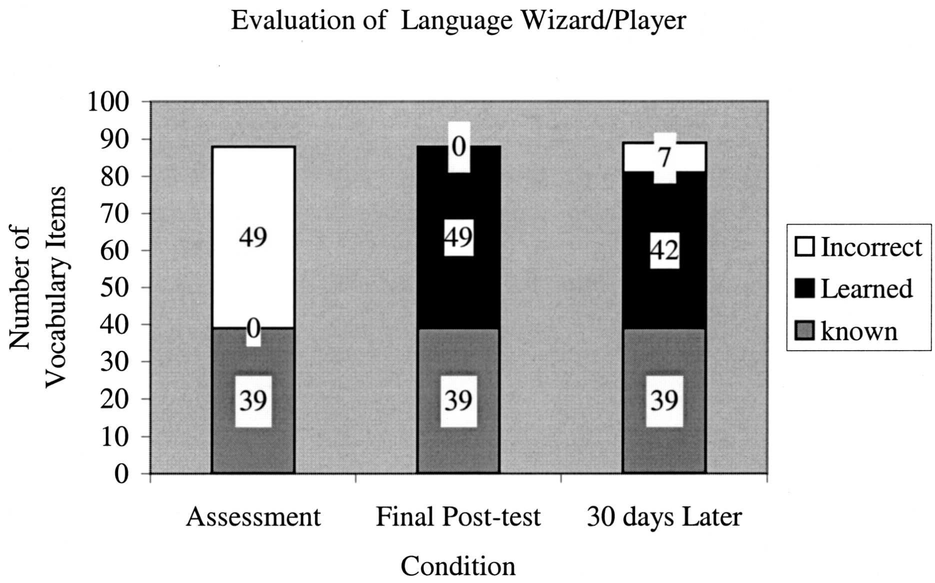

Fig. 3. Results of language learning using the Language Wizard/Player in Experiment 1. The results give the average number of words that were already known, the average number learned using the program, the average number retained after 30 days and the total amount of time spent in training. The results showed significant vocabulary learning, with about 91% retention of new words after 30 days.

assessment. The format of stages administered to the students differed from Experiment 1 in that the assessment included repeated probing for performance (Table IV). The generalization assessment was identical to the format of the initial assessment but with new instances of the vocabulary items. The vocabulary taught ranged in difficulty from identifying common nouns (i.e., safety pin, donkey, bib, clothespin, etc.) to identifying objects by their function (i.e., this is worn on the waist [belt], wrist [watch], hands [gloves], finger [ring], etc.).

Table III. The Number of Items Known at the Initial Pretest Assessment before Training (Known), the Number Learned (Learned), and the Number Retained at Least 30 Days after Training Was Complete (Retained): the Total Number of Items (Total) and the Total Training Time in Hours (Time on Task) for Each of the Eight Students in Experiment 1

Student	Known	Learned	Retained	Total	Time on Task
1	71	76	56	147	9.43
2	50	46	39	96	7.1
3	28	54	43	82	8.02
4	44	71	59	115	13.95
5	39	54	54	93	4.14
6	57	53	48	110	4.61
7	6	10	8	16	1.14
8	19	31	26	50	8.65
Total	314	395	333	709	57.04
Mean	39.3	49.4	41.6	88.6	7.13
SD	21.1	21.1	17.3	40.4	3.9

Procedure

Eighteen different vocabulary words were uniquely selected for each child, which were randomly separated into three sets of six for each of the six students. The instructors and speech therapists agreed that they would not teach or use these words during our investigation. Given that the training regiment was conditional on the student's performance, each child had a unique sequence of lessons and tests. Table V documents the pretraining, training, and posttraining probe stages for Subject 4.

Table IV. Detailed Description of the Assessment and Generalization Used in Experiment 2

Lesson	Description
Assessment	Contained pretest exercise only. Did not contain orthographic labels of vocabulary items or captioning of speech. Student was asked to identify each item by clicking on the appropriate region. Designed to assess the student's knowledge of vocabulary items. Vocabulary knowledge was probed three times.
Generalization	Identical in format to the assessment tests; however, contained new instances of the vocabulary items. The position of each vocabulary item was randomized for each generalization assessment.

Table V. Day by Day Condition and Schedule for the Four Initial Pretraining Probes, Probes, Training (TR), Stages of Training (Stage), and Generalization Tests (GT) for Student 4 in Experiment 2

Day	Condition	Schedule
1	Pretraining probe	Set 1, 2, 3
2	Pretraining probe	Set 2, 1, 3
3	Pretraining probe	Set 3, 1, 2
4	Pretraining probe	Set 2, 3, 1
5	Begin training set 1	Stage 1, 2
6	Probe	Set 3, 2, 1
7	Training set 1	TR stage 2 (×2)
8	Probe	Set 1, 3, 2
9	Training set 1	TR stage 2 (×2)
10	Training set 1	TR stage 2, 3, GT 1
11	Probe; training set 1	Set 2, 1, 3 TR set 1 stage 3 GT 2
12	Training set 1	TR stage 2 (×2), 3
13	Probe	Set 3, 2, 1
14	Training set 1	GT 3; TR stage 1, (×2)
15	Probe; Training set 1	Set 1, 2, 3 TR stage 2
16	Training set 1	TR stage 3, GT 4, 5
17	Finish GT for set 1; Begin training set 2	Set 1 GT 6, 7; TR set 2 stage 1
18	Training set 2	TR stage 1 (×2), 2
19	Training set 2	TR stage 3, GT 2; TR stage 1
20	Probe; training set 2	Set 3, 1, 2; TR stage 2
21	Training set 2	TR stage 2, 3; GT 3, 4
22	Probe; GT	Set 1, 3, 2; GT 5, 6
23	Begin training set 3	TR stage 1, 2(×2)
24	Training set 3	TR stage 2, 3(×2)
25	Training set 3	TR stage 3; GT 2, 3
26	Probe; finish GT	Set 2, 3, 1; GT 4, 5
27	Probe	Set 3, 2, 1
28	Probe	Set 3, 2, 1
29	Probe	Set 3, 1, 2
30	Probe	Set 3, 2, 1
31	Probe	Set 2, 1, 3
32	Probe	Set 3, 2, 1
33	Probe	Set 3, 1, 2

Note: Set x, y, z gives the order of the word sets, GT x, y gives the image sets for the generalization training, and stage gives the stage of the vocabulary tutor lesson (as described in Table II).

During all pretraining, training, posttraining, and generalization sessions, the students were required to work independently. The experimenter sat behind the student to observe performance during all sessions. Exceptions were made for Students 2–5 during all pretraining sessions. These students refused to complete the task because of either lack of reinforcement and acknowledgement from the program (Students 2–4) or because the test items were "unknown" (Student 5). The experimenter therefore provided noncontingent verbal praise periodically, such as, "Good job answering the question" and "You're doing great, keep it up." A food reinforcer (potato chip, goldfish, cracker, etc.) was given every third response during the first and second sessions and then faded to every sixth response during the remainder of the pretraining sessions.

Pretraining Sessions

Four counterbalanced assessment tests for each of the three word sets were conducted across 4 days to establish pretraining performance. During these sessions, the items were repeated in random order and presented three times each, providing three independent observations for each of the six vocabulary items.

Training Sessions

The method of training was identical to that in Experiment 1. The students were trained in roughly 10- to 30-minute sessions, for Students 1–4, 5 days a week, and for Students 5 and 6, twice a week. During the training sessions the students were administered the lessons labeled Stages 1–3. Once the student completed all stages of training and achieved 100% identification accuracy on the Stage 3 lesson posttest exercise, no additional training with the original vocabulary images was carried out.

Probe Sessions

After the student reached the criterion of 100% on the posttest of a given training stage (1, 2, or 3), the assessment test was administered to probe performance for both trained and untrained word sets. The assessment test used during these sessions was identical to the one used to collect the initial pretraining performance. These probe sessions were issued at the beginning of the day's session, and if time remained in the session, the experimenter resumed training from the previous day.

Generalization across Stimuli

Once the student completed all stages of training and achieved 100% identification accuracy on the Stage 3 lesson posttest exercise, a generalization test was carried out with novel images in new positions. During this test, the student was asked to receptively identify each vocabulary item three times, providing three independent observations for each of the six vocabulary items. If the student was unable to accurately identify each vocabulary item at least two out of the three times, tutorials were administered following our standard training procedures. If they did meet criterion, then another generalization test was given. We considered generalization to be established once the student was able to attain criterion across four consecutive generalization tests, each with unique images.

Transfer to and Use in a Natural Environment

To assess whether the vocabulary knowledge would transfer outside of the computer environment to a person not associated with the training program, an additional probe session was conducted in the student's work area with his or her instructor. During this session, the student was presented with a word set and asked to receptively identify each vocabulary item by pointing to or handing the instructor the image. Each word set was probed three times; each probe used a new image of the vocabulary item. Thus, for each word set, the students were presented with three unique instances for each vocabulary item. The instructors recorded correct and incorrect responses.

Results

Figure 4 displays the proportion of correct responses for each student during the probe sessions conducted at pretraining and posttraining for each of

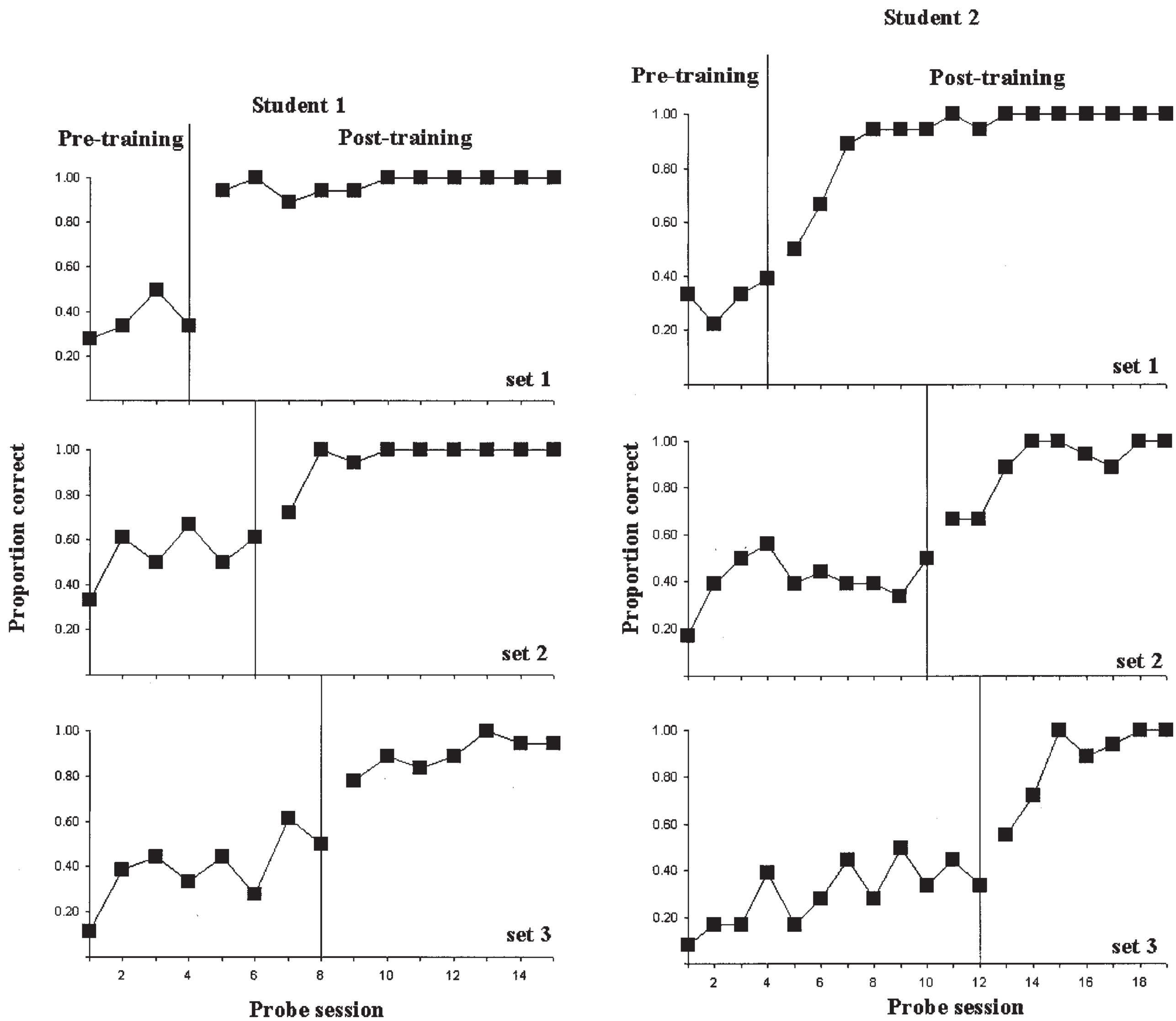

Fig. 4. Mean proportion correct during pretraining and posttraining probes for each of the three word sets and each of the six students in Experiment 2. The vertical line separates the pretraining and posttraining conditions. The figure illustrates that once training was implemented identification performance increased dramatically. (*Continued on next page*)

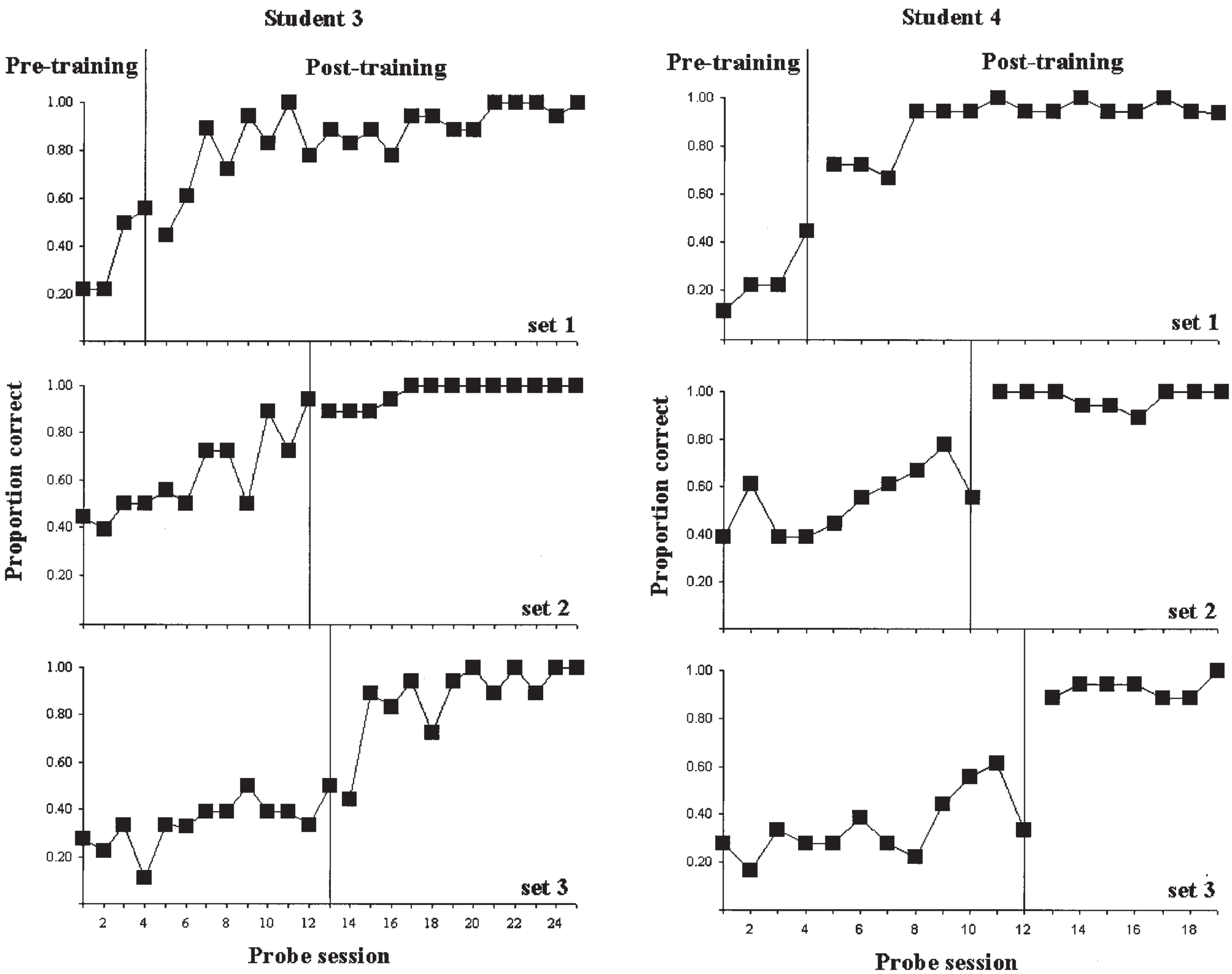

Fig. 4. (*Continued from previous page*)

the three word sets. As can be seen in the figure, performance varied dramatically across the children and across the word sets during the pretraining sessions. The vertical lines in each of the three panels indicates the last pretraining session before the onset of training for that word set. The average number of training sessions across the six students between posttraining and probe sessions were 1.7, 1.9, and 2.3, respectively. Table VI provides a general training schedule that each student completed. Some of the words were clearly known before training and were even learned to some degree without training. Given training, all of the students attained our criterion for identification accuracy for each word set and were also able to generalize accurate identification to four instances of untrained images.

Table VII provides the average performance for pretraining and posttraining performance for these word sets. As shown in the table, the pretraining assessment test produced an average .34, .59, and .38 correct, for word sets 1, 2, and 3, respectively. Evidently one or two words were known without training because chance performance would be about .17.

Identical to the procedure followed in Experiment 1, the students received training following the standard training procedure until 100% identification accuracy on the posttest of the last stage of training. Because training continued after the students may have mastered the words, students were performing very accurately during most of the training sessions. As analysis of training performance reveals that across all students and word sets, performance was very good and

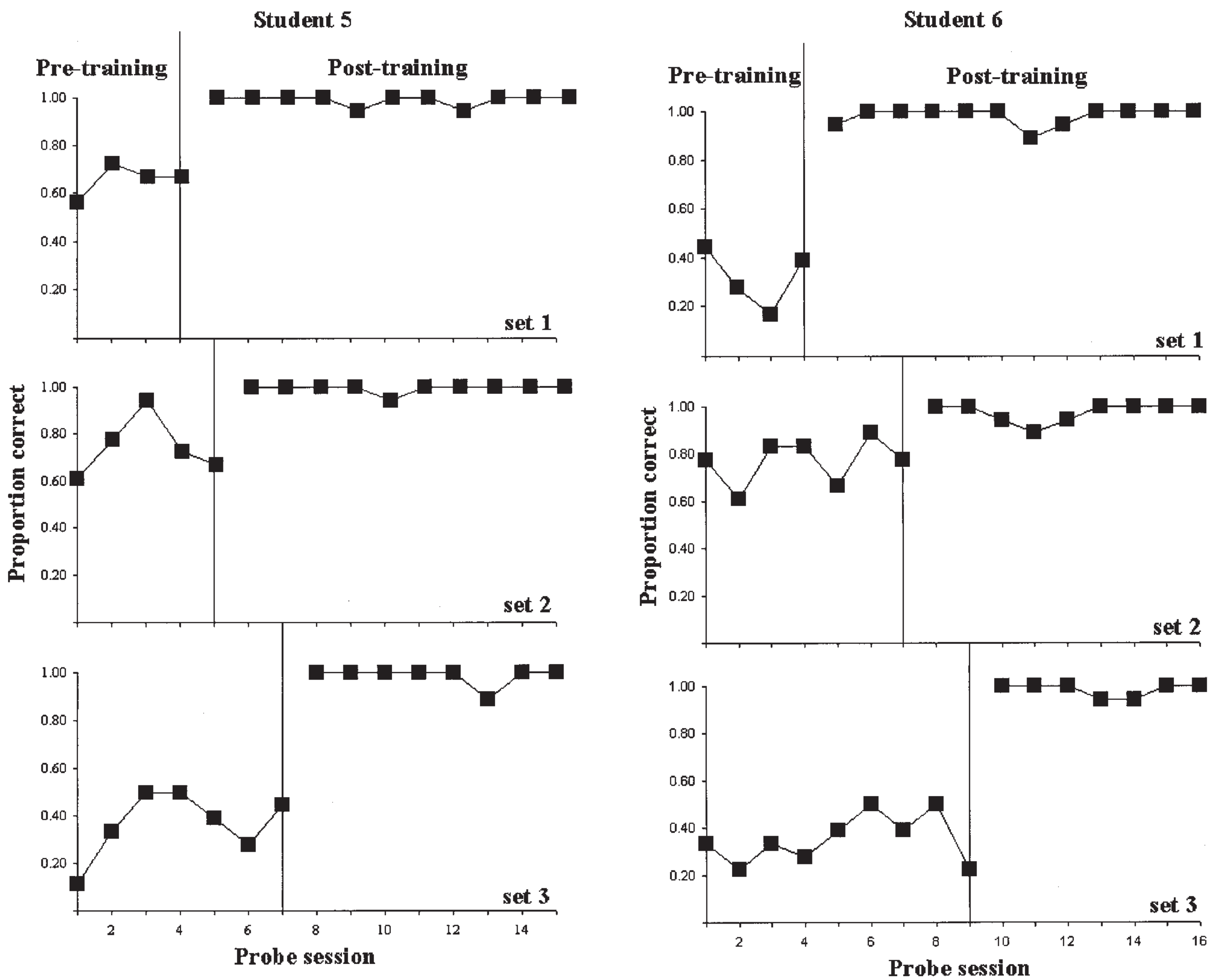

Fig. 4. Mean proportion correct during pretraining and posttraining probes for each of the three word sets and each of the six students in Experiment 2. The vertical line separates the pretraining and posttraining conditions. The figure illustrates that once training was implemented identification performance increased dramatically.

Table VI. Individual Training Regimen of Word Sets 1, 2, and 3

	Word set									
	1			2			3			
Student	T	*M*	*SD*	T	*M*	*SD*	T	*M*	*SD*	Time on Task (minutes)
1	8	2.0	1.2	3	1.5	0.7	4	2.0	1.4	141
2	11	2.0	0.8	11	2.2	1.3	11	2.8	2.4	345
3	16	2.0	0.5	6	2.0	1.0	6	2.0	1.0	286
4	9	1.5	0.6	5	2	0	3	3.0	0.0	168
5	3	3.0	0.0	1	1.0	0.0	2	2.0	0.0	41
6	5	1.7	0.6	3	1.5	0.7	2	2.0	0.0	74

Note: The total number of training days (T) required for each word set, the average number of days trained before each probe (*M*), the standard deviation (*SD*) of *M,* and the total amount of time in minutes spent in training (Time on Task).

Table VII. Proportion of Words Correct During Pretraining and Posttraining for the Six Students Across Word Sets 1, 2, and 3

	Word set					
	1		2		3	
Student	pre	post	pre	post	pre	post
1	.36	.97	.54	.96	.39	.90
2	.32	.92	.43	.92	.30	.81
3	.38	.87	.62	.97	.35	.88
4	.25	.91	.54	.98	.34	.93
5	.65	.99	.74	.99	.37	.99
6	.32	.98	.77	.98	.35	.98
M	.34	.91	.59	.97	.38	.93
SD	.12	.14	.18	.07	.17	.11

significantly more words were identified during the posttest ($M = .93$, $SD = .03$) relative to the pretest [$M = .90$, $SD = .05$; $t(5) = 2.92$, $p < .05$].

All probes during posttraining give the student's performance once training was implemented. Posttraining identification accuracy produced an average of .94. As illustrated in Fig. 4 and Table VIII, all of the students identified significantly more words during posttraining ($M = .94$, $SD = .22$) compared with pretraining performance [$M = .43$, $SD = .07$, $t(5) = 2.02$, $p < .001$] Table VII provides the individual performance for word sets 1, 2, and 3 for each of the six students.

Generalization accuracy averaged .91. Variation occurred in the number of generalization lessons administered both across students and across word sets. On average, the students were trained on 3.3, 2, and 1.7 new instances of the word sets 1, 2, and 3, respectively, before generalization to new instances occurred without any additional training. Table IX provides the number of lessons containing new images (including the three stages within each lesson) required for each student before generalization occurred.

Table VIII. The Proportion Correct for the Six Students During Both Pretraining and Posttraining Probes Averaged Across the Three Word Sets

Student	Pretraining	Posttraining
1	0.43	0.95
2	0.34	0.9
3	0.35	0.87
4	0.41	0.92
5	0.56	0.99
6	0.49	0.98
M	0.43	0.94
SD	0.08	0.05

Table IX. The Number of Additional Lessons (with Three Stages within Each Lesson) Required for Each Student Before Generalization Occurred; Each Lesson Contained New Instances of the Vocabulary Items

	Word set		
Student	1	2	3
1	4	1	1
2	6	4	4
3	4	2	2
4	3	2	1
5	1	1	1
6	2	2	1
M	3.3	2	1.7
SD	1.75	2	0.5

The students were able to transfer and use the vocabulary in a new environment. Performance accuracy averaged .93 when assessed by an individual not associated with training. Some variation occurred both across students and across word sets. On average, the students were able to identify .94, .94, and .91 for the word sets 1, 2, and 3, respectively. Table X provides the individual performance of the six students.

Discussion

Students are indeed learning vocabulary from the Language Wizard/Player. All of the students showed an increase in identification accuracy once training was implemented. The children demonstrated generalization of the learned vocabulary to new instances of the vocabulary items either immediately or after just a few training sessions. Furthermore, the children were able to generalize their knowledge from the

Table X. Average Individual Performance on Probes During the Transfer Test in a New Environment

	Word set		
Student	1	2	3
1	0.89	0.94	0.94
2	0.83	0.67	0.67
3	1.00	1.00	0.94
4	0.94	1.00	0.94
5	1.00	1.00	0.94
6	1.00	1.00	1.00
M	0.94	0.94	0.91
SD	0.07	0.13	0.12

Note: These probes were conducted in the student's work area with the student's instructor. Each item was probed three times, and each probe presented a new image of the vocabulary item.

computer program to an independent assessment by an instructor.

Some of the words were clearly known before training, but for whatever reason the student did not show knowledge of these words during the instructor's initial assessment session. This finding illustrates the importance of repeatedly assessing knowledge before implementing a treatment plan with this population.

Several issues arise from this investigation. The first is the sudden increase in performance during the pretraining sessions for some of the students. Student 3 in particular demonstrated a dramatic increase on word set 2 during training on word set 1. Typically, it would not be surprising that some learning occurs even without specific feedback because this situation occurs in much of language acquisition. For children with autism, however, it represents a somewhat novel observation. It is possible that the structure of the Wizard/Player encourages this type of learning, which would be an additional unforeseen benefit. Knowing several of the items would make it possible to determine what the other items had to be.

The second issue regards the reluctance of several of the students to cooperate during the pretraining assessments. Once training was implemented, however, these students participated willingly during the rest of the study. The reluctance we encountered during the pretraining assessments may be the result of their unfamiliarity with the vocabulary and the lack of feedback.

Our final issue concerns the development of odd response preferences for several of the students during our pretraining sessions. For instance, Student 2 developed perseverance in a specific response pattern. During pretraining probe sessions, the student clicked on "Hippopotamus" when asked to "Click on the Bib." During training, however, the student would correctly identify both items. During both the post-training probe and generalization probes, the student would incorrectly respond hippopotamus for bib even when both the image and the spatial location were changed. This phenomenon might reflect "overselectivity" (Lovaas, Schreibman, Koegel, & Rehm, 1971) in which the child perseveres on a particular response. Overselectivity was also observed in Student 3, who always misidentified a specific vocabulary item. These errors were corrected, however, with additional training sessions. To ensure learning, we repeatedly administered training lessons even after these students attained 100% identification accuracy. These additional training sessions account for the greater number of probe sessions for these students compared with the others.

GENERAL DISCUSSION

The goal of our investigation was to evaluate the potential of using a computer-animated talking tutor for children with autism. In Experiment 1 we examined whether children with autism could learn new vocabulary using the Language Wizard/Player. An assessment of the student's performance showed a significant gain in vocabulary. We also found that the students were able to recall the new vocabulary with 85% accuracy when reassessed 30 days after learning. In our second experiment, we examined whether the students were learning the vocabulary from the computer program, whether the vocabulary the children learned could generalize to novel images, and whether the knowledge would transfer outside of the computer program. Using a single-subject multiple-baseline design, we found convincing evidence that the learning is indeed occurring from the computer program, that vocabulary knowledge can generalize to novel images, and that it can transfer outside of the computer program.

Some learning occurred during the pretraining probe trials. The students were able to figure out some of the words through multiple presentations or perhaps became aware of the words in the environment through repeated exposure. If indeed learning can occur simply though multiple exposures without feedback, then we can treat this finding as an emergence of learning more generally (Bjork, 1994).

We demonstrated the effectiveness of the Language Wizard/Player to teach new vocabulary and foster generalization across new images in different spatial locations. We also found that the children were able to transfer and use what they learned to a natural environment with an individual not associated with the training. We did not evaluate whether the children used this new vocabulary in spontaneous speech. Research shows that even those children with autism who successfully recognize thousands of labels in training situations do not typically transfer these words to spontaneous speech (Lovaas *et al.,* 1973). It has been argued that highly structured training procedures that specifically control the environment may inadvertently confine these skills to such settings; thus, what is learned during training is often absent from spontaneous speech (Carr, 1980; Carr & Kologinsky, 1983). Future research with the Language Wizard/Player should investigate to what extent the language acquired through multimedia training transfers to social interactions.

We believe that the children in our investigation profited from having the face and that seeing and hearing spoken language can better guide language learning than either modality alone. A direct test of this hypothesis would involve comparing learning with and without the face. Baldi can actually provide more information than a natural face. He can be programmed to display a midsagital view, or the skin on the face can be made transparent to reveal the internal articulators. The orientation of the face can be changed to display different viewpoints while speaking, such as a side view, or a view from the back of the head (Massaro, 1999). The auditory and visual speech can also be independently controlled and manipulated, permitting customized enhancements of the informative characteristics of speech. These features offer novel approaches in language training, permitting one to pedagogically illustrate appropriate articulations that are usually hidden by the face. More generally, additional research should investigate whether the influence of several modalities on language processing provide a more comprehensive understanding of the potential perceptual and language abilities of children with autism.

Several advantages of using a computer-animated agent as a language tutor include the popularity of computers and embodied conversational agents and the availability of the program. Instruction is always available to the child, 24 hours a day, 365 days a year. Furthermore, instruction occurs in a one-on-one learning environment for the students. We have found that the students enjoy working with Baldi because he offers extreme patience; he does not become angry, tired, or bored; and he is in effect a perpetual teaching machine.

APPENDIX 1

Table AI. Diagnostic Information for the Eight Children

Student	Additional diagnoses	C.A.	I.Q. or C.F.	Adaptive functioning	Reading level
1	Mentally Retarded	10:6	N.A.[a]	N.A.[a]	First grade
2	—	11:1	57[b]	32[c]	Beginning kindergarten
3	—	9:11	N.A.	N.A.	First grade
4	—	7:4	38[c]	52[c]	First grade
5	Mentally retarded[a]	11:1	94[b]	38[c]	Beginning first grade
6	—	9:4	38[d]	57[c]	Beginning kindergarten
7	—	12:5	N/A[a]	N/A[a]	Beginning kindergarten
8	—	9:7	N/A[a]	N/A[a]	Beginning kindergarten

Note: The primary diagnosis for all of the children is autism. The chart contains additional diagnoses, chronological age (C.A.), nonverbal I.Q. or measure of cognitive functioning (C.F.), level of adaptive functioning, educational program, and reading level for each student.
[a] Information provided in next section.
[b] Wechsler Intelligence Scale for Children–Third Edition (Wechsler, 1989).
[c] Vineland Adaptive Behavior Scales (Sparrow, Balla, & Cicchetti, 1984).
[d] Psychoeducational Profile Revised (PEP-R) Schopler, Reichler, Bashford, Lansing & Marcus (1990). This score represents the developmental age equivalent (in months).

Student 1

Standardized assessments:

Both verbal and nonverbal IQ: Could not be conclusively determined at last testing. Clinician determined that he fell within the range of mental retardation. His expressive language was so low that all other scores were altered.

Social interactions and language use:

Tends to avoid social interactions. He will occasionally request attention while watching a video or while playing (e.g., “look at that”). Language use is rare and centers around his immediate needs and desires. He has very little spontaneous speech. Does not engage in reciprocal conversation with peers.

Nonadaptive/nonfunctional behavior:

Unintelligible nonfunctional vocalizations and occasional hand flapping. This child engages in repetitive activities. Throwing hands up over head and yelling “no” or “Oh no” and looking at desired objects with only one eye open, peripheral gazing, and finger picking (until bleeding).

Aggression:

Does not exhibit any observed aggressive behaviors toward others.

Student 2

Standardized assessments:

See chart above

Social interactions and language use:

This child is aware of others, often seeking attention and praise of adults. He does not use speech spontaneously, initiating conversation only if prompted or in limited, scripted situations. He can construct sentences up to seven words.

Nonadaptive/nonfunctional behavior:

Rocking, nonfunctional vocalizations (repetitive sounds; e.g., ba, ba, ba; but, but, but, or laughing), inappropriate touching, repetitive touching (finger to mouth to "wipe away" something that is not there, rubbing arm or fingers, etc.).

Aggression:

This child will aggress towards self and others: pinching, hitting, screaming, pulling hair, and scratching. Aggression is frequent (zero to five times a day) and generally occurs to escape a difficult or undesired task.

Student 3

Standardized assessments:

Unable to obtain standard scores on either verbal or nonverbal standardized tests due to noncompliance and disruptive behaviors.

Social interactions and language use:

This child has very little spontaneous speech, interacting with others when requesting or seeking a desired object or activity.

Nonadaptive/nonfunctionalbehavior:

Nonfunctional vocalizations (including vocalizations that are not true words and words repeated from a book, video, or song); frequent crying, whining, whimpering, and screaming; frequent hand flapping, rocking, tensing body, and hands; responding in an inappropriate speaking voice, and "running off" suddenly.

Aggression:

Aggressive behaviors/tantrums are observed zero to five times a day, including kicking, hitting, and head butting. These behaviors are typically observed when he is required to complete an undesired task, unable to engage in desired activity, or when leaving reinforcing items/activities.

Student 4

Standardized assessments:

See chart above.

Social interactions and language use:

This child has very little spontaneous speech, interacting with others only when requesting or seeking a desired object or activity.

Social interactions and language use:

Nonfunctional vocalizations, noncompliance, crying, nonfunctional hand movements, and throwing self on the floor. Frequently seeks negative attention from adults; for example, making intentional errors and prompting the adult to say, "Don't click on the wrong thing, you need to click on the right thing."

Aggression:

Does not exhibit any observed aggressive behavior towards others.

Student 5

Standardized assessments:

There is a large discrepancy in his IQ; nonverbal IQ is average (94), whereas his verbal IQ is 48, placing him in the range of mentally retarded.

Social interactions and Language use:

He will typically interact with others. He uses speech spontaneously to direct another's attention to an object or activity. He is very competitive in all areas of academics, games, and sports. If he is unable to be first in line or is unable to answer a question of any sort, he will tantrum. According to his instructor, he is reluctant to attempt to learn new subject matter. He frequently tantrums when beginning a new task not yet understood or mastered. Fear of failure results in emotional outbursts. He can construct simple sentences containing up to four words.

Nonadaptive/nonfunctional behaviors:

Repetitive nonfunctional vocalizations, pacing a room, hitting self on the head with fists, and hitting/pushing others in the room.

Aggressive behavior:

Hitting, punching, screaming, scratching, and kicking. Aggression generally occurs to escape a difficult or undesired task and occurs frequently (more than five aggressive episodes per day).

Student 6

Standardized assessments:

See chart above.

Social interactions and language use:

He is limited in his attempts to interact with peers and adults. Social play level is at parallel developmental stage in school environment, although he becomes highly frustrated in peer interactions and has difficulty cooperating in group situations (tries inappropriately to control group activities). Language use is limited in social interactions/activities, typically directed toward own needs and desires. He is beginning to share his own experiences with others by directing adult's attention toward his focus of attention (i.e., "look"). He does not follow speaker's direction of attention unless specifically instructed to do so. Shows empathy toward others and can identify and display appropriate emotion.

Nonadaptive behaviors:

Nonfunctional speech (e.g., repeating phrases from books and movies), repeatedly hitting self, and throwing self on the floor and participating in repetitive routines.

Aggression:

Engages frequently in aggressive behaviors (more than five aggressive episodes per day). Displays noncompliance and aggressive behaviors directed toward others. These behaviors typically occur. Aggression is directed toward self and others: pinching, hitting, screaming, kicking, and scratching generally occur during nonstructured activities, new activities, difficult tasks, and transitions from one activity to another to escape/avoid a nondesired activity transition and during academic activities.

Student 7

Standardized assessments:

According to the student's records, the severity of disability prohibits successful participation in standardized testing.

Social interactions and language use:

Primary form of communication is through picture/word exchange system, visual symbols, American Sign Language, and some nonword vocalizations. He is expressively limited, both verbally and through sign language, and will not initiate interactions with others. Using sign language, his sentence length is one sign; he does not string signs together to form sentences. He typically relies on body language/gestures. Many of the signs he uses are made up. He frequently tantrums during transitions or social interactions (pinching hitting).

Nonadaptive/nonfunctional behavior:

Nonfunctional vocalizations, hand flapping, and engaging in repetitive activities.

Aggression:

Hitting, kicking, pushing, and pinching. Aggression is frequent (five to ten episodes a day) and typically occurs during transitions from one activity to another.

Student 8

Standardized assessments:

According to the student's records, the severity of disability prohibits successful participation in standardized testing.

Social interactions and language use:

He has very little spontaneous speech, interacting with others only when requesting or seeking a desired object or activity. He will occasionally seek attention from adults while watching a video or playing (e.g., "look at that," "wow"). Sentence length is approximately three to five words.

Nonadaptive/nonfunctional behavior:

Noncompliant behaviors; for example, saying negative statements, not following directions, grabbing items without permission, running away, falling out of chair, noncontextual vocalizations, and nonfunctional vocalizations.

Aggression:

Does not aggress toward others.

APPENDIX 2

Table AII.

Types of vocabulary	Number of lessons containing vocabulary items or concepts	Examples of vocabulary items/concepts contained within the lessons
Verbs	4	Washing, blowing, building, pulling, Jumping, chasing, kicking, swimming, climbing
Food	1	Apple, carrots, bread, orange, etc.
Body parts	1	Arm, leg, head, knee, foot, leg, etc.
Internal body parts	1	Stomach, heart, liver, diaphragm, lungs
Animals	4	Dog, cow, cat, giraffe, buffalo, pig, rabbit, camel, bird, elephant, zebra, deer, goat, bear
Bugs	3	ladybug, fly, beetle, butterfly
Birds	2	Turkey, pigeon, seagull, chicken, owl, goose, flamingo, ostrich, duck
Shapes	3	Square, triangle, pentagon, circle, rectangle, octagon, line
Colors	5	Blue, green, red, yellow, orange, gray, black, white, pink
Colors and shapes[a]	1	Red circle, blue circle, red square, blue square, red triangle, blue triangle
Pronouns[b]	3	He, she, it, they
Opposites[a]	5	Thin/fat big/small tall/short night/day Soft/hard, narrow/wide, black/white, up/down, happy/sad
Adjectives[c]	7	Hot, cold, big, light, tall, dry, thin, quiet, wet, heavy
Plurals	1	Bug/bugs, flower/flowers, orange/oranges, glass/glasses
Kitchen items	2	Tea spoon, table spoon, glass, fork bowl
Prepositions[b]	2	Over, under, next to, in front of, behind, inside
People	1	Doctor, fireman, postman, veterinarian, chef, farmer, police officer
Vehicles	1	Car, fire truck, school bus, tractor, helicopter, airplane
Whole object	1	Car parts: door, windshield, tire, headlight
Garage items	1	Screwdriver, pail, hose, pliers
Locate within a picture	7	Bathroom, garage, living room, bedroom
Big and little[a]	3	Big dog/little dog, big heart/little heart, big house/little house, big star/little star, big chair/little chair, big bird/little bird
Counting	2	Three bears, four bears, five shoes, a pair of shoes
States	7	California, Arizona, Washington
Emotions[a]	5	Happy, sad, surprised, mad, disgusted, scared
Numbers	2	Digit identification: 1–10
Bathroom Items	1	Mirror, toothbrush, razor, shaving cream, toothpaste, washcloth
Alphabet	3	A–Z letter identification

Note: These are just a few examples of the types of lessons administered to the students.

[a] Generalization required. The students progressed through a series of lessons in which the same vocabulary concepts were presented; however, different images were used in each lesson. For example, for the five emotion lessons, each required identifying the emotions happy, sad, mad, and so forth, and each lesson showed one person displaying the emotions; however, we used faces of different people in each of the lessons. Likewise for the big/little applications, the same concept was used (differentiating between big and little); however, once learned, the student was required to generalize this knowledge to different objects.

[b] These lessons were divided into smaller lessons. This usually occurred when the concept being learned was too difficult for the children. For example, one of the preposition lessons contains six different images. Many of the students were having difficulty learning the prepositions. To facilitate learning, we developed lessons in which the students were presented with only two prepositions, then three prepositions, and so on, until all six of the prepositions were presented and accurately identified. In the analysis, those lessons that were separated into smaller lessons were counted as part of the tutorial series.

[c] Many of these vocabulary items are contained in the opposites lessons, also. The difference between these lessons is that the adjective lessons focus on identifying the characteristic of the adjective, and opposites focuses on identifying the opposite of the named vocabulary item. For example, a lesson contains an image of a “fat” man and a “thin” man. In the adjective lesson, the student is asked to identify the “fat” or “thin” man. In the opposite lesson, the student is asked to identify the opposite of “fat” or the opposite of “thin.”

ACKNOWLEDGMENTS

This research was supported by National Science Foundation (grant no. CDA-9726363, grant no. BCS-9905176, Public Health Service grant no. PHS R01 DC00236) and the Cure Autism Now Foundation. We thank the reviewers for their helpful comments on the original submission of this article and to thank Caroline Henton and Rachael Lando for reading the manuscript.

REFERENCES

American Psychiatric Association (1994). *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.). Washington, DC: Author.

Baer, D. M., Wolf, M. M., Risley, T. R. (1968). Some current dimenstions of applied behavior analysis. *Journal of Applied Behavior Analysis, 1,* 91–97.

Barker, L. J. (2003). Computer-assisted vocabulary acquisition: The CSLU vocabulary tutor in oral-deaf education. *Journal of Deaf Studies and Deaf Education, 8,* 187–198.

Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe and A. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 185–205). Cambridge, MA: MIT Press.

Calvert, S. L. (1999). *Children's journeys through the information age.* Boston: McGraw Hill.

Carr, E. G. (1980). Generalization of treatment effects following educational intervention with autistic children and youth. In B. Wilcox & A. Thompson (Eds.), *Critical issues in educating autistic children and youth* (pp. 118–134). Washington, DC: Department of Education, Office of Special Education.

Carr, E. G. (1982). Sign language. In R. L. Koegel, A. Rincover, & A. L. Egel (Eds.), *Educating and understanding autistic children.* San Diego, CA: College Hill.

Carr, E. G., & Dores, P. A. (1981). Patterns of language acquisition following simultaneous communication with autistic children. *Analysis & Intervention in Developmental Disabilities, 1(3-sup-4),* 347–361.

Carr, E. G., & Kologinsky, E. (1983). Acquisition of sign language by autistic children II: spontaneity and generalization effects. *Journal of Applied Behavior Analysis, 16,* 297–314.

Chun, D. M., & Plass, J. L. (1996). Effects of multimedia annotations on vocabulary acquisition. *Modern Language Journal 80,* 183–198.

Cohen, M. M., Beskow, J., & Massaro, D. W. (1998). Recent developments in facial animation: An inside view. In *Proceedings of Auditory Visual Speech Perception '98.* (pp. 201–206). Terrigal-Sydney Australia, December, 1998.

Cohen, M. M., Walker, R. L., & Massaro, D. W. (1996). Perception of synthetic visual speech. In D. G. Stork & M. E. Hennecke (Eds.), *Speechreading by humans and machines* (pp. 153–168). New York: Springer.

Courchesne, E., Townsend, J., Ashoomoff, N. A., Yeung-Courchesne, R., Press, G., Murakami, J., Lincoln, A., James, H., Saitoh, O., Haas, R., & Schreibman, L. (1994). A new finding in autism: Impairment in shifting attention. In S. H. Broman & J. Grafman (Eds.), *Atypical cognitive deficits in developmental disorders: Implications for brain function* (pp. 101–137). Hillsdale NJ: Lawrence Erlbaum.

Dubois, M., & Vial, I. (2000). Multimedia design: The effects of relating multimodal information. *Journal of Computer Assisted Learning, 16,* 157–165.

Gupta, P., & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: computation and neural bases. *Brain and Language, 59,* 267–333.

Handleman, J. S. (1979). Generalization by autistic-type children of verbal responses across settings. *Journal of Applied Behavior Analysis, 12,* 273–282.

Heimann, M., Nelson, K., Tjus, T., & Gilberg, C. (1995). Increasing reading and communication skills in children with autism through an interactive multimedia computer program. *Journal of Autism and Developmental Disorders, 25,* 459–480.

Horner, R. D., & Baer, D. M. (1978). Multiple-probe technique: A variation of the multiple baseline. *Journal of Applied Behavior Analysis, 11,* 189–196.

Jahr, E. (2001). Teaching children with autism to answer novel wh-questions by utilizing a multiple exemplar strategy. *Research in Developmental Disabilities, 22,* 407–423.

Koegel, L. K. (2000). Interventions of facilitate communication in autism. *Journal of Autism and Developmental Disorders, 2,* 383–391.

Koegel, L., Koegel, L. K., Surratt, A. (1992). Language intervention and disruptive behavior in preschool children with autism. *Journal of Autism and Developmental Disorders, 22,* 141–153.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview—Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism & Developmental Disorders, 24,* 659–685.

Lovaas, O. I., Koegel, R., Simmons, J. Q., & Long, J. S. (1973). Some generalization and follow-up measures on autistic children in behavior therapy. *Journal of Applied Behavior Analysis, 6,* 131–166.

Lovaas, O. I., Schreibman, L., Koegel, R., & Rehm, R. (1971). Selective responding by autistic children to multiple sensory input. *Journal of Abnormal Psychology, 77,* 211–222.

Massaro, D. W. (1998). *Perceiving talking faces: From speech perception to a behavioral principle.* Cambridge, MA: MIT Press.

Massaro, D. W. (1999). From theory to practice: Rewards and challenges. In *Proceedings of the International Conference of Phonetic Sciences,* San Francisco, CA, August.

Massaro, D. W. (2000). From "Speech is Special" to Talking Heads in Language Learning. In *Proceedings of Integrating speech technology in the (Language) Learning and Assistive Interface,* (InSTIL 2000) August 29–30.

Moore, M., & Calvert, S. (2000). Brief report: Vocabulary acquisition for children with autism: Teacher or computer instruction. *Journal of Autism and Developmental Disorders, 30,* 359–362.

Prizant, B. M. (1983). Language acquisition and communicative behavior in autism: Toward an understanding of the "whole" of it. *Journal of Speech & Hearing Disorders, 48,* 296–307.

Rincover, A., & Koegel, R. L. (1975). Setting generality and stimulus control in autistic children. *Journal of Applied Behavior Analysis, 8,* 235–246.

Schopler, E., Mesibov, G. B., & Hearsey, K. (1995). Structured teaching in the TEACCH system. In E. Schopler & G. B. Mesibov (Eds.), *Learning and cognition in autism. Current issues in autism.* (pp. 243–268). New York: Plenum Press.

Schopler, E., Reichler, R., Bashford, A., Lansing, M., & Marcus, L. 1990. The Psychoeducational Profile Revised (PEP-R). Austin, TX: Pro-ed.

Sparrow, S. S., Balla, D. A., & Cicchetti, D. V. (1984). Vineland Adaptive Behavior Scales. Circle Pines, MN: American Guidance Service.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21,* 360–406.

Stokes, T. F., Baer, D. M., & Jackson, R. L. (1974). Programming the generalization of a greeting response in four retarded children. *Journal of Applied Behavior Analysis, 7,* 599–610.

Tager-Flusberg, H. (1999). A psychological approach to understanding the social and language impairments in autism. *International Review of Psychiatry, 11,* 355–334.
Tager-Flusberg, H. (2000). Language development in children with autism. In L. Menn & N. Bernstein Ratner (Ed.), *Methods For Studying Language Production* (pp. 313–332). Mahwah, NJ: Lawrence Erlbaum.
Van Lancker, D., Cornelius, C., Needleman, R. (1991). Comprehension of verbal terms for emotions in normal, autistic, and schizophrenic children. *Developmental Neuropsychology, 7,* 1–18.
Vermeer, A. (2001). Breadth and depth of vocabulary in relation to L1/L2 acquisition and frequency of input. *Applied Psycholinguistics, 22,* 217–234.
Wechsler, D. (1989). Wechsler Preschool and Primary Scale of Intelligence–Revised. San Antonio, TX: Psychological Corporation.
Wood, J. (2001). Can software support children's vocabulary development? *Language Learning & Technology, 5,* 166–201.
Yamamoto, J., & Miya, T. (1999). Acquisition and transfer of sentence construction in autistic students: Analysis of computer-based teaching. *Research in Developmental Disabilities, 20,* 355–377.