# Learning to Read with a Virtual Tutor:

# Foundations to Literacy

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Reference: Wise, B.; Cole, R.; van Vuuren, S.; Schwartz, S.; Snyder, L.; Ngampatipatpong, N.; Tuantranont, J.; & Pellom, B. (In Press). Learning to Read with a Virtual Tutor: Foundations Literacy. In Kinzer, C. & Verhoeven, L. (Eds). Interactive Literacy Education. Mahwah, NJ: Lawrence Erlbaum

# 1. Introduction

This chapter describes the *Foundations to Literacy* component of the Colorado Literacy Tutor, a comprehensive literacy program that uses computer-based learning tools incorporating human language technologies to teach students to read and comprehend text. The Colorado Literacy Tutor project, or COLit (COLit, 2004), is headed by Professor Walter Kintsch at the Institute for Cognitive Science at the University of Colorado. Co-investigators of grants supporting the project include Donna Caccamise, Ron Cole, Lynn Snyder, Barbara Wise, and Tom Landauer, who all collaborate at the University of Colorado on the projects mentioned here.

COLit combines *Foundations to Literacy*, the animated learning tools developed at the Center for Spoken Language Research (CSLR), with *Summary Street,* a program developed at the Institute for Cognitive Science (ICS) at the University of Colorado. *Summary Street* (Summary street, 2004)*,* is designed to train students to comprehend what they read and express their understanding of text in complete and concise summaries. *Foundations to Literacy* consists of a set of tightly integrated computer-based multimodal learning applications in which children interact with a lifelike computer character to learn to read well and to comprehend stories.

## 1.1 Background

The Colorado Literacy Tutor project was initiated in 2000 following the award of grants from the National Science Foundation, National Institute of Health, Department of Education and the Coleman Institute for Cognitive Disabilities to the University of Colorado (Ron Cole and Walter Kintsch, Principal Investigators). But the theory, pedagogies, methodologies, and technologies underlying the COLit project builds on over twenty years of research and development of human language technologies by Cole and colleagues at CSLR, at Carnegie Mellon University, and at Oregon Graduate Institute (Cole, 1999; Cole et al., 1998, 1999, 2003). It builds on thirteen years of research on computer-assisted reading for children with reading difficulties, by Wise and colleagues (e.g., Wise & Olson, 1995; Wise, Ring & Olson, 2000) and on teaching children with reading disabilities (Wise, 2002, 2001a,b, 1999). It also builds on theoretical and empirical work on comprehension by W. Kintsch (1998) and E. Kintsch and colleagues (Kintsch & Kintsch, 1997; Kintsch et al., 2000; Landauer & Dumais, 1997).

Two precursor projects will be mentioned again later in this chapter, since both projects involved members of the COLit research and development team, and both provided insights and lessons that have played an important role in informing the design of our *Foundations to Literacy* programs in COLit. In the "Baldi" project, a 3D talking head with accurate visible speech was used to teach vocabulary to children with profound hearing loss (Barker, 2003; Cole et al., 1999). In the "Reading with ROSS" project, students read from books on the computer in the presence of a research assistant, and received synthetic speech support for any difficult word they targeted with a mouse (e.g., Wise et al., 2000). Each of these projects will be briefly discussed in the context of providing relevant information about our current program.

### 1.2 Vision

The vision that drives the COLit project is to develop a new generation of learning tools, informed by cognitive theory and scientifically-based reading research, which integrate state- of-the-art human language and communication technologies to provide students with engaging, enjoyable, and effective learning experiences. We work towards this goal by designing learning experiences in which the student interacts with a "Virtual Tutor," a lifelike, interactive computer character in immersive multimodal environments in well-designed learning tasks.

Research has established the power of one-on-one tutoring (Bloom, 1984), and Vaughn and colleagues (2001) found that small group instruction with a well-educated teacher can be as powerful as one-on-one tutoring. Whether in small groups or one-on-one, effective teachers customize learning tasks to the interests and needs of each student and provide individualized feedback and guidance. Individualized instruction is so effective because the teacher can apply all of her experience and knowledge to the learning process while keeping the student engaged, focused, and motivated. We propose that we can provide similarly optimal learning experiences by designing effective multimodal learning applications in which intelligent animated agents behave as much as possible like sensitive and effective teachers. Inventing such agents requires research to improve speech and visual recognition technologies so the animated agents can recognize and interpret students' behaviors and requires research to understand and model the behaviors of master teachers. The seminal work of Reeves and Nass (1996) suggests that, if such embodied animated agents are well designed, learners will interact with these agents as if they are working with real teachers. Our own prior work with an animated agent, Baldi, that taught vocabulary to children with hearing problems, strongly supports this claim (Barker, 2003; Cole et al.; 1999). Students talked about Baldi as if he were a real person: "Baldi helps me learn," "Baldi is patient with me, and he listens carefully to what I say," and "Sometimes Baldi doesn't hear what I say."

The Virtual Tutor in our project, Ms. Readwrite, "lives" within Interactive Books and Foundational Exercises. During these tasks, she gives hints and explanations to help children to figure out answers while learning about phonological awareness, reading, spelling, and comprehension. She helps children learn to recognize words, to read fluently, and to understand what they read, providing engaging practice with individualized support and focused hints.

In our applications, the Virtual Tutor pronounces words distinctly, with accurate movements of the lips, tongue, and jaw. Rather than using synthetic speech, which is certainly easier and faster, we use recorded speech, synchronized with the movements of the visible articulators. By using a recorded voice, we produce a more natural and effective user experience that benefits from the remarkable range and communication abilities of the human voice. When the character reads a story or interacts with the child, she does so with the appropriate prosody and emotional content in all contexts. In our Interactive Books, we record all sentences, prompts, questions, and reading supports produced by the agent. We also record each word pronounced individually in isolation, so that the Tutor pronounces it clearly and distinctly if the student clicks on the word. In the Foundational Exercises, we record all instructions and prompts, as well as individual sounds, syllables, words, and distracters as needed in each application. In our current deployment, children's interaction with the Virtual Tutor is limited to mouse clicks and typed responses by the student. However, in the very near future (see Sections 4 and 8), deployments will incorporate speech recognition, face tracking, and gaze tracking technologies.

**1.3 Organization**

This chapter proceeds in Section 2 by describing the background for the *Foundations to Literacy* portion of COLit: its goals, motivation, theoretical background, and the instructional principles that guide it. Section 3 gives an overview of its instructional components—Foundational Reading Exercises, Interactive Books, Managed Learning Environment, Assessments, and Study Plan. Section 4 describes the system architecture and the technology servers that support the system. As Foundational Exercises are a major focus of this chapter, we provide the theoretical and scientific rationale for our selection of foundational domains in Section 5, and examples of Exercises in each domain in Section 6. Section 7 describes initial results from a pilot study with some Foundational Exercises and previews a summative evaluation underway in 24 treatment and 12 control classrooms in four schools in kindergarten to second-grade classrooms. Section 8 concludes with a brief discussion of future plans.

## 2. Philosophy and Rationale

### 2.1 Goals

The overarching goal of the COLit project is to design an accessible, affordable, scalable and sustainable comprehensive literacy program. We say "comprehensive" to describe a literacy program that will serve the needs of many individuals of many ages, especially those having difficulties with reading due to lack of good educational experience, learning difficulties, language differences, or difficulties due to cognitive, sensory, or physical disabilities. By comprehensive, we also mean that the program teaches and supports many aspects of reading and reading problems. It teaches *Foundations to Literacy* to children whose reading difficulties stem from difficulties with reading words. It also supports and improves reading comprehension and fluency after these students have mastered accurate word reading skills. Eventually, it will develop and improve processes underlying poor language comprehension for those readers with specific comprehension difficulties even with spoken material, who may or may not have any problems at the word reading level. In short, the Colorado Literacy Tutor is designed to teach people to read well, and to improve their comprehension of what they read.

While these are ambitious goals, we argue that they are achievable in the foreseeable future. We believe this is possible due in large part to increased knowledge of effective instructional practices gained from scientifically-based reading research, to the low cost of computers and computing infrastructure, to the increasing power of computers, and to the value of emerging speech, language, computer vision and character animation technologies. These emerging technologies have the potential to transform interactions with computers into powerful communication experiences, through immersion of learners in multimodal learning environments with face-to-face conversations with sensitive and effective Virtual Tutors. Such interactive Virtual Tutors can increase the effectiveness of classroom teachers in several ways. They can provide positive, independent, individualized, and effective practice for students, and they can give the teacher detailed feedback on each student's progress. They can help free teachers' time by enabling students who need more individualized instruction to work independently with effective learning tools on a computer, while other students in the classroom receive more interaction and attention from the teacher. In situations with high teacher turnover or lack of well-trained teachers, COLit can provide the independent, structured, intensive, individualized reading instruction that may be lacking. Beyond the school day, *Foundations to Literacy* programs may help students increase their reading time in after-school programs, in libraries, in community centers, or in homes. Schools simply do not have enough hours or sufficient resources to teach all children to read well, and our programs aim to relieve that problem.

The programs are designed to be easy to use for students and teachers. We want students to be able use the system independently following minimal initial training and to require little or no ongoing support from teachers. The program is also being designed so that teachers can easily access, understand, and report students' needs and progress easily. Following Connor et al. (1999), we have conducted extensive participatory design activities with teachers to ensure that the programs meet their own and their students' needs. At the same time, our constant focus is to implement and extend the consensus findings from scientifically-based reading research about what is essential in early and remedial reading instruction (see Rayner et al., 2001; and Report of the National Reading Panel, NRP, 2000). This creative dynamic enlivens discussions during the design process, and has already led to programs that students enjoy and are using independently in most of the classrooms where they are currently deployed. The programs have been designed to be easy to use in classrooms by individual students without disrupting concurrent activities; as such, they were not designed to integrate into a specific language arts curriculum.

### 2.2 Motivation: The Critical Need for Early Literacy Programs

The U.S. educational system has an unsolved crisis. Despite growth of knowledge about what is essential in early and remedial reading instruction, the reading achievement of our poorest readers has not improved. In fact, achievement has even declined in recent years, especially among children at the poverty level (see Allington, 2002, p. 11-12, and Simmons & Kameenui, 1998, p. 3). Simmons and Kameenui cite data showing that one in six children will encounter a problem in learning to read, and that the problem usually emerges during the first three years of school. If reading problems are not addressed during this period, there is strong likelihood that the student will suffer lifelong consequences.


**Figure 1** Example of a Foundational Reading Exercise and an Interactive Book.

Reading is essential to academic achievement and to producing literate citizens. Poor academic achievement negatively impacts our society in devastating ways, including the reduced well-being of children, reduced numbers of qualified personnel for jobs, and increased risks to the economy. Great financial costs are associated with this problem; the U.S. spends about $38 billion per year on special education (12% of total education spending), more than twice the what is spent on regular education (Parrish, 2000; Chambers et al., 1998). Even this amount is insufficient. Far too few teachers are qualified to cover these needs (Brady & Moats, 1997; Lyon, 1999; NRP, 2000). Even with the U.S. government's Reading First plans to prepare more qualified teachers, the small-group and individualized instruction favored in reading research is hard to achieve without strong and flexible learning tools to expand teachers' resources.

We assert that effective and engaging computer-based reading instruction, which enables students to work independently, and which adapts to the skills and special needs of each student, will significantly ease this crisis. Our "Foundational Exercises" and "Interactive Books" are designed to work together to achieve these objectives in an integrated fashion in *Foundations to Literacy* and in the whole Colorado Literacy Tutor program. Figure 1 shows examples of a Foundational Reading Exercise and an Interactive Book.

### 2.3 Theoretical Background for the COLit System

2.3.1 Simple Model.

Our Foundational Exercises and Interactive Books have been designed around Gough and Tunmer's Simple Model of Reading (1986; Gough, Hoover, & Peterson, 1996). In this model, reading performance depends on continuous interactions among the component processes that underlie word reading with the processes that underlie comprehension. In our program, comprehension monitoring and constructive comprehension processes are assessed and practiced mainly in the Interactive Books**,** where children read books on the computer with help available for accurate reading and comprehension. The Foundational Exercises mainly teach and practice component foundational skills underlying word reading and spelling**.** Skills learned in Exercises are applied and evaluated in Interactive Books, and review activities are assigned as needed. Extra support for vocabulary will soon be available in both Books and Foundational Exercises.

2.3.2 What underlies poor reading for most children?

Good reading comprehension is the goal of reading instruction. Yet, for most children with reading difficulties, poor reading comprehension is a secondary problem, caused by inaccurate or inefficient word reading (See Lyon, 1995; Rayner et al., 2001; Snow, Burns, & Griffith; 1998, and the Report of the National Reading Panel, 2000). Most of these children, often described with "specific reading difficulties," comprehend spoken material about as well as average readers, but they struggle with inaccurate or slow word reading. Reading comprehension is obviously hindered when a child misreads a word. But even if the struggling reader becomes accurate in his word reading, his reading comprehension can still suffer if that word reading remains slow and labored and uses up so much attention that few cognitive resources remain for reading comprehension (Perfetti, 1985; Perfetti, Marron, & Foltz, 1996; Felton & Brown, 1990).

For most of these children, weak phonological processes underlie their word-reading problems (Lyon, 1995; Rayner et al., 2001). Most seem to have "imprecise" or poorly differentiated phonological representations for words, reflected in subtle difficulties in spoken and heard language, such as in repeating nonsense words and in judging correct from incorrect pronunciations (Snowling, 2000; Elbro, Borstrom, & Peterson, 1998). Most children with reading disabilities also have weak short-term memory, weak phoneme awareness (the metacognitive ability to identify and manipulate sounds in spoken words), and weak phonological decoding skills (sounding out print to speech, Lyon, 1995; Olson, Wise, Conners, & Rack, 1989). These last two difficulties lead directly to problems in word reading and spelling, which lead to the secondary difficulties in reading comprehension discussed above (Perfetti, 1985; Perfetti et al., 1996). While inherited, brain-based factors relate to these difficulties (Frith, 1997; Gayan & Olson, 2001; Olson et al., 1999; Shaywitz, 2003), a very encouraging research finding is that these weaknesses can indeed be remedied with intensive instruction that is designed to strengthen the underlying phonological processes and to integrate them with extensive practice reading accurately in context (Hatcher, Hulme & Ellis, 1994; Lovett et al., 1994; Rayner et al., 2001; Wise & Olson, 1995; Wise, Ring, & Olson, 2000).

#### 2.3.3 A less common route to reading problems.

A smaller but interesting group of children has problems understanding text material, even though their phonological and word reading skills are intact at normal levels (see review in Wise & Snyder, 2002). These children have problems comprehending main ideas and making inferences, even in spoken material. They appear to have problems with higher-level language skills such as recognizing syntactical relationships, pronoun referents, and making inferences (Nation & Snowling, 1998 a & b; Stothard & Hulme, 1995, 1996). Our program addresses their needs currently within our Interactive Books. In the near future, we also plan to develop Foundational Exercises that directly address the difficulties underlying weak oral comprehension, which will then be applied and practiced within the books.

#### 2.3.4 Preventing and Remedying Reading Difficulties

Intensive, structured, and sustained instruction in phoneme awareness and phonics, carried into extensive, accurate practice in engaged reading for meaning helps most children with reading difficulties to improve their foundational skills and learn to read (NRP, 2000; Rayner et al., 2001; Snow et al; 1998). The younger the child begins this kind of instruction, the greater the benefit (Lyon, 1999; Torgesen, 2002; Torgesen, Wagner & Rashotte, 1997). Research consensus suggests the necessary components of good instruction include phonological awareness, phonics (alphabet, decoding, and encoding), fluency (sight words, automaticity, and prosody), vocabulary, and comprehension (NRP, 2000; Rayner et al., 2001). A remaining challenge in research and practice is to help these skills become automatic, or effortless, enough that they don't deplete the cognitive resources needed for comprehending while reading. Another challenge is to help children apply these skills in reading and writing in context, and to use them independently after training is completed (Torgesen et al., 1997; Van der Leij & van Daal, 1999; Wise, 1999; Wise et al., 2000; Wolf, 1999). We propose that lasting, accurate, fluent, and independent reading should result from

a) integrated practice of foundational skills in engaging, imaginative ways,

b) to automatic levels,
c) with much application in fluent reading and writing in context,
d) both in and away from the teaching situation.

Thus, our program is designed to help children learn, automate, and apply these skills in context. We plan to encourage transfer of the learning and skills by letting children print sight word lists and stories that they have mastered in the programs, for practice and reinforcement at home.

2.3.5 Lessons Learned from *Reading with Ross*

Wise and Olson's (1992; 1995; Wise et al., 2000, 1999) computer-supported *Reading with ROSS* programs linked the best synthetic speech available at the time (DECtalk) to book-reading computer programs and, for some children, to phonological exercises. In all studies from 1995 on, a trained research assistant taught groups of four or five children 7 to 9 hours of phonological or comprehension strategies, depending on their condition. Children also practiced what they learned for about 22 hours of computer time reading stories or reading stories and doing phonological exercises. The researcher also sat with and listened to each child read with the computers one day per week, encouraging the child to know when he needed to "target" misread words. All instruction happened during sessions of about 30 minutes, four days per week, taken from regularly scheduled language arts or special education time. Children in both conditions made strong and significant gains in reading and reading-related skills, sometimes relative to untrained controls, and always with interesting differential gains related to differences in their instruction. Most of the programs in these studies merely supplied correct answers when asked; they did not encourage active problem solving nor self-checking by the students.

The COLit system has far greater capabilities, suggesting that gains COLit gains should surpass ROSS's, if we can ensure that the children read as accurately as ROSS children did, but without the oversight of a research assistant that was employed in the ROSS program. We are working to accomplish this challenge, and to surpass other aspects of ROSS. We incorporate the best ideas from all these previous studies, and we improve on them in terms of more programs with more complexity, thoughtful support, high-quality speech recognition and production, animation, and semantic parsing technologies that provide accurate analysis of spoken or written summaries or answers to questions. None of these were available in the earlier research systems. These capacities and the fact that our programs build in linguistic knowledge, allow our Virtual

Tutors to give focused, supportive hints and adaptive feedback, based on recognition of students' particular responses. This encourages our students to be engaged and active problem-solvers while they learn skills, rather than to be passive recipients of correct answers.

Another of our challenges relates to scalability. All of our studies occur in classrooms to help us make sure that the programs are stable and robust, that the learning tools and study plans do what they are intended to do, and that students can use them independently. We have not yet achieved all this, but we continually improve the software as we learn from problems, and we do this in a minimally disruptive way through automatic remote monitoring of our software and rapid response to problems. In addition, a team of five observers monitor classroom activities and provide valuable input about the classroom and user experience. This process of monitoring, observing, and responding to problems is producing more stable and robust software and better experiences for both teachers and students. At present, systems deployed in kindergarten to second-grade classrooms are becoming stable. They "crash" infrequently, reboot automatically after power failures, and require minimal support from our project staff on a weekly basis. Most students currently log on to the system and work independently, requiring little or no teacher support. This contrasts to the ROSS program, which required a trained assistant for every group of four to five children, at all times. ROSS was abandoned by the schools after grant funding stopped, as the programs were complex and difficult to run without daily support.

### 2.4 Principles that Guide Instruction

Some general principles guide instruction in both Interactive Books and Foundational Exercises in the *Foundations to Literacy* programs. We will discuss these principles and italicize them as we go. Many of them are used in *Linguistic Remedies* (Wise, 2001a & b, 2002) a reading instructional program by the first author. The principles are also used in many good programs and derive from many other educational theorists and practitioners, including our colleagues (Kintsch et al., 2000; Kintsch, 1998) and going back to Vygotsky (1978) and Bruner (1960, 1977). These writers suggest that students learn, maintain, and generalize best when they actively engage in learning tasks that challenge their thinking, while encouraging success. Thus all our programs aim to *engage students, promote active thinking,* and *encourage success*.

Our programs also *incorporate the key principles of scientifically based reading research*. The Report of the National Reading Panel (NRP, 2000) and a comprehensive review article (Rayner et al., 2001) summarize the implications of scientific reading research for instruction. This research suggests that balanced reading instruction covers five domains of reading with sequenced instruction that is intensive, explicit, structured and direct and that includes application in reading with comprehension and work towards fluency and automaticity. The domains include phonological awareness, phonics (alphabet, decoding, and spelling), fluency (automaticity and reading with natural expression), vocabulary, and comprehension.

Most reading professionals agree that these domains are important in balanced reading instruction, and *Foundations to Literacy* in COLit is designed to cover and integrate them well. It covers the five domains suggested by the NRP, and more—and does it *explicitly and intensively in carefully sequenced* ways. Yet many professionals still wonder just how explicit and intensive the instruction must be for children with different profiles, and what is the best balance between skills and reading in context for children with different levels of reading (Allington, 2002; Wise, in press). We believe *Foundations to Literacy* will provide an excellent *research tool* for examining, and perhaps resolving, some of the questions about the best ways to teach the domains and the balance of instruction among domains for children with different needs.

Our program teaches and supports *balanced*, *comprehensive*, and *individualized* reading instruction. Foundational Exercises and Interactive Books will be *fully integrated*, with skills learned in Exercises being applied in Books and soon with errors in Books being reviewed and practiced in the Exercises. Programs are individualized, initially by assigning the student to a specific set of activities based on performance in pre-tests. They become more individualized as they adapt to each individual student's performance to ensure progress.

All our Foundational Exercises also aim for *simplicity*, *engagement*, and the *empowerment* of success. The experience of success is encouraged by presenting the sequenced items in a "*scaffolded*" order (Vygotsky, 1978), ensuring that children start with "*comfort level*" items from a previously successful level, proceed to *supported instructional levels*, and end again in "*comfort level.*" This scaffolding is done seamlessly by the program, as it would be by an expert teacher. We also encourage a full cycle of learning from *discovery* and *practice* to *competenc*e. After students attain *competence* with a skill or concept, the program assigns speeded practice with it to get it *automatic*, *applies it* in reading in context, and will eventually work to encourage *transfer* of the skill to independent reading and writing.

We *promote and support active thinking* in one way, by having the Virtual Tutor give *focused hints* so the child learns to *self-correct*, rather than simply providing every correct answer, which allows the child to remain passive. We also carefully design distracter items and choices to *encourage careful thinking, self-checking*, and sometimes to *encourage making distinctions* of the kinds we would like children to notice. For example, in our Exercise with initial consonant blends, we include items and distracters that begin with blends or single sounds, to encourage fine-tuned distinctions among single consonants and clusters Thus in building "place," with "ace" given, the beginning choices could be "p, pl, pr, b, bl," and either "pace" or "lace" would be a likely item to build later in the same set. The Virtual Tutor can direct students to watch her mouth, or notice their own pronunciations, if they demonstrate some typical error patterns that may have to do with indistinctiveness in the hearing or pronunciation of an item (Elbro et al., 1998; Snowling, 2000; Snowling & Hulme, 1994). Thus, if a child chooses "thin" when the Tutor has said, "fin," the Tutor may say, "Watch and listen carefully at the beginning of "fin." In multiple choice questions in Books, alternative choices to the correct answer and support for responses are also carefully designed to encourage thinking. We code and include other main idea, major fact, or inference distracters, and the Tutor explains why a distracter is incorrect and gives hints to the correct answer if children make an error (see Section 3.2).

## 3. Overview of the *Foundations to Literacy* Program

This section provides an overview of the main components of the *Foundations to Literacy* literacy program. These components include:

a) Foundational Reading Exercises, a set of applications that teach the foundational skills that underlie reading,
b) Interactive Books, which teach fluent reading and comprehension of text,
c) The Managed Learning Environment, which tracks and displays progress within and across students,
d) Assessments, which place students in an Individual Study Plan and measure learning outcomes, and
e) Adaptive Individualized Study Plan, which guides the student through a specific sequence of activities, based on the student's performance within all learning tasks.

**3.1 Foundational Reading Exercises**

Foundational Exercises (Figure 1a) provide focused activities designed to develop core competencies needed first to learn to read words accurately and later to read them automatically. The Foundational Exercises have been designed for early and remedial readers, in close collaboration with teachers and students. Many of the Exercises were adapted from activities in the first author's *Linguistic Remedies* program, and they follow principles of good remedial instruction (Wise, 1999, 2001, 2002). Foundational domains, described in Section 5, include alphabet knowledge, phonological awareness, reading and spelling regular (sound-out) words, reading and spelling high-frequency sight words, and future options: language comprehension, vocabulary elaboration, and articulatory training. Vocabulary and Comprehension are also already taught and practiced in Interactive Books. Foundational Exercises are a main focus of this chapter, and one Exercise per current domain is described and illustrated in section 6.

**3.3 Managed Learning Environment (MLE):**

The MLE logs all student and system behaviors in applications, and displays progress graphics for each student in relation to district learning goals at each grade level. For server-client deployments, which are currently used in school classrooms, the MLE resides on a server that communicates with all client machines that run COLit applications. For stand-alone systems, the MLE resides on the same computer as the learning tools. The MLE enables teachers and administrators to monitor and analyze student performance on applications, and even play back individual sessions. The MLE also provides an adaptive *individual study plan* for each student, which determines the sequence of learning task presented to the student by analyzing performance on prior and current tasks. Based on the study plan, students can move quickly through a set of Foundational Exercises to more advanced Exercises and Books, or be taken to lower levels for remediation and practice on specific core competencies.

**3.4 Assessment**

Assessment in our programs occurs prior to, during, and after instruction. With the current deployment, we have access to measures given by the schools, including the Colorado High Stakes testing, or CSAP. We also currently give 10-20 minutes of short standardized paper and pencil measures of these skills for pre-, mid-, and post-testing, described in section 7.1. Trained testers administer the tests to all students in control and treatment classrooms. All other assessment is ongoing, within the instructional programs. Foundational Exercises are assigned according to need, and the student progresses within the program according to performance on Foundational Exercises and Books, under the control of logic incorporated within the study plan. Already the rate of progress and the type of feedback adapt according to student performance, and soon the Foundational Exercises will review and practice words that students miss in books.

Although the tests can be administered in 10-20 minutes, the testing time required for all students is a barrier to scaling, and we are eager to have our own tests in use within the system. We expect to have some in place by school year 2004-2005, and more in following years. Our goal is to develop ICARE: an Independent, Comprehensive, Adaptive Reading Evaluation system that can screen children quickly who do not require instruction to ameliorate difficulties, and which can provide a strong base for individualized study plans for those who do.

### 3.5 Individual Study Plan

We sequence Foundational Exercises in linguistically sound ways, and we individualize which Exercises are assigned and at what level, according to the initial needs and the progress of the child. Our Foundational Exercises follow a default sequence: from alphabet learning and phonological awareness, to decoding and encoding of simple consonant-vowel-consonant (CVC) words, to more complex orthographic patterns in one syllable words, and eventually they will extend into multi-syllable words and morphologic work as in the *Linguistic Remedies* program (Wise, 2001a, 2001b, 2002). The program selects words from this sequence to match students' needs, and authoring tools allow teachers to insert words of their own into some of the Exercises (currently into Sight Reading and Sight Spelling), so students can practice words currently being studied in class. The programs have default settings for time allowed on Exercises per domain. The balance of instruction leans more towards foundational skills work at kindergarten and first grade levels and moves to more and more reading in context as students progress, following findings from the ROSS study (Wise et al., 2000).

Students practice new skills and concepts until they become competent with them. "Competence" is defined in the study plan, according to percent accuracy and/or number of mouse-clicks to hear alternatives before choosing an answer. Currently students progress up one level after they score 80% or more correct on two item-sets in a row. If they score below 50% on two sets, or 20% on one set, the program adjusts to an easier level, without the student even realizing it. This is just as an expert human tutor, operating at her best, continually adjusts materials to match student performance. Most of our Foundational Exercises begin with one or two items that from a previously successful "comfort zone" level, move to seven to eight items at instructional level, and finish with a comfort zone item, following Vygotsky (1978).

Currently we measure progress within Foundational Exercises by noticing that a child moves ahead with reasonable progress while scoring at least 80% correct on daily Exercises, and that she makes progress on mid- or end-year assessments. The word-reading Exercises score a child's first response; progress there is based on demonstrated knowledge. However, word-building Exercises in phonological awareness and spelling currently allow the child to hear any letter-pattern choice before clicking OK. Soon we will have advanced versions developed with less speech support for those Exercises, to determine with more confidence when a child achieves a goal at a defined skill level. For a student to advance, she will need to do one set at 100% or two sets at or above 80% correct, with no speech support for letter patterns until after she has chosen her answer.

Just as progress within the program depends upon students' performance, so does the type of feedback the Tutor gives. Currently, when students respond accurately to most choices, the feedback occurs on a randomized 1:4 ratio, and the encouragement phrases adapt according to performance (e.g. extra praise after many successes; hints for given errors; particular choices of phrases for the first correct response after making an error). Soon, students doing very well will receive help less often and support will be terse. Children responding slowly, making errors, or checking responses many times before choosing will get more support and more encouragement. This kind of adaptive feedback has been found to be quite effective in motivating both kinds of learners, according to Bouwhuis (2001). We plan to incorporate more and more of this kind of adaptivity as we continue to develop the programs.

## 4. System Architecture and Technologies

This section describes the System Architecture, which enables real time interaction between students and various technology servers and media, and the speech, language, animation and computer vision technologies within the *Foundations to Literacy* system.

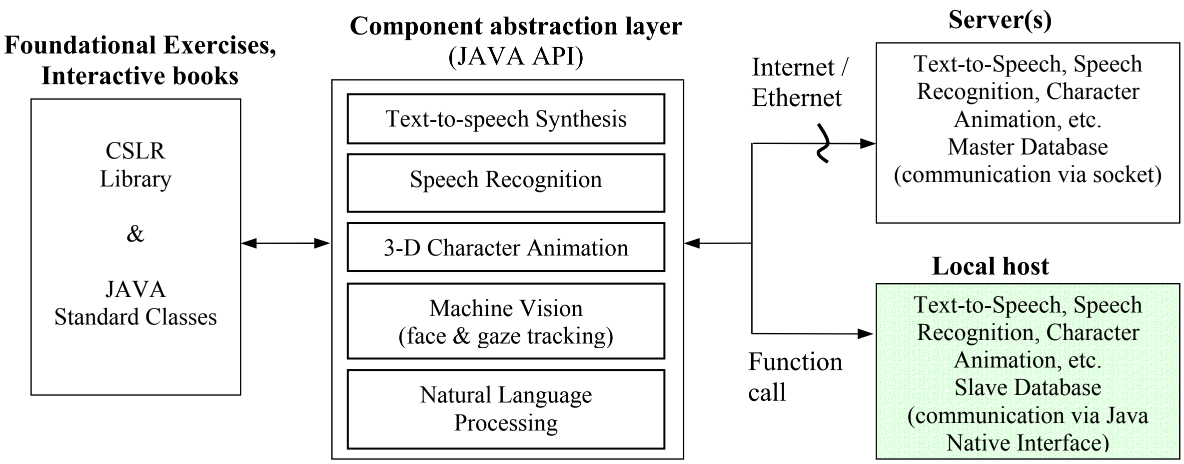



**Figure 3** The system architecture: local or distributed.

### 4.1 System Architecture and Technology Servers

Figure 3 shows the architecture that enables realtime interaction with the Virtual Tutor within Foundational Exercises and Books. The architecture includes technology servers, all media content (e.g., images, speech files) stored in databases, and communication between the user's responses and the system. All the components can run in distributed (server-client) or stand-alone (client) modes. The web-based graphical user interface is written in JAVA.

### 4.2 Technology Servers

We note that Figure 3 includes:

a) technology services that are fully integrated into the system and currently deployed in schools at the time of this writing (e.g., 3D character animation),
b) technologies that are integrated into the system and work well enough to be field tested in classrooms, but are not yet deployed, pending further testing and interface development (e.g., speech recognition for reading aloud and transcription of spoken summaries; robust semantic parsing for interpreting student's spoken or typed responses to questions; and face tracking for locating the user's position in front of the computer), and
c) technologies for which working prototypes exist, but are not yet accurate or fast enough to be incorporated into the learning tools (e.g., computer vision-based gaze tracking and emotion classification). Each of these technologies is currently being developed within the COLit project; either at CSLR and ICS (speech recognition, natural language

understanding, character animation) or at the Machine Perception Laboratory at the University of California at San Diego (MPL, 2004) under the direction of Javier Movellan (face tracking, gaze tracking, emotion recognition).

We now describe the four main technology components that will be integrated into our learning tools. *Character animation* is already deployed in classrooms. In Spring 2004, *speech recognition* and *natural language understanding* will be tested in classrooms. Machine perception systems (*face tracking, gaze tracking, and emotion classification*) will be field-tested in Fall 2004 or Winter 2005 in classrooms. Additional information can be found in Cole et al., 2003 and on the CSLR (CSLR, 2004) and MPL Web sites (MPL, 2004).

**4.3 Character Animation**

The CU Animate system, developed at CSLR by Jiyong Ma and JieYan (Ma et al., 2002; 2004a; 2004b) produces the real time animation sequences in Foundational Exercises and Books. The system produces extremely accurate visible speech automatically, when given a text string and recording of the speech corresponding to the text. The text string is expanded to a sequence of expected phonemes, and the SONIC speech recognizer, described below, is used to align the sequence of phonemes to the digitized speech waveform. The sequence of phonetic segments is then used to control the movements of the polygons of the lips and lower face regions during speech production by the 3D model, and these movements are aligned exactly to the acoustic signal. CU Animate's authoring tools also enable us to design animation sequences so that a 3D character can speak, emote, and gesture during interactions with students. These animation sequences are then assigned symbols, which can be inserted into the text strings using a mark-up language within CU Animate; in this way, the character can produce head nods and facial expressions.

At present, the 3D model (Virtual Tutor) deployed in classrooms presents only the head and shoulders, although complete full body models have been developed for ten 3D models, including African-American, Hispanic, and Asian characters to be incorporated into Interactive Books in the future. The head can be presented from any orientation while speaking, and can be made semi-transparent to show the movement of the tongue within the mouth during speech production at any speed. The model can express six basic emotions and can vary facial expressions such as by lifting one eyebrow or lifting just one corner of the mouth. In current applications, most speech is produced with a neutral, pleasant face that blinks occasionally. About 100 animation sequences have been developed that have natural facial expressions for common prompts (e.g., "No, that's not right." or "Keep trying, you'll get it.") and these will soon be introduced into the Foundational Exercises.

**4.4 Speech Recognition**

Automatic speech recognition uses SONIC (Pellom, 2001; Pellom & Hacioglu, 2003), a state-of-the-art, large vocabulary, continuous speech recognition system. The recognizer works well in English, French, German, Italian, Japanese, Spanish, and Turkish. SONIC also achieves state-of-the-art performance on children's speech (Hagen, 2003). SONIC is fully integrated into Interactive Books and has been tested for question-answering, reading aloud, and summarizing stories with third to fifth-grade children's speech (Hagen et al., 2003; Pellom, 2004). It is now being field tested in classrooms in read aloud applications with Interactive Books, in which a cursor follows, in real time, the words being read by the student. Recognition accuracy for words spoken by young children in these applications is around 90%. Words that are misrecognized have low confidence scores, so they can be flagged for later checking by the student. That is, these words can be highlighted at the end of a sentence if the child does not self-correct them. The student can click on the word to hear the Virtual Tutor pronounce it correctly for self-checking or correction.

**4.5 Natural Language Understanding**

Natural language understanding is being investigated in Interactive Books using latent semantic analysis (LSA) within the *Summary Street* system (Kintsch et al., 2000; SSWeb, 2004). *Summary Street* analyzes summaries of text automatically and provides feedback to the student about the adequacy of information presented for each main subtheme in the text. We are incorporating its automatic analysis of typed summaries within a set of 27 books at fourth, fifth, and sixth grade levels. We are also investigating the feasibility of applying *Summary Street's* automatic grading of summaries to assess and train comprehension using spoken summaries produced by students in first, second and third grades. If this approach proves feasible given the constantly improving performance of the SONIC recognizer, it opens up the possibility of extending *Summary Street*'*s* comprehension training to children who cannot yet type and even to those who cannot yet read. In this way, the Virtual Tutor could read stories to non-readers, *Summary Street* could score their spoken summaries, and then the Tutor could refine and discuss the summaries with the children.

### 4.6 Face Tracking, Gaze Tracking and Emotion Recognition

Machine perception systems that use computer vision will become an integral part of our Foundational Exercises and Books in the future. A face tracking system, developed by Javier Movellan and his team at the Machine Perception Lab (MPL) at UCSD (Fasel et al., 2004; Movellan et al., 2002, 2004a; 2004b) has already been integrated into the system architecture. The system accurately tracks the user's face, which is necessary for estimating the distance of the user from the screen, for locating the positions of the eyes for gaze tracking, and for recognizing emotions and inferring the cognitive state of the learner. A gaze tracking system and an emotion recognition system (that classifies expressions as neutral, sad, happy, surprised, angry, afraid, disgusted at about 90% accuracy on test data), have also been developed, and are being integrated into the system architecture for testing and refinement. Descriptions of these systems can be found on the MPL web site (MPL 2004). We believe that developing an accurate gaze tracking system provides great potential for teaching fluent reading. By combining information provided by the speech recognition system and the gaze tracker while the child is reading aloud, we should be able to determine which word the child is trying to read with great accuracy. This will enable us to provide help or hints after an appropriate interval. A Virtual Tutor who reacts to the students' movements seems alive and engaged, and we believe this will also improve the engaging aspects of the system.

## 5. Domains of Foundational Reading Knowledge

Foundational Exercises teach and practice competencies within the following essential knowledge domains, which are taught to students as determined by need in assessments and by progress within the Exercises and Books.

### 5.1 Alphabet and Letter-sounds

Learning the alphabet is essential before children can learn to decode, read, or spell. Letter knowledge becomes automatic with repeated correct experiences in naming letters and matching them with their sounds. In order to use letter-sound knowledge in reading, children must not only know the letters and their sounds, but they must know them so automatically that they can use them without effort (LaBerge & Samuels, 1974; Samuels, 1985). A child who must use conscious effort to recognize a letter or use its sound will have little attention remaining for decoding words, much less for comprehension. Alphabet knowledge in kindergarten has consistently been shown to be one of the two strongest predictors of later reading ability, along with phonological awareness, below.

While children must recognize letters and know their sounds prior to learning to decode our alphabetic system, children vary widely and significantly in how well they know letters and sounds on entering school (Snow et al., 1998). Chall reported long ago that pre-readers' knowledge of letter names was a strong predictor of success in early reading (Chall, 1967). Knowing letters' names may make learning their sounds easier, perhaps because letter-names usually include the sound of the phoneme somewhere in their name. Children often make use of this knowledge in their invented spelling (McBride-Chang, 1998; Treiman, 1993). Letter knowledge is an important precursor of phonemic awareness, and has been shown to influence early progress both in segmenting and blending sounds (Wagner, Torgesen & Rashotte, 1994)

Nevertheless, just teaching children the names of letters doesn't help reading much. Children need both the accuracy and the fluency that comes with the full knowledge of letter names and their sounds (Adams, 1990). Both letter-sound knowledge and phonological awareness are essential foundational skills needed for children to grasp the alphabetic principal and to understand how print and sounds go together in English. These skills bear a direct and strong relationship with early reading (Adams, 1990).

While children must recognize letters and know their sounds prior to learning to decode our alphabetic system, children vary widely and significantly in how well they know letters and sounds on entering school (Snow et al., 1998). Computer instruction has been shown to be one effective way of helping children with weak letter knowledge to improve this foundational skill (Torgesen, 1997; Wise & Olson, 1995). Computers are ideal for individualized instruction and also for the repeated, speeded practices necessary for helping skills such as letter recognition become automatic. Thus, computers seem to be a great way to help level the playing field and help at-risk readers practice and improve some necessary prerequisite skills, while easing the need for one-on-one help from teachers.

### 5.2 Phonological Awareness

Phonological awareness is the conscious awareness of sound units in spoken words. It includes the ability to identify, count, and manipulate syllables (e.g. bas-ket-ball), onsets and rimes which are the beginning (pre-vocalic) and the rhyming (post-vocalic) parts of words (e.g., th-in, pl-ant), and phonemes, all within spoken syllables (e.g., th-i-n, p-l-a-n-t). Training phonological awareness usually includes identifying and manipulating all the above sound units within spoken words. Thus, phonological awareness activities may include syllable work, such as "Say 'snowflake' without the 'snow;" rhyming activities, such as "Which of these words rhyme: cost, most, lost?" and Phoneme activities, such as "Say 'cart' without the /k/." Phoneme awareness training, on the other hand, involves counting, deleting, and manipulating just phonemes, as in the last example above.

Phonological awareness is an essential pre-reading skill. Phoneme awareness and alphabet knowledge are the strongest predictors of later reading progress through grade school and beyond. Interestingly, the development of phonological awareness is also reciprocal with learning to read and spell (Perfetti, Beck, & Hughes, 1987). That is, on the one hand, children need a basic ability to identify and manipulate sounds in syllables in order to grasp and use the "alphabetic principle" and learn to read (Shankweiler et al., 1979). This "alphabetic principle" is the insight that English spelling represents the sounds, or phonemes, of words. On the other hand, in the process of learning to read, children do also improve in phonological awareness.

Children vary greatly in their levels of phonological awareness both when they first approach learning to read and as they progress and improve in reading ability. And it is those children who cannot easily identify and manipulate speech sounds in syllables who struggle greatly with learning to read and spell. Happily, phonological awareness can also be improved with explicit and intensive training. Instruction in phoneme awareness leads not only to gains in this skill itself, but also to subsequent gains in reading and spelling (Lundberg, Frost, & Peterson, 1988; Rayner et al., 2001). Most studies show larger benefits from phonological awareness when it is linked with letters and sounds than when it is done in speech alone (Blachman et al., 1999; Brady, Fowler, Stone & Windbury, 1994; Bradley & Bryant, 1983;

Byrne & Fielding-Barnsley, 1991). Studies of reading remediation among older children with reading problems have shown that these children also improve in reading after explicit work in phonological awareness and decoding (Hatcher, Hulme & Ellis, 1994; Torgesen, Wagner, & Rashotte, 1997; Lovett et al., 1994; Wise et al.; 2000). Computer-assisted instruction has helped children improve phonological awareness and decoding in both early reading and reading remediation (Torgesen, 1997; Wise et al., 2000.)

**5.3 Reading Regular Words (decoding, or sounding-out)**

Learning to decode words accurately is another important foundational skill for reading. Children with reading difficulties usually have specific difficulties with reading words and nonwords accurately, and this difficulty has been shown often to have a brain-based, inherited component related to phonological awareness (Frith, 1997; Gayan & Olson, 2001; Olson et al.; 1999; Shaywitz, 2003). Happily, much research has shown that systematic and structured work on phonological awareness and the code can improve this skill, even in children with severe reading disabilities. In fact, in most intervention studies that attempt to do this, the first noticeable gains will be in untimed sounding out of regular words and nonsense words.

"Regular" words refer to words with predictable letter-sound patterns. They can be sounded out by phonics patterns that have been taught. The more of these patterns that have been learned by phonics teaching or by reading experience, the more words can be considered to be sound-out words. Children with poor phonological skills often guess words from context and from the first sound, misidentifying many words even in context. Stanovich (1984) showed that poor readers rely on context for word recognition much more than good readers do; however they are also much weaker, not only in decoding, but also in their ability to use context.

Misread words lead directly to mistakes in comprehension. Children need to learn to decode regular words accurately, and older readers still need good decoding for deciphering novel words and long words. Children who have learned to decode words accurately, but slowly, can still have secondary problems in comprehension, because so few resources remain available for comprehension (Perfetti, 1985; Perfetti et al., 1996). While most struggling readers have had reading problems from the outset, research suggests that some struggling readers emerge later in fourth grade, in at least three ways (Lyon, 1999; Scarborough, 1998a; 2001):

a) Some of these struggling readers have only moderately weak phonological decoding skills that have escaped attention so far during their schooling, but who now show problems as the reading system gets more complex and more resources are needed for comprehension.
b) Some have slow word reading skills either (1) related to lack of practice (Cunningham & Stanovich, 1998; Stanovich, 1986; McBride-Chang et al., 1993) or (2) related to slower speech or access of words. Slower access of words is often measured by tests of Naming Speed, or how many familiar letters a student can read in say, 45 sec (Scarborough, 1998b).
c) Finally, some do have specific comprehension problems, which can be noticed even in listening comprehension of spoken passages. Often, this may not get noticed until spoken and written text becomes more complex in later elementary and middle school.

Developing strong and then fluent decoding skills can help alleviate some problems, at least those due to reasons a and b(1) above. Many remediation studies have succeeded at helping children to learn to decode accurately by improving their phonological awareness and then teaching them the regular patterns of English in a systematic, structured and intensive way. Yet the challenge remaining for most studies is to get reading rates to average levels. We believe computers are perfect tools to improve automaticity, given their ability to time items, individualize activities by adapting to the student's performance, provide repeated practices, and give immediate rewards based on performance. In a pilot study (Wise et al., 1999), students were extremely motivated by speed trials with words after they had learned to read them accurately. Recent work by Breznitz (1997a & b) supports that fluency and automaticity can be improved, and that this also leads to improvements in comprehension. Therefore, after students learn to decode words accurately with our programs, they also practice the patterns until they become accurate, fast, and easy, so they demand few cognitive resources while reading.

**5.4 Spelling of Regular Words (encoding)**

Besides learning to communicate sounds clearly in writing, learning to sound out regular words in spelling is extremely important for its benefits to phonological awareness, to decoding, and to reading (Ball & Blachman, 1991; Blachman et al., 1999; DiVeta & Speece, 1990; Ehri & Wilce, 1987; Frith, 1980; NRP, 2000). Earliest readers often learn to decode print, or to sound words out, by first learning to blend sounds together and spell them. Learning to represent the spellings of words reasonably, with appropriate vowel sounds and with sounds in order, improves phonological awareness and decoding, which both underlie the ability to understand and use the alphabetic system in reading.

In an early study, Hohn and Ehri (1983) found that letter-based spelling, without training in segmenting and blending, did not help kindergartners improve in decoding. Yet in 1987, Ehri and Wilce found that using phonetic cues in learning to spell did improve beginning readers' abilities to read and to spell similarly spelled words, compared to a group of children who spent similar time learning letter-sound associations. Hecht and Close (2002) recently found the same pattern of results (of gains in reading, phonological awareness, and spelling from learning to spell phonetically, but not from just learning letter-sound associations), in a kindergarten training study using a powerful "talking" computer program (Waterford Institute, 1999).

In a study in a summer reading clinic, Wise and Olson (1992) found that exploring spelling with a "talking" computer program improved the ability of poor readers to decode novel nonwords, especially when they could compare pronunciations of their errors with the correct word, besides getting feedback about letter placement. Spelling's importance in strengthening decoding is probably the most important reason for including it in a balanced reading program. It is the main reason we include spelling in the Foundational Exercises.

**5.5 Reading Sight words (orthographic coding), for accuracy and for fluency.**

"Sight words" is the term most teachers use for high-frequency words. Some have predictable phonics patterns, as in "that" and "here," and some have unpredictable patterns, as in "what" and "were." If these are known automatically, or without the need to sound them out, reading becomes much more efficient. Reading sight words automatically does still involve some phonological coding (Van Orden, 1987). However, it depends mainly on orthographic coding, the coding or memory of specific spelling patterns. Just as children differ in their proficiency with hearing sounds in words and in decoding print to sound, children also differ greatly in how long it takes them to build up strong, automatic orthographic images for words. Reitsma (1983; Van Daal & Reitsma, 1993) found that second-grade children who read normally needed far fewer correct practices with a word to maintain the ability to read it than did children with reading disabilities. While orthographic skill has a genetic component, it is highly influenced by reading experience (Gayan & Olson; 2001; Stanovich & Cunningham, 1992). Children improve in time-limited "sight" reading from accurate reading in text (Wise et al., 2000), and they improve with training in sight reading and spelling activities (Ehri, 1998).

**5.6 Spelling of sight words (orthographic encoding).**

Learning to spell high-frequency words has obvious benefits for intelligible and intelligent-looking written communication. Beyond than, Ehri (1998) has demonstrated that spelling words improves children's orthographic images of them. Having strong and accurate orthographic or spelling images may have another benefit beyond helping spelling and decoding. It may also develop stronger, and perhaps more automatically retrievable mental images for words. A precise and strong mental representation for a word includes many kinds of information. Current interesting studies point to the importance of strengthening the entire "word form" for words—including their phonology, orthography, morphology, history, and meanings (Berninger, Abbot, Billingsley, & Nagy.; 2001; Wolf & Katzir-Cohen, 2001). It is possible that strong orthographic mental images not only strengthen accuracy in word reading, but also lay the groundwork for later automaticity in reading, which in turns helps comprehension.

**5.7 Additional Domains: Specific Comprehension Difficulties, Vocabulary, and Articulation Training**

Thus far we have discussed knowledge domains related to foundational word decoding and encoding processes. These correspond to specific Exercises described below, which teach foundational competencies that are practiced until automatic, to overcome slow or inaccurate word reading that can secondarily impede comprehension. The following paragraphs describe some other knowledge domains for which we plan to develop Foundational Exercises, with an eye towards research about interesting instructional questions and towards helping more children with individual needs in these areas.

A smaller group of children exists whose higher-level language difficulties hinder their comprehension directly, even in spoken language (Nation & Snowling, 1998a & b; Stothard & Hulme, 1995, 1996). These children are rarer than those whose problems stem from word-reading difficulties. We hope to design Foundational Exercises for them in the future that will help with processes and strategies to help them learn to make and justify connections in text for use in finding main ideas and making inferences. Such Exercises could be designed to help them recognize, explain, and use cohesive devices such as pronoun referents and syntactic cues that could help them notice and make connections in text (Cain & Oakhill, 1998). We are also intrigued with work that encourages children to "converse with the author" in monitoring their comprehension (Beck, McKeown, Hamilton, & Kucan, 1997; McKeown & Beck, 2001; Tovani; 2000). These strategies seem ideal for our system, and we hope to explore them further.

A well-elaborated vocabulary is important both in improving word recognition and in supporting comprehension (Baker et al., 1995; Beck & McKeown, 1991; Beck, McKeown, & Omanson, 1987; Wolf, 1999; Wolf & Katzir-Cohen, 2001). We reported earlier on very successful work teaching basic denotative vocabulary to hearing impaired children at TMOS (Barker, 2003). We hope within the next few years also to develop Foundational Exercises that will work on elaborating vocabulary development by teaching multiple meanings in various contexts, and by grounding vocabulary growth in work on word structure and word history (see Henry, 1999; Wise, 2001a & b). We expect this work to improve vocabulary directly, and to lead to secondary improvements in reading, spelling, and comprehension.

A final future domain is awareness and practice of articulatory features of sounds for phoneme discrimination and as a potentially stronger base for phonological awareness. It could be used as an option by teachers who like this approach, and it is likely to be of special importance also for non-native speakers who are learning to read English. It may provide a platform for studying an interesting educational question, and it might prove particularly beneficial with the weakest phonological awareness or with imprecise speech (Wise et al., 1997; Elbro et al; 1998). Some research has not found differences in phonological awareness taught with or without an articulatory base, particularly with computer support (Torgesen, 1998; Wise et al. 1999). However, another researcher did recently find an advantage for teaching phonological awareness with an articulatory base without a computer (Castiglioni-Spalten & Ehri, 2003). Teaching this foundation does fit with grounding the knowledge deeply for better transfer (Bruner, 1960). And Montgomery (1981) did find that children with reading disabilities also had worse articulatory awareness than did children who read normally. The work of Elbro (1998) and Snowling and Hulme (1994) also lends support for the possibility that refining articulatory knowledge and precision could improve the preciseness of underlying phonological representations of poor readers. For all these reasons, the question may be worth studying further with a system where the teaching could be supported with an accurate and explorable animated mouth, and where thoughtful questioning and guided hints can support children's active problem-solving, as was not done in the earlier computer-assisted studies.

## 6. Foundational Reading Exercises

This section describes the participatory design process for the Foundational Exercises. We then describe the characteristics of all Foundational Exercises and illustrate one example of a Foundational Exercise currently developed for each domain discussed in section 5.

### 6.1 Participatory Design

Teachers have a unique understanding of instructional needs in the classroom and the qualities software should have for it to be used effectively in classrooms. For this reason, teachers, reading specialists, and speech pathologists have been intimately and actively involved in participatory design in all aspects of program development from day one (Connors, 1999; Schwartz et al., 2002; 2003). We believe we are thus helping to ensure the utility and thus the scalability of the learning program through these participatory design activities.

To date, over 100 Interactive Books and over 30 Foundational Reading Exercises have been developed. The participatory design process includes all of the following steps. After discussing the various kinds of activities we plan to develop with classroom teachers and reading specialists to teach *Foundations to Literacy*, we brainstorm with them to conceptualize and plan specific Foundational Exercises. During the participatory design process, teachers help create Foundational Exercises and interface designs, help prioritize which Exercises get developed first, and help us understand what they want in their classrooms. In our process, Foundational Exercises are first sketched out by CSLR team members or by a teacher team, and then the development team creates a prototype from the sketch. Next, teachers use the prototype in the presence of members of the research team. We then conduct observations, interviews, and brainstorming sessions. Teachers report on the following aspects of each Foundational Exercise:

a) Content: Does the Foundational Reading Exercise practice a skill that the teachers believe is important in teaching literacy?
b) Teaching Sequence: Is the teaching sequence appropriate and compatible with how they teach, or is it too fast, or too slow?

c) Design: Do the teachers think their students will easily and clearly grasp how to use the Foundational Exercise?
d) Interface: Is the interface user-friendly, clean, pleasant, and helpful, or is it confusing, distracting, busy, or annoying in any way?
e) Interface for age of child: How appropriate is the interface, in relation to the age of the child it is targeted for (Is it too low, too high, confusing for that age, insulting for that age, well suited for that age?)
f) Independent use: Could their student use the Foundational Exercise independently enough that the teacher could work with other students with minimal monitoring of the computer user?
g) Use: Would they use this Exercise with their students, if they have students at this level?
h) Changes: Is there some modification that could make this Foundational Exercise better?

The applications are then modified based on teacher feedback. This process reiterates until the design and test cycle produces an interface that satisfies teachers and project staff. We then conduct user testing with students to make sure that the interface is intuitive, that students can use the application independently, and that they are engaged by it. We interview students about their experiences using the Foundational Exercise. We have found that children, especially those who play video games, are excellent critics of and consultants for our software.

Finally, during and after deployment into the classrooms, teachers provide the team with information about the most effective use of the programs in the classroom. This includes computer placement in the room, best times to use the software, scheduling of students, time on task for different grade levels, new interface issues, and suggestions of ways to monitor children using the software (i.e. the name of the child and time on task are now displayed on the screen).

### 6.2 Characteristics of all Foundational Reading Exercises

Foundational Reading Exercises teach and practice foundational skills integral to good reading and spelling. Introductory screens and dialogues motivate the purpose of each Exercise and some also teach basic concepts. However, most of the learning and practice happens within the Exercises. Screens for Foundational Exercises are bright and simple, and we have made their functionality as clear and obvious as we could, with the help of teacher and student input. As described earlier in the Study Plan, all Foundational Exercises aim to start children with two items from a "comfort" or easy level, then work at an instructional level with support, and finish with another comfort item from a previously successful level, to ensure that the child begins and ends with success. This, and the focused hints, are our way of "scaffolding" learning so that students stay interested, challenged, and successful (as in Vygotsky, 1978).

Currently, the Virtual Tutor is available and appears large and to the right of the screen, as shown in the various figures below, so children can have a clear view of her mouth as she pronounces words. We plan future experiments to evaluate where and how the Virtual Tutor is most helpful. Our hunch is that the Tutor's visible mouth will be more helpful in single word and phonological Exercises, and that she can be smaller for books, which allows us more screen space for the book itself. We also imagine that the presence and optimal size of the Tutor may vary for children with different needs, and we hope to investigate this in the future.

In all current Foundational Exercises, the children can always make the Virtual Tutor repeat the "target" word and repeat any sound-letter choices on the screen. If the child chooses correctly on his first attempt, the Tutor repeats the word the child chose or built and gives a reward and intermittently gives praise. If the child makes an error, the Tutor repeats the incorrect choice and gives a focused hint to help him self-correct on his second try. That is, the Tutor often asks the student to focus on the part of the "target" word that needs correcting. For example, if the child chose 'thin' for 'fin,' the Tutor might say, "You chose 'thin.' Watch me, and carefully check the beginning of 'fin.'" Currently, the child receives a "gold coin" on the screen, for being correct on the first try with most Exercises. If the child misses on the first try, the Tutor repeats the word he chose, gives a hint about the correct answer, and the child receives a "silver coin" on the screen for being right on the second try. On the correction, the Tutor praises the child's checking, and also gives praise on the next correct item. If the child, instead, misses a second time on an item, he earns a bronze coin, and the Tutor tells the correct answer.

### 6.3 Examples of Foundational Exercises

Most of our Foundational Exercises cover extensive levels of skills, and many of them practice skills that cross domains. For instance, most of the phonological awareness Exercises also practice alphabet knowledge, since most research suggests phonological awareness work is most powerful when combined with alphabet work. In this chapter, for each domain, we describe one Foundational Exercise that focuses particularly on the skills in that domain.  Examples of

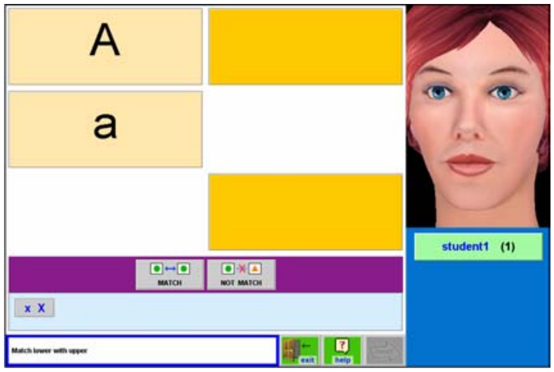



**Figure 4** Upper-lower Memory-Match Exercise.

more Exercises are described on the CSLR reading web site (CSLR, 2004), and more will be described as they are completed.

6.3.1 Alphabet and Letter-Sound Foundational Exercises

Our program has many activities to help children learn and become automatic in reading letters and in associating them with their most common sounds. The program currently includes some Exercises dealing mainly with alphabet knowledge. In these Exercises, children:

a) choose the letter to match the letter name or to match a picture that starts with its sound.
b) match upper and lower case versions of letters, which are named by the Tutor, in matching and memory and speeded matching games.

The program also includes many exercises that practice both alphabet knowledge and phoneme awareness in integrated ways, as seen in the following section.

Figure 4 illustrates Upper-lower Memory-Match, one of our alphabet Foundational Exercises. Its aim is to strengthen and practice orthographic memory for letters, after their name and sound have been learned in Exercises on letter names and sounds. In this activity, the child clicks on a card to turn it over, and the Tutor says the letter name. The child turns over another card. If it matches the first, the child gets to “keep” the pair, and the play is over when all matches have been made. The child can do this Exercise on his own, or with a partner.

6.3.2 Phonological Awareness Foundational Exercises.

Our program includes a few Foundational Exercises that deal mainly with phonological awareness. In these Exercises, children:


**Figure 5** Syllable Counting Exercise.

a) count, identify, and manipulate syllables in words,
b) identify the first, last, or vowel sound in a word and find the letter to represent it, and
c) manipulate sounds in words, and move sound units to match what the Tutor says.

Figure 5 illustrates a Syllable Foundational Exercise above. The Tutor says a word of one or more syllables, and shows the student how to clap the syllables, watch the drop of the chin on the Tutor, or notice the drop of the student's own chin as he repeats the word that the Tutor says. Then the child clicks on tokens to count, identify, and delete syllables in words that the Tutor pronounces and the child repeats.

While the syllable Exercise above deals with spoken units without print, most of the phonological awareness Exercises combine practice in phoneme awareness with practice in letter-sound knowledge and decoding. In these Foundational Exercises, children:

a) hear, match, identify, and select the first, middle, or ending sound in a one-syllable word,
b) hear, match, identify, select, or manipulate onset and rime units (e.g., cat = c/at), requiring noticing which sound changes and choosing the correct letter or rime to match the change,
c) compare and check items, following the Tutor's hints to correct errors and notice small sound-letter changes among similarly spelled real words.

Most Exercises that involve spelling or building words have choices listed at the bottom of the screen, and the Virtual Tutor pronounces what a child selects, before the child clicks OK. In advanced versions of these Exercises, the Tutor will not pronounce choices at the bottom; rather, the child will be scored on his first choice. This feature is being added so that students do

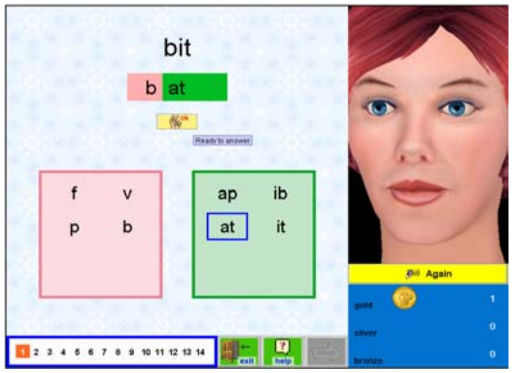



**Figure 6** Rhyme-changing Foundational Exercise.

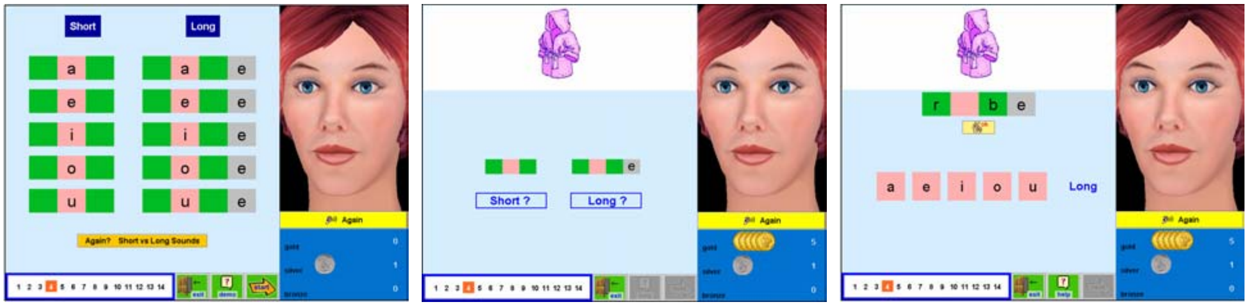
not advance to higher levels until they succeed with the Exercise at 80% correct on their first attempt on two item sets, or 100% on one set, before speech support.

Figure 6 shows the "Rhyme-changing" Foundational Exercise. In this Foundational Exercise, the Tutor initially asks the child to build a word out of a set of four onset choices and a set of four "rime" choices, in this example "Let's build 'bit.'" The child can hear each unit pronounced by the Tutor as he clicks on it, and it moves up to the word-building space. The child clicks OK, and the program scores him correct, or the Tutor gives him a hint to check the beginning or the rhyming part, if he made an error. After the first item is correct, the Tutor now says, for example, "Now let's change 'bit' into 'bat'." The child must notice which part of the word changed, and find the correct beginning (onset) or "rhyming part" (rime) to make the word on the screen match what the Tutor has pronounced.

<u>6.3.3 Spelling regular words (Encoding, sounding out)</u>

Spelling's importance in strengthening decoding is the main reason we include it in our balanced reading program, although we do also value it as a component of fluent writing skills. The program includes Exercises that teach common spelling patterns, like vowel spelling patterns, where the Tutor teaches some concepts in introductory screens. In Fall of 2004, it will also contain a program that applies these patterns in spelling regular words, where the Tutor gives detailed hints to help students use the patterns they learned in more basic Exercises.

The system has a sequence of 18 "Vowel Finding" Foundational Exercises. In these Exercises, the Tutor takes the children through the basic vowel patterns in one-syllable words, first without and then with consonant blends, and also has children check to choose which of two




(a) (b) (c)

**Figure 7** Finding Long Vowels Exercise: (a) Teaching screen, (b) Short/long choice screen, and (c) Letter-choosing screen.

or three learned kinds of vowel patterns it has (e.g., "Is the vowel 'short' or 'long' in the word "pine"?) In these Exercises, the Tutor first introduces concepts about vowel spellings and sounds in brief introductory screens. These lessons are short: the Tutor speaks only two to three sentences about concepts, but over a few days the child hears a lot about the vowel pattern. As an example of a few teaching sentences, the Tutor may say "The long sound of a vowel sounds just like the name of its letter. Ending a word with magic 'e' is one way to make a vowel letter say its long sound. Click on any vowel letter to hear its long sound."

Vowel-finding Foundational Exercises (Figure 7) first teach short sounds, then long sounds, and then have children compare and choose whether a word has a short or a long sound. Then the Tutor teaches children about "long vowel teams" (ee, ea, ai, ay, oa), and "ruling r's" (ar, or, er, ir, ur), and "O-team" vowels (two pronunciations of oo, and oi, oy; ou, ow; and aw, au. The children practice choosing the correct ones in the Exercises. These terms resemble those used in *Linguistic Remedies* (Wise, 2002) and in many other phonics programs, and still allow us to keep the five choices that we use in so many of our word-building programs. In some vowel-finding Exercises, the child chooses which of five vowel letters makes the vowel sound in the word the Tutor says, and the Tutor can pronounce each letter before the child must choose OK to indicate he has built the correct word. In more difficult Exercises, the child must first decide on one screen whether the vowel is (for example) short or long, and then proceed to choosing the correct letter, which has its sound pronounced by the Tutor before the child chooses OK. In this activity, the child must be correct on both choices (short or long? And which letter) to earn the gold coin and to progress to a higher level. In the most challenging vowel finding Exercises, to be deployed in Spring of 2004, the child must choose OK before hearing the Tutor pronounce the sound of a vowel letter on the letter-choice screen.

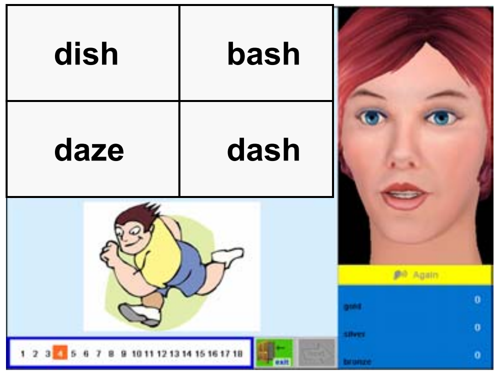



**Figure 8** 4-Square Sound-out Reading Exercise.

Figure 7 illustrates the teaching screen, choice screen, and letter-choosing screen for Short Vs Long Vowels. Prior to doing this Exercise, students have already become competent with short and long vowel knowledge in three earlier Foundational Exercises or in assessments. On the teaching screen a) above, over different days, the Tutor reminds the child what they learned that vowels say their long sounds (which sound like the name of the letter) with a magic e at the end. She reminds them that vowels say their short sounds in closed syllables with a consonant at the end. On this screen, children can click on any vowel to hear it say its long or its short sound. When the Exercise starts next in the short/long choice screen b), the Tutor asks, "Is the vowel sound short or long in the word 'robe'?" The child chooses, and the Tutor agrees, or corrects her. On the letter-choosing screen c) the Tutor says, "Choose the correct long vowel in 'robe.'" The child chooses the vowel letter that correctly completes the word, where the consonant letters and magic 'e' are already supplied. This is a highly supported Foundational Exercise, where the student can click on and hear any vowel letter pronounced, before she clicks OK to indicate she is happy with her choice.

6.3.4 Reading Regular Words (Decoding, or sounding out)

In our programs, children practice reading words that are predictable from phonics patterns, after they have learned the patterns in phonological awareness and sound-out spelling Exercises. Figure 8 shows 4-Square Sound-Out Reading, a Reading Regular Words Exercise. In this Exercise, the Tutor pronounces a real word, and the child must choose the correct word and not one of three distracters designed to resemble the real word visually. If the child chooses the correct word on the first try, the Tutor reads it after she chooses it, and she receives a gold coin, with praise about one in four times. If she misses a word, the Tutor gives her a hint (e.g., if she

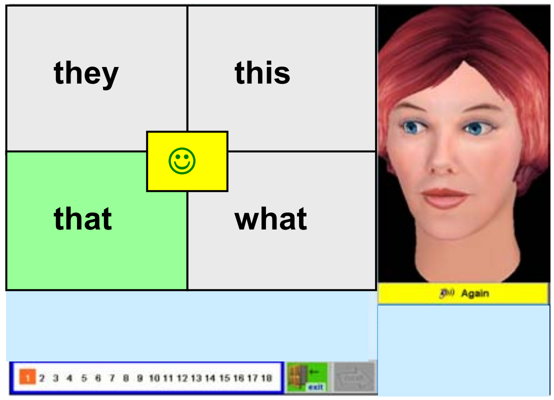



**Figure 9** Speedy Reading Sight Word Exercise.

chooses ‘dish’ for ‘dash’ the Tutor may say “Watch my mouth to help you hear the vowel sound as I say “dash.”) If the child gets the word right on the second try, she receives a silver coin, and praise for good correcting. If she misses it again, the Tutor supplies the word, and the child earns a bronze coin.

6.3.5 Sight Word Recognition Exercises (Orthographic coding)

Our programs aim to improve Sight Word recognition with extensive practice reading in Interactive Books, and we also have Exercises dedicated to improving this skill. Practice with sight words will occur after children achieve success with basic consonant and vowel work and accurate decoding with 3-letter words with short and long vowels. Between kindergarten and third grade, children learn the 300 most frequent sight words used in the Boulder Valley School District, which were gathered from tables by Carrol, Davies, and Richmond (1971).

In *Foundations to Literacy*, these words are first studied in a 4-Square Sight-word Exercise, very like the one used for Sounding-Out reading, but with distracters thought to be common miscues for sight words, from teacher experience and by orthographic similarity. After reading a word successfully 4 times, the word is put into a buffer with other “competent” sight words. Competent words are then practiced in Memory-Match and in Speedy Reading programs (Figure 9). These programs will be deployed in Spring and Fall of 2004. When speech recognition for young children is enabled, children will also have timed readings of lists of competent words. They will read these words as quickly and accurately as they can, and the list

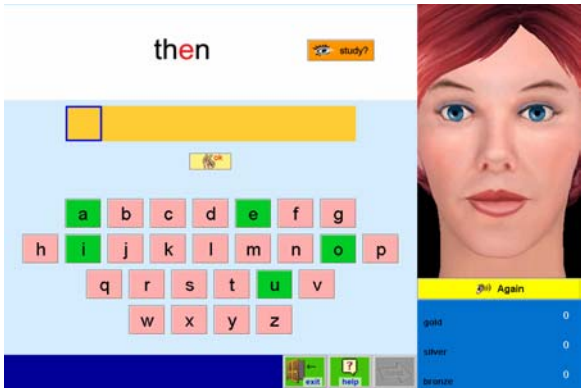



**Figure 10**: Sight Spelling Foundational Exercise

will be considered automatic when times reach an asymptote, and no longer decrease. The length of the timed list differs for different ages and abilities.

Figure 9 shows a working model of Speedy Reading. Here, children read and click on sight words they have mastered earlier in untimed 4-Square. Now, in Speedy Reading, a happy face appears in the middle of 4-Square, each time the child reads the word correctly and as fast or faster than he last read it. At the end of a set, a graphic compares the child's previous speed with the set with his current speed. Once the speed of the set asymptotes, the set is stored in a "Mastered Stack," so the child can see the words he has mastered.

### 6.3.6 Sight Word Spelling Exercises (Orthographic encoding)

The COLit program is deploying a Sight Word Spelling Exercise in Spring 2004. The program teaches the child to spell high-frequency words that he has previously learned to read competently in the Sight Word Reading Exercise. Children reading at early first grade level practice three words in a set; readers at late first grade practice five words in a set, and readers at or beyond second grade practice eight words in a set. The goal of the program is to strengthen the ability to spell sight words, both to improve writing, and especially to strengthen the child's orthographic images for these high frequency words (Ehri, 1998).

In the Sight Spelling Exercise shown in Figure 10, the Tutor pronounces a high-frequency word and asks the child to spell it. The letters are arranged the same in all Sight and Sound-Out Spelling Exercises. Letters are arranged on lines broken as in the alphabet song, centered on the lower screen, and vowel letter squares appear in green, all in hopes of making it easier for children who cannot type to find the letters they want. Older children who can type will be able to select a keyboard arrangement of letters, or may choose to use the keyboard itself.

In Sight Spelling, the exact length of the word is not indicated, so the child has no hints for his first attempt. The child clicks on letters and they appear in order on the working, yellow, line. The child clicks OK when he thinks he has spelled the word. If he spells the word correctly on the first try without any help, the word is put aside for the day, and will come up for later review in another session. If the child spells the word correctly also on the second try, the word will not studied again in this Exercise.

If, on the other hand, the child misspells the sight word, the correct spelling appears at the top of the screen, with any missed letters in red. Here the child may have tried to spell "then" but spelled "thin," so the 'e' is in red for the child to visualize and memorize. The child studies this word as long as he wants, and clicks ready when he is ready to attempt to spell it again. When he clicks ready, the study word disappears and the child makes his second attempt at the word. The child is given three tries to spell the word correctly, and on the fourth try the study word stays on screen and the child copies the letter correctly. Any word not spelled correctly without help stays in the list of words to be learned, until it is eventually spelled correctly on four different attempts in a row. At that point, it will go into a stack for later review, and will appear again at two later sessions.

## 7. Assessing Progress with the Foundational Exercises

Do the Foundational Exercises work? At this point, we must answer: We certainly hope so. Formal evaluation is currently underway, and results will not be known until June 2004.

A small set of Exercises was piloted with first graders in Spring of 2003. A broader range of Foundational Exercises and extensive Interactive Books are currently deployed in an evaluative study in 24 Kindergarten to second grade classrooms during school-year 2003-2004. We briefly describe these efforts below.

### 7.1 Preliminary Study Spring 2003

In a preliminary study, eighty-four first-grade students in four trained classrooms and forty-seven students in two control first-grade classrooms all received two computers per room.

Only the trained classrooms received the COLit programs. University support included providing and installing computers, training teachers on the use of the computers, helping teachers schedule students, and monitoring and correcting technical problems with software or hardware.

Students were pre-tested in February and March and post-tested in late May 2003 on five measures. The measures included

a) Time-limited Word Reading, and
b) Time-limited Decoding (both from the *Test of Word Reading Efficiency* TOWRE: Torgesen, Wagner, & Rashotte, 1999),
c) Untimed Word Reading (the Letter-Word Identification subtest of the *Woodcock-Johnson III Tests of Achievement* , WJ-IIIACH; Woodcock, McGrew, & Mather; 2001)
d) Untimed Decoding (our own non-standardized untimed version of the TOWRE nonword stimuli untimed), and
e) Phonological Awareness (the Phoneme Elision subtest of the *Comprehensive Test of Phonological Processes*, CTOPP, Wagner, Torgesen, & Rashotte, 1999).

Students in the trained classrooms read independently with COLit programs about 15 minutes a day. Most training time, for most students, was spent practicing with Foundational Exercises in the domains of alphabet, letter-sound knowledge, phonological awareness, and regular word reading (decoding). At that time, only three Foundational Exercises: rhyme-changing, initial blends, and 4-Square word reading, extended up into complex words with consonant clusters and vowel digraphs. Three books were completed and introduced for book-reading in May.

Due to the nature of the pilot and the testing resources at the time, trained and control students were not in the same schools, and they were not tested at the same times. This created two confounds from school differences and from time of testing differences, which means we must be cautious in interpreting results. Preliminary analyses of covariance were conducted to evaluate group effects for the measures, covarying out any variance due to initial level of pretest. These initial analyses on all students suggested significant gains for trained students over control students on all measures except time-limited decoding, whether on raw scores or on standard scores where available. However, we report here instead a second, more conservative, set of analyses where the 16 control and 2 trained students who were pre-tested after Spring break were removed, to reduce the confound due to time of pre-testing. We did these analyses on raw scores, because of some instability in Standard Scores on some of the measures due to differences in time of testing and of age. In these more conservative analyses, trained children gained significantly more than control children did on time-limited word-reading ($p < .03$) and on untimed decoding ($p <.02$). Trends reflected similar patterns in untimed word reading ($p = .06$) and in phonological awareness ($p= .12$), where there were few items in the test, and very few at first grade level. Children in both groups gained very little in time-limited decoding, and did not differ. Given the age of the children, and the Exercises that they did, we did not expect gains in time-limited decoding. We are eager to see if our much better controlled evaluation study in school year 2003-2004 supports and extends these preliminary results which do support that the Exercises improve foundational skills in reading.

We feel more confident of the observational and qualitative results in the Spring 2003 pilot study. These suggest that children and teachers enjoyed the programs and found them easy to use. Students and teachers were generally very positive about their experience with COLit. We were extremely pleased with the level of engagement and independence of the students, who came to and used the programs with little or no reminding or support needed from teachers. Nearly all students who participated chose to participate again in the study using both Exercises and Books in school-year 2003-2004. We believe these results support the hypothesis that simple, engaging, and theoretically grounded Foundational Reading Exercises and Interactive Books can be designed with the assistance of teachers and students in ways that will help them be used independently and well in schools.

### 7.2 Current Development and Assessment Activities

In November 2003, we began formative evaluation of the *Foundations to Literacy* learning tools with over 400 children in 24 kindergarten to second-grade classrooms in four public schools in the Boulder area, with a similar design of treatment and control classrooms. However, in the current study, control and trained classrooms are in the same school, so pre-testing and post-testing is being done at the same times within each school, for all children. The current deployment includes the Managed Learning Environment, Foundational Exercises, and Interactive Books. At present, speech recognition is disabled in Interactive Books pending further testing. Students in the treatment classrooms are spending about 20 minutes per day using the learning tools, and initial experiences are again mainly very positive. That is, students are able to use the programs, are clearly eager to get onto the computer when it is their turn, are fully engaged during their session, and appear to enjoy using them. The teachers also have also reported mainly positive experiences, with one or two teachers having experienced hardware problems, which can be discouraging to teachers and students. At this stage in our development, teachers and students also still report software bugs, which, so far, we have been able to deal with rapidly. Formative evaluation is now underway, using basically the same tests as last year, and children will be post-tested in May 2004. At one school, which was in the 2003 study and which began the earliest in 2004, students will receive mid-year evaluation in February.

**7.3 Classroom Experiences**

In addition to quantitative measures, we devote significant effort to understanding how students experience the learning tools, and how the tools are integrated into classroom activities. A team of observers, supervised by Kathy Bunch, Lecia Barker, and Kathy Garvin-Doxas and including Laura Dempert, Laura McMillan, Eric Snow, Chris Hovey, and Pamela Cole have been trained to be expert users of the software. This team visits treatment and control classrooms to observe and record how teachers teach literacy in their classes. The observers also record how students use the software in the treatment classrooms, including their apparent levels of engagement and the problems they experience. They also observe, in more general ways, how the use of the tools affects classroom activities. The observers report classroom observations on a website reporting system, which the project staff reviews.

Observers gave us valuable help in Spring 2003, and again in 2004.We have learned that students enjoy most of our programs and can use them independently following brief initial training. Most teachers are very positive and have high hopes for the programs to help their children learn. We have also learned, from initial observations and prior surveys, that the teachers have great differences in experience, attitudes, and expectations regarding the programs. For example, one kindergarten teacher enlisted the aid of a parent volunteer to teach each student to log into the system and provide an initial orientation. The students in this class work independently and enthusiastically with the system. We expect to learn much from these observations and subsequent interviews with teachers and students about how to improve the Exercises and to integrate the programs more effectively into classroom activities.

# 8. Future Work

We are currently focusing most of our efforts on rapidly fixing problems of deployed systems, on developing and testing new Foundational Exercises, on expanding the content of Interactive Books, on incorporating and testing speech recognition and natural language understanding technologies (for "read aloud" and *Summary Street* comprehension training), on developing and deploying a Spanish version of the system, on improving the interface of the Managed Learning Environment to provide a more intuitive and effective tool for teachers to monitor student progress, and on porting our tools to several inner city schools in Denver. While these activities keep us busy, we also are working to extend our literacy tools to serve students with special needs. In this section, we describe these outreach activities. We then mention some future directions for research and discuss the potential impact of new technologies, now under development, to improve learning and user experiences within our program.

## 8.1 Scaling-up for Students with Special Needs

Our team is now focused on porting the *Foundations to Literacy* program to classrooms in several schools to serve students with special needs. In each case, we will deploy systems on new computers (is come cases provided by the project, and in some cases acquired by the schools), and then observe how students with different learning backgrounds and abilities use the learning tools. We will then modify the tools to serve the needs of these students, collaborating with teachers and students. In each case, we are collecting pilot data by assessing reading skills before and after students use the Foundational Exercises to gain insights about ways in which the Exercises help students learn, and ways in which they can be improved.

### 8.1.1 Inner City Schools:

We have begun to deploy our program in kindergarten through third grades in two inner city parochial schools in Denver. In one school, the vast majority of students are Hispanic, and in the other school the majority of students are African-American. During these deployments, we will introduce and field test speech recognition during read aloud activities, and we will investigate automatic grading of spoken summaries of text using Summary Street.

Assessment of learning outcomes in these classrooms will be conducted through random assignment of students within classrooms to treatment and control conditions. Although we are just beginning to work with these schools, one encouraging outcome has already happened. We originally intended to go into only one school. But after several administrators and teachers saw and used the system, the assistant superintendent of the school district aggressive sought and received a donation that enabled the district to purchase two computers per classroom for K-3 classrooms in a second school. We believe this is an important outcome; it addresses the issue of scaling up a program that requires powerful computers (i.e., sold over the counter in the last year or two), which most schools do not yet have. The assistant superintendent understood that the cost of new computers for four classrooms was justified given the potential benefits to the students (about $8000 for 8 computers, or $1000 per computer, although suitable computers can be purchased for half this price). Two computers in a class can provide 20-30 minutes of one on one tutoring to all children every day, and a computer will last about 5 years. Thus, the cost of acquiring a computer system with reasonably-priced software is between one and two orders of magnitude cheaper than training and employing reading specialists to provide individualized or small group instruction to students over this same time period.

8.1.2 Students with Cognitive Disabilities:

During Spring of 2004, with support from a grant from the Coleman Institute for Cognitive Disabilities, we will also deploy our literacy tools in special education "resource rooms" in six schools in the Denver Colorado area to test the usability of our Foundational Exercises and Books with children with autism spectrum disorders and children with Downs Syndrome. The goal of this work is to observe students working with the Foundational Exercises and Books, and then modify the programs as necessary to optimize their ease of use and effectiveness for these students. We have conducted prior work using an animated agent to teach classroom subjects to children with autism, with good outcomes; it has been observed that many children with ASD have a special affinity for computers, and we have found that they enjoy interacting with a Virtual Tutor (Cole et al., 2003; Schwartz et al., 2002; 2003).

8.1.3 Students with Hearing Loss:

During Spring of 2004 we are also deploying our programs at Tucker Maxon Oral School (TMOS) to investigate their usability and effectiveness in classrooms both with children with normal hearing and children who are profoundly deaf and experience sound through cochlear implants and amplification. We learned much about the importance of listening to and working with teachers, and about applying participatory design methods to develop of learning tools using animated agents from our earlier good collaboration with educators and researchers at TMOS. This work led to a program, reported in several publications (e.g., Cole et al., 1998; 1999) and featured on national television (ABC TV's Prime Time Thursday (Payson, 2001) and the US National Science Foundation Home Page, that resulted in dramatic improvements in speech intelligibility and language use by students at TMOS (Barker, 2003). Through continued collaboration with TMOS, we hope to modify our literacy program to produce effective tools for teaching language though literacy to students who are profoundly deaf.

#### *8.1.4 English Literacy Training for Spanish Speakers:*

Finally, we are working to transform *Foundations to Literacy* into an English-Spanish bilingual literacy program. All of the Books and their associated comprehension questions are being translated into Spanish, and all of the Foundational Exercises are being adapted to Spanish phonology and vocabulary to teach foundational reading skills in Spanish. This work is being conducted in close collaboration with Ingrid Kirschning and her colleagues in the TLATOA speech group at the Universidad de las Americas in Puebla Mexico. We are also working with Corby Connolly, an ESL teacher in Boulder Colorado who has developed an excellent bilingual literacy program for teaching English to native Spanish speakers (Volando 2004) which we are transforming into a multimodal and multimedia learning program within Interactive Books.

### 8.2 Future Directions

#### 8.2.1 Research on Individual Differences in Response to Instruction

Computers provide an ideal tool not only for providing individualized instruction and remediation, but also for studying questions that relate to optimal instruction, with or without the computer. Because computers don't have an opinion about the best way to teach reading, they can add objective data to inform instructional debates. In earlier sections of the chapter, we have brought up interesting instructional questions about what works best for children of different ages, abilities, and profiles. Information concerning these questions will improve our programs, and they will also add important information about how best to teach reading in teaching situations without computers. Some of these crucial questions include what is the optimal balance of instruction between reading in books and doing foundational exercises, or between practice and automaticity training, and what are the most powerful ways of teaching different competencies to children with different strengths and needs. These questions will be addressed in future studies, and they should provide information important to all those interested in the most effective ways of helping different children learn to read. Our planned ICARE Independent Comprehensive Adaptive Reading Evaluation System will also help a great deal in studying how children with different profiles respond to theoretically grounded variations in the *Foundations to Literacy* system.

8.2.2 Research in human-computer interaction.

Another of the most exciting aspects of this project is that it provides a novel and powerful platform and environment for conducting leading edge research in human computer interaction with virtual agents through integration of spoken dialogue, computer vision, and character animation technologies. The COLit system provides two major benefits as an environment for conducting leading edge research in human language and communication technologies and for studying face-to-face communication with Virtual Tutors. First, a system architecture has been developed that supports both integration of machine perception (speech perception, natural language processing, face and gaze tracking, face and emotion recognition, gesture recognition, etc.) and machine generation (Virtual Tutors that speak, gesture and emote), enabling real time conversational interaction with a virtual human. Second, the COLit system, by incorporating Foundational Exercises and Interactive Books, enables assessment of human computer interfaces for a variety of users in well defined tasks (e.g., reading, comprehending) for which standardized assessment instruments and methodologies have been established. Because of these advances, we and other researchers have a new opportunity to create Virtual Tutors and study their effectiveness for children of different ages, profiles, and needs.

We have yet to realize the vision of perceptive animated agents that interact with people like people interact with each other, but we are making progress toward this goal. We are establishing critical infrastructures and improving the requisite technologies that offer great promise to future learners. Imagine how effective a Virtual Tutor will be using all these advances. She will be able to track the word a student is reading precisely, by combining speech recognition and gaze tracking. When the programs can analyze a current error against the backdrop of the history of the child's typical errors, and can also be informed by analyzing the child's expression, the Virtual Tutor should be able to produce just the right hint at just the right time to help the child figure out the word under consideration. Imagine also the effectiveness of a Virtual Tutor who can engage in a dialogue with a student to consider the author's likely intent contained in the passage of a story.   These capabilities are currently beyond of the state of the art, but they are beginning to seem within reach.

## 9. Summary

This chapter has described the purpose, design, development, and initial deployment of a theoretically-grounded set of reading programs that aim help children to learn to read and to reduce reading problems. The Foundational Exercises are integrated into the *Foundations to Literacy* system, a balanced reading system with Interactive Books and a Managed Learning Environment that is part of the broader COLit system. This effort uses cutting-edge technology, scientifically-based reading research, and participatory design throughout to make the system simple to use, engaging, and scalable. Preliminary testing has shown that children and teachers enjoy using the programs, and use them almost independently following initial training of students to use the software.   Measures of gains in preliminary testing support the notion that the Foundational Exercises do indeed help children improve in foundational reading skills. Current and future work will continue to extend the entire system to work at more complex levels with more languages and to increase individualization and engagement for all students.

## Acknowledgements

We thank Drs. Ludo Verhoeven and Charles Kinzer for the informative workshop in Nijmegen that led to this chapter and for their gracious tolerance of our delays in its writing. We thank colleagues Jiyong Ma, Taylor Struemph, Jie Yan, Tim Weston, Cathy Bunch, Lecia Barker, Eileen Kintsch, Walter Kintsch, Donna Caccamise, Richard Olson, Jerry Ring and staff members of CSLR, Atlas, and ROSS for all their help prior to or collaborating on the COLit project. We gratefully acknowledge support by the U.S. National Science Foundation (NSF) for ITR-HCI grant IIS-0086107, NSF-IERI grant REC-0115419 107 and NSF/IERI: EIA-0121201, and by the National Institute of Child Health and Development for NICHD-IERI grant 1R01HD-44276.01 and for grants HD 11683 and HD 22223 to Richard Olson and Barbara Wise, and the Coleman

Institute for Cognitive Disabilities for a grant to support participatory design of the Foundational Exercises. Finally, we thank Jean Riordan and Jana McMillan of the Boulder Valley School District as well as the teachers, staff and students who contributed insights during participatory design and current use of our learning tools.

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