MindStars Books: Improving Children's Motivation, Self-Efficacy, Science Learning and Reading Proficiency

MindStar Books represents a new generation of intelligent tutoring systems for children in science and in reading. We seek great strides, in the context of the NSF SBIR Educational Technologies and Applications (EA) track, to immerse students more effectively in multimedia learning activities in which they are challenged, motivated and empowered, through conversational interactions with a sensitive and effective virtual tutor, to acquire the knowledge and strategies to learn science and the basic skills required to read expository texts fluently and with comprehension. MindStar Books are designed to scaffold effective science learning and fluent reading skills with the following three aims: 1) They will enable students, especially including English language learners, to acquire the prerequisite vocabulary and concepts to listen to and understand science texts that are read aloud to them by a virtual tutor while they view illustrations that help them visualize the science being explained. 2) They will assess and facilitate students' understanding of the science through spoken presentation of deep reasoning questions, challenging answer choices representing common misconceptions, and immediate formative feedback on their answer choices. Finally, 3) MindStar Books will engage students in activities that lead to accurate, fluent and expressive reading of expository texts; skills that correlate highly with reading comprehension and future reading success. Key Words: *Intelligent tutoring system, Virtual Tutor, Immersive Learning, Science Achievement, Reading Proficiency.*

Intellectual Merit: This Small Business Innovation Research Phase I project aims to provide new insights and contribute to scientific knowledge about how students learn using technology, and how technology can be designed to optimize young learners' engagement, motivation, self-efficacy and learning. The MindStar books are based on theory and research on how children learn through social interaction in multimedia environments, and based on prior research with a virtual science tutor that highly engaged primary school students in spoken dialogs about science presented via media, resulting in learning gains equivalent to expert human tutors. MindStar Books extends this research to improve oral reading fluency and reading comprehension.

Broader /Commercial Impact: Successful outcomes of the proposed work will provide initial evidence for the feasibility and promise of a new generation of intelligent tutoring systems that can simultaneously improve science learning and reading proficiency, while increasing young learners' excitement, motivation and self-efficacy. The innovation addresses a critical national need to improve both science learning and reading proficiency of young learners in our nation's schools. The innovation is intended to provide teachers and students with an accessible, affordable and highly effective learning tool that can improve teachers' effectiveness and students' engagement, motivation, learning and academic achievement. The commercialization plan presents a business and financial model for marketing the resulting product to schools in the U.S. and globally, with potential for broad societal impact.

Part 1: Identification and Significance of the Innovation.

The Phase 1 research innovation we propose is an Intelligent Tutoring System called MindStars Books. MSBs are designed to immerse children in learning activities with Marni, a lifelike conversational tutor that produces accurate and graceful head movements, facial expressions, and visual speech. Each MSB consists of two related activities: listening comprehension, and oral reading fluency. The goal of listening comprehension is to help students acquire science vocabulary and concepts, and learn to reason about science. Students develop listening comprehension and reasoning skills through multimedia presentations in which Marni explains science concepts and phenomena presented in pictures and animations, followed by question-answer dialogs in which students are presented with deep reasoning questions with challenging answer choices that require them to reason about the science; students receive immediate, feedback following their answer choices. Oral reading fluency (ORF) training occurs immediately after students have completed the listening comprehension activities. Having reading training follow listening comprehension activities is based on the idea that students will learn to read and understand science texts more efficiently and effectively as they gain familiarity with the vocabulary and concepts. The goal of ORF training is to enable students to read the grade-level science text accurately and fluently through repeated readings of each page, with practice reading words and sentences, and receiving feedback on their word recognition accuracy and reading rate following each reading.

The technical innovation address a critical need to improve students' science achievement and reading comprehension in the United States K12 education system. The 2009 National Assessment of Educational Progress (NAEP) [1] reports that fewer than 2% of 4th, 8th, and 12th grade students demonstrated advanced knowledge of science. Over two-thirds of all students in these grades were scored as *not proficient in science*. Reading results were similar: fewer than 40% of 4th, 8th and 12th graders nationwide performed at or above the proficient level. *English learners are especially at risk*: Analyses of NAEP scores in reading, math and science over the past twenty years indicate that the gap between English learners and English-only students, which is over one standard deviation lower for English learners, has increased rather than decreased. For these students, reading fluently and with adequate comprehension is still a challenge that hinders their educational development.

The proposed MSBs are expected to enable learners to develop the listening comprehension and scientific reasoning skills required to demonstrate a deep understanding of the science vocabulary and concepts covered in the books, and to learn to read grade-level science texts fluently and with comprehension. Since MindStars Books will be aligned to national and state science standards and grade level reading expectations, a sequence of MindStars Books can provide teachers with a powerful tool to help students achieve academic success in both science and reading. Since both science and literacy can be taught at the same time, MSBs are expected to provide teachers and students with a highly efficient and effective interdisciplinary program that can be readily integrated into classroom instruction.

In sum, MSBs, are designed to scaffold effective science learning and reading proficiency with the following three aims: 1) enable students, especially including English language learners, to acquire the prerequisite vocabulary and concepts to listen to and understand science texts that are read aloud to them by a virtual tutor while they view illustrations that help them visualize the science being explained; 2) assess and facilitate students' understanding of the science and development of scientific reasoning strategies through spoken presentation of deep reasoning questions, challenging answer choices representing common misconceptions, and immediate formative feedback on their answer choices; and will engage students in activities that lead to accurate, fluent, and expressive reading of grade-level texts; skills that are correlated highly with reading comprehension and future reading success [2-8]. These are important and exciting aims based on prior research and they are within our grasp.

Part 2: Background and Phase I Technical Objectives

MindStars Books (MSBs) have been under development at Boulder Language Technologies (BLT) since September 2012, in the context of an NSF Science Across Virtual Institutions (SAVI) project,

Innovations in Education and Learning (http://innovationsforlearning.net). The researchers in the SAVI project created eight different teams that partnered researchers in the U.S. with researchers in Finland. Our team includes researchers at Boulder Language Technologies (Ron Cole, Eric Borts), Southern Methodist University (SMU; Doris Baker) and Pepperdine (Eric Hamilton) and a team of researchers at the University of Jyvaskyla in Jyvaskyla Finland (Heikki Lyytinen, Ulla Richardson, Jarkko Hautala) Aleksi Keurulainen). A major focus of this collaboration was development of MindStars Books for use in both U.S. and Finnish elementary schools. Participation by the U.S. team was supported by a one year supplement (September 2012-August 2013) to NSF grant 0733323: *Collaborative Research: Improving Science Learning in Inquiry-based Systems.*

Work conducted during the SAVI project resulted in an alpha release of the MindStars Books Toolkit, an authoring and runtime environment for developing MSBs, and publishing them in a library for use by teachers and students. An initial set of eight books were developed at BLT, and translated into Spanish and recorded by a bilingual speaker in both English and Spanish. These books tested in a pilot study with kindergarten and first grade students, described below.

Our collaboration with researchers at the University of Jyvaskyla resulted in a Finnish version of the eight MSBS developed thus far. In these books, Marni speaks Finnish, and can produce English translations of Finnish prompts. The development of the Finnish speech recognition system, by the Finnish research team, was an important outcome of the collaboration. The Finnish research team is planning to evaluate the Finnish MSBs third grade classrooms in Jyvaskyla schools in January, 2014. These books will include an initial version of the oral reading fluency component.
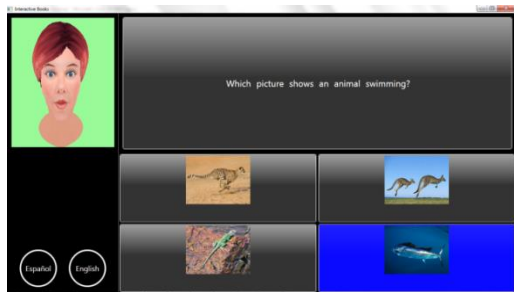

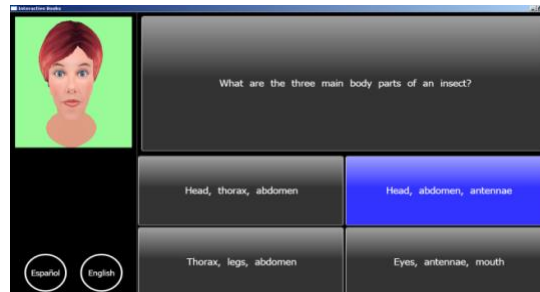*Figure 1*. MS Books MCQ with picture answer choices.

Figure 2. Marni reads questions and answer choices aloud in English and Spanish.

Design and Organization of MindStars Books

Listening Comprehension: In MS Books, Marni narrates each page of a science text while the student views illustrations that help them visualize the science. The narration is self-paced in alignment with research that indicates that self-paced presentations improve learning [9-11]. Students can stop and resume the narration after Marni speaks each sentence, and have Marni repeat the sentence in English or say a Spanish translation of the sentence. After listening to one or more pages of text, Marni presents students with multiple choice questions (MCQs) to assess their understanding of the vocabulary and concepts. These are deep reasoning questions with challenging answer choices that represent common misconceptions. Students can listen to the question and answer choices either in English or in Spanish as often as they like. After selecting an answer, the student receives immediate feedback about the answer they selected. Marni provides positive feedback to a correct answer. If the student selects an incorrect answer choice, Marni scaffolds learning by providing a hint; e.g., that spider has 8 legs, so it can't be an insect. After two tries, the correct answer is presented to the student, along with an explanation as to why the answer is correct. We note that during listening comprehension activities, words are not presented on the page, as the goal is to have students listen carefully while viewing illustrations; printed words can distract the student's attention from the illustrations and reduce learning [12].

Oral Reading Fluency (ORF): ORF practice and training occurs immediately after the listening comprehension activities are completed; that is, after all pages of the science text have been narrated to

the student and MC questions have completed. The goal of the ORF training is to help students learn to read grade level science texts accurately and fluently; oral reading fluency has been demonstrated to a strong predictor of reading comprehension and later reading proficiency [3, 4, 13, 14]. Fluency training occurs through repeated reading of each page of the science text. The student is presented with the first page of the text, with each sentence displayed on the page. The student can choose to practice reading the text, with support from Marni, before reading it independently. During practice, the student can listen to Marni read an entire sentence, or pronounce individual words in a sentence. The student can record themselves reading these sentences or words and play back their recordings to compare their reading with Marni's. English learners can listen to Marni read a translation of the sentence in Spanish. When the student has finished practicing, they click an icon to read the page independently. Immediately after reading the page, the student receives feedback on the number of words they read correctly (out of the total number of words on the page), and their reading rate (relative to Marni's natural reading rate). The MindStar book highlights words that the speech recognition scored as misread or skipped, so the student can practice reading these words and sentences. Repeating readings of the page, with practice before each reading and feedback on the student's reading performance immediately after independent reading, continues until the student achieves a criterion level of oral reading performance (90% word reading accuracy, reading speed within 10% of Marni's) or after three independent readings. Repeated reading of texts with feedback and practice following each reading has been shown to be a powerful tool to improve reading fluency, which correlates highly with reading comprehension[15-20].

The MindStars Books Toolkit: The MindStars Books Toolkit was developed to provide an easy to use authoring environment for developing the listening comprehension activities in MS Books, and publishing the book in a library. The tool enables an author to (a) type in each sentence Marni will say, (b) record the sentences in English and record the Spanish translation of each sentence, (c) select a picture that will be presented with each narrated sentence (portions of pictures are highlighted using Photoshop), (d) design one or more multiple choice questions, with optional illustrations, that are presented after the page has been narrated, and (e) record the questions and answer choices in both English and Spanish. Once the listening comprehension activities have been developed, the oral reading fluency training activities, which follow listening comprehension, are generated automatically, using the text that is narrated by Marni during listening comprehension training. In May 2013, BLT hosted a workshop in which 7 research staff from BLT and SMU and a primary school teacher learned to use the authoring tools to create new books.

MindStars Books Pilot Study

An initial set of eight books that supported listening comprehension activities in English, with Spanish translations of Marni's speech, which could be invoked by users, was tested in Kindergarten and first grade classrooms during May, 2013. The books were based on life science themes (e.g., Insects, Life Cycle of the Monarch Butterfly, What do Animals Need to Live?). Students were able to start and stop the (self-paced) multimedia presentation at any point, and repeat the entire presentation if they desired. They could also have Marni repeat questions and answer choices as often as they liked before choosing an answer. When a correct answer was chosen, Marni provided positive feedback to the student, and often expanded on the correct answer. When students chose an incorrect answer, Marni provided a hint (e.g., that spider has 8 legs, so it isn't an insect), and asked the student to choose again. If the second choice was incorrect, Marni explained why the choice was incorrect, and provided the student with the correct answer. English learners who spoke Spanish as their first language also listened to Marni in English during these activities, but had the option of clicking on an icon to hear Marni produce a Spanish translation.

The results of the pilot study provided initial evidence that children were highly engaged in using the books and that they were effective in helping students learn science vocabulary and concepts. Eight kindergarten and first grade students interacted with Marni in 6 to 8 different books. All together, the students were presented with 301 multiple choice questions. Across all students, 273 (90.7%) were

answered correctly on their first choice. An additional 26 (8.3%) were answered correctly on students' second choice. While these results are encouraging, additional research is needed to determine if students will retain the knowledge acquired in the books, or will be able to transfer it to new contexts.

Four English learners who used the books each invoked Spanish translations of prompts by Marni, and these occurred most often during their review of answer choices to multiple choice questions. The student who invoked Spanish translation most often—over 90% of the time during MCQs was proficient in English. This student shared that he enjoyed listening to Marni explain science and ask questions and read answer choices in both English and Spanish because it helped him understand the science.
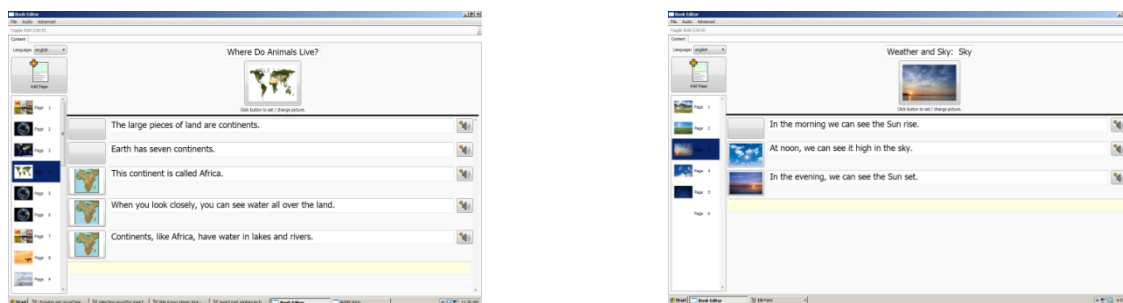

Figure 3.Screenshots of MS books authoring tool.

Scientific Foundations

MindStars Books are grounded in a solid foundation of theory and scientific evidence. Three decades of research have demonstrated that learning is optimized when students receive individualized instruction in small groups or one-on-one tutoring [21-24]. Factors that improve tutoring outcomes include frequent, regular and well-structured tutoring sessions, coordination with classroom activities, and dialogs structured to stimulate thinking and knowledge construction[25, 26] through effective scaffolding and feedback. There is growing evidence that intelligent tutoring systems can be designed to achieve learning gains comparable to human tutors. A recent meta-analysis by VanLehn [27] compared learning gains achieved by students who received one-on-one tutoring with human or Intelligent Tutoring System (ITS), using stringent criteria for selection of studies based on methodological rigor. The studies included human tutoring and intelligent tutoring systems in STEM topics. When compared to students who did not receive tutoring, the effect size of human tutoring across studies was d=0.79 whereas the effect size of tutoring systems was d=0.76. VanLehn concluded that intelligent tutoring systems "are nearly as effective as human tutoring systems." ([27], pg. 197).

MindStars Books are based on theory and evidence indicating that a student's ability to read and understand a text– their reading comprehension ability– consists of two component skills: *listening comprehension* and *word reading automaticity.* Listening comprehension is an individual's ability to listen to a text and answer spoken questions about it. Reading fluency is the ability to recognize words accurately and effortlessly. Research shows that students' reading comprehension abilities can be accurately predicted by independent measures of their listening comprehension skills and their ability to recognize words accurately and rapidly[28-30]. MindStar Books are designed to help students develop these two essential skills.

Foundational Work at BLT Leading to MindStars Books

BLT has conducted research with that provides the scientific foundations and the technical infrastructure for the proposed work. Research with My Science Tutor, an intelligent tutor system, informs the design of listening comprehension activities in MSBs. Research on assessing oral reading fluency provides the expertise and infrastructure for oral reading fluency activities in MSBs.

My Science Tutor (MyST): MyST is an intelligent tutoring system that has been show to engage students in tutorial dialogs with the virtual tutor Marni leading to learning gains comparable to those achieved by

expert human tutors [31, 32]. A version of MyST was evaluated during the 2011-2012 school year that engaged in learning activities similar to those described above in MindStars Books. In this evaluation, students were first presented with a science problem (How does a simple circuit work?). They were then presented with a narrated multimedia presentation that explained the science. Immediate following the multimedia presentation, Marni presented students with one or more multiple choice questions, with challenges answer choices. In this study, Marni tutored students in two conditions: either one-on-one tutoring of individual students or tutoring with groups of 2 to 4 students. The two conditions were identical in that in both conditions, Marni asked questions, and a single student responded to the question. However, in the small group condition, students were encouraged to discuss Marni's questions before one of the students (the "speaker," who rotated across sessions) provided a spoken answer. Students were able to discuss Marni's questions during the spoken dialog following the narrated animation, and before selecting an answer following presentation of the multiple choice question. In both conditions, students received feedback to their answer choices. Evaluation of learning gains of students in these two groups was compared to students who did not receive tutoring, using standardized pretest and posttest assessments of science knowledge. The evaluation revealed that, relative to students who did not receive tutoring, students who received individual tutoring and students who were tutored in small groups achieved equivalent learning gains, with effect sizes of d=0.62 and d=0.60 respectively. Analysis of small group conversations indicated that all students actively participated in the discussions, and that authentic dialogs, in which students built on each other's ideas, occurred about 40% of the time and lasted 30 seconds on average.

We note that the one on one tutoring condition in this study is very similar to the listening comprehension activities in MindStars Books. The MyST evaluation provides evidence that listening the comprehension activities in MSBs are likely to produce significant learning gains.

FLORA: FLuent Oral Reading Assessment: The NSF MyST project also supported development of an open-source speech recognition system, Bavieca [33, 34], which has been trained on over 200 hours of children's speech to accurately score words as correct or incorrect when children read grade level text passages out loud. The ability to accurately score words as read correctly or incorrectly (mispronounced or skipped over while reading a text) is necessary to estimate children's oral reading fluency proficiency. Oral reading fluency, or ORF, is typically measured in terms of the number of, *words correct per minute* (WCPM) that a student reads in a grade-level text passage. WCPM is widely used in schools throughout the US to screen students who may be at risk for learning to read, and to measure students' reading progress during the school year in response to reading interventions. Because WCPM scores on grade level text passages have been collected for tens of thousands of students across the US during the fall, winter and spring trimesters, norms exist for identifying whether students fall below the 50% mark. These students may be at risk for learning to read based on their WCPM scores [36]. Moreover, a significant body of research has demonstrated that ORF scores correlate highly with independent measures of reading comprehension, and predict students' future success in reading proficiently [3, 35-39]. A second independent measure of ORF is how expressively the text is read. The NAEP has developed a 4-point rating scale and rubric for scoring text passages from disfluent (1) to highly fluent (4). Expressiveness is also an important indicator of reading comprehension, since students who read texts with appropriate prosody are integrating the prior discourse structure of the text to emphasize new and important information as they read aloud.

Our research examined the ability of the Bavieca speech recognition system to score over 800 grade level text passages read by over 300 children in first through fifth grades. We compared judgments of experienced school teachers who scored each text passage in terms of WCPM and the 4-point NAEP fluency scale to scores computed automatically using Bavieca. In terms of WCPM, scores produced by Bavieca differed from the human judges by about 3.5 words, whereas the average disagreement between the human judges was 2 words [40]. In terms of the 4-point NAEP expressiveness scale, scores produced by Bavieca agreed with the human judges significantly better than the human judges agreed with each other [41]. These important results indicate that MindStar Books can provide accurate

feedback to student's words and sentences they need to practice to improve their oral reading fluency performance following independent reading of text in MindStar Books.

Part 3: Phase I Research Plan. The proposed research and technical development has three specific aims:

1. Integrate face and eye tracking to increase student engagement and learning. The purpose of this enhancement is to monitor students' attention and cognition engagement and use this information to design interactions that increase students' engagement and rapport with Marni.
2. Conduct research to optimize oral reading fluency training. We will conduct research that aims to increase students' self-efficacy and reading proficiency during oral reading fluency training.
3. Conduct an initial pilot study in classrooms to assess the feasibility and promise of MSBs. We will conduct a pilot study during the final two months to a) assess teachers' impressions of the MSBs and their willingness to integrate them into classroom instruction, and b) gain insights into student's experiences and learning gains that can be attributed to using the MSBs.

In the remainder of this section, we will justify each of these objectives, and describe the technical challenges and research that will be conducted to develop and measure them.

Aim 1: Incorporate face and eye tracking into MSBs. Although our prior work indicated that Marni engaged and motivated students, she is not a particularly empathic or expressive tutor, except for her voice, which is recorded by an expert tutor, and produces prosody appropriate to the dialog. Marni produced natural head movements, eye blinks, eyebrow raises, and natural head movements while speaking or listening to students, or waiting for them to respond. Because the MSB system does not yet have computer vision, Marni cannot see the student; she is functionally blind. She cannot sense or respond to students' visual behaviors.

There are significant benefits to incorporating computer vision into the MSBs. By integrating face tracking, head pose estimation and gaze tracking into MBs, Marni can detect where the student is looking, what they are attending to, and respond appropriately to these behaviors. In order to make Marni visually aware and responsive, the system must detect students' head movements and pose and eye gaze and use this information to respond appropriately.

The BLT avatar system was recently enhanced to orient Marni's head and eyes to any point, as shown in Figure 4. Marni's head will now move to any region or point, and her eyes will focus on any point or region, e.g., following students' eyes (when she talks) or mouth (when the student is talking. Our research has also demonstrated that users' can accurately determine where Marni's gaze is focused on the screen, enabling Marni to, for example, view individual words when the student is practicing them.

As part of Aim 1, we will integrate face tracking, head pose and gaze tracking functionality into the MSBs. Great strides have been made in recent years towards developing systems for measuring and understanding eye gaze [42, 43]. Measures of eye gaze and fixation duration provide a constant stream of information that can be used to estimate students' attention and cognition [44, 45]. Moreover, several open-source software systems have been evaluated and improved for eye/gaze tracking research and applications [46].

Our approach to gaze tracking and pupil measurement is to save time and cost, and avoid reinventing tools, by investigating, comparing, selecting, and refining (if necessary) a state-of-the-art open-source systems for face tracking, head pose estimation eye gaze measurement. We selected *TrackEye* [47], an open source eye tracking system that uses a computer's webcam. It was awarded "Best C++/MFC article of June 2008" in an international competition to implement a real-time eye-feature tracker with specific capabilities. TrackEye provides real-time face tracking under Windows OS with scale and rotation invariant specification. It tracks the eye area individually and independent of other face components. Additional details of TrackEye can be found in [47].

Figure 4. Eye focusing feature of Marni.

During the first two months of the project, we will work with Dr. Mohammad Mahoor to integrate the TrackEye system into the MSB toolkit. During months 3 and 4, we will conduct research to inform the design of interactions in which Marni responds to users' head movements and gaze to optimize engagement and learning. We will examine students' visual behaviors, manipulate Marni's responses to these behaviors, and correlate these interaction patterns with users' experiences and subsequent responses. This research will be conducted initially in the laboratory with project staff (month 3), and then with 10 to 20 children in classrooms (month 4). The primary goal of this phase of the research is to model the dynamics of natural face to face communication during tutoring, so Marni responds gracefully and believably to students' verbal and non-verbal behaviors. The overarching goal of this research is to increase students' perceptions of Marni as an attentive, empathic, and responsive tutor. For example, when presenting students with multiple choice questions and answer choices, should Marni look at the questions and answer choices on the screen, or look at the student? When students are practicing reading texts out loud, should Marni look at the text the student is reading, watch the student, or switch back and forth between the screen and the student? During the second phase of the research we will attempt to investigate and specify interaction patterns that motivate students and increase their self-efficacy, by providing visual feedback (e.g., smiles and nods) following correct answers, or following significant improvements in oral reading fluency. During the final eight weeks of the project, we will test the MBS system with children in second grade classrooms. Videos of students' interactions with Marni and media (from each computer's webcam), which include information about the students' gaze patterns, will be analyzed to gain insights about where students were looking, how Marni responded to these behaviors, and students' responses to Marni's behaviors.

Aim 2: Optimize interactions between Marni and students during oral reading fluency training. The authoring and runtime functions in MSBs that support oral reading fluency training have been developed and tested by project staff. All of these functions work as desired. That is, users can practice listening to Marni read sentence or pronounce individual words, and record sentences and listen to their recordings as each word in the sentence is highlighted. They can practice until they decide they are ready to read the page independently. After reading the page independently, users receive feedback on their word recognition accuracy, relative to the number of words on the page, and their reading speed, relative to Marni's reading of the text at a natural speaking rate. Words the system scored as misread are highlighted on the page, and students are invited to practice these words and sentences before reading the page again.

While these functions work, they have not been empirically tested with children. The goal of Aim 2 is to refine interactions between students and Marni to optimize students' engagement, motivation, and learning. In designing interactions that can achieve these goals, it is critically important to remember that a substantial number of children have difficulty learning to read English texts accurately, fluently and effortlessly. Approximately 20 percent of children have specific reading disabilities and have difficulty learning to recognize words accurately and automatically. Learning how to decode words and develop word level automaticity is thus a significant challenge for many students, and especially for English learners who are not proficient in English who lack knowledge of the words they are trying to decode.

For this reason, we believe it is important to conduct research that enables children with reading challenges to receive scaffolding and feedback during practice, and to receive positive feedback that is contingent on *performance improvements* between successive independent readings of a page of text. For example, a student who has correctly read 5 words on a page of 30 words during their first independent reading, then practices reading the page for 1 minute, and then reads 10 words correctly during the second reading, should be reinforced for reading twice as many words the second time. Thus, we will investigate feedback strategies that motivate and reinforce struggling readers in making improvements, rather than discouraging them by providing feedback based on absolute benchmarks that such students may or may not ever achieve. We also plan to investigate effective ways to provide feedback to students when they practice reading the test, i.e., before reading it independently, such as highlighting sentences in green that they read accurately and fluently, and highlighting them in yellow if they should practice the sentence again.

We expect that adapting scaffolding and feedback to students' abilities, and reinforcing performance contingent on individuals' improvements will increase their motivation and self-efficacy. Self-efficacy is an individual's perception of their ability to perform and complete a task. Individuals with high self-efficacy are more motivated to attempt new tasks and persevere when doing them, relative to students with low self-efficacy [48-52]. According to Bandura [49], "The most effective way of creating a strong sense of efficacy is through mastery experiences" (pg. 2). Additionally, research has shown that engaging students in interesting and challenging tasks that enable them to achieve learning goals improves their self-efficacy and intrinsic motivation [53, 54].

Preliminary findings suggest that self-efficacy is a significant predictor of English learners' (ELs) academic performance [55]. It is plausible that ELs have lower self-efficacy because their past experiences have not been successful due to language constraints and cultural influences. Our view is that, while science may be an ideal environment for learning new vocabulary, concepts, and new ways of thinking and talking about the world, it is critically important to understand the specific challenges of ELs and other at-risk students, and to conduct research that will optimize communication, engagement, and motivation, leading to increased self-efficacy and learning. A focus of our research, to be conducted by Dr. Doris Baker at SMU, is to increase ELs self-efficacy and learning by analyzing and improving communication between English learners and Marni. Dr. Baker will observe and interact with children using the MSBs to identify prompts they have difficulty understanding, and work with the research team to improve these prompts.

Aim 3: Conduct a Pilot study to assess the feasibility and promise of the technical innovations. During the final eight weeks of the project, we will conduct a pilot study in eight second grade classrooms, four each in Boulder Valley and Adams 12 school districts. Classrooms will be selected in low performing schools with a high percentage of English learners, based on publicly available demographics information and scores on Colorado state math, reading, and science tests. All consented students will be invited to participate in the study, and will receive proper information prior to consent consistent with all IRB regulations. We emphasize that *we received IRB approval from the University of Colorado IRB board to conduct an initial pilot study with the MSBs*, which was conducted during the spring of 2013. In this study, students interacted with Marni during listening comprehension activities. The IRB approval will be renewed for the proposed SBIR pilot study.

Students in each classroom will receive classroom instruction in life science content using the Full Option Science System (FOSS) life science module. FOSS is a kit-based program used by over 2 million children in over 100,000 classrooms in the U.S. The FOSS life science module is aligned to the Next Generation Science Standards and Colorado state science standards. Classroom instruction centers on 16 "hands-on" science investigations which children conduct in small groups over an 8 week period. Sixteen MSBs will be provided to students; each MSB will be aligned to the vocabulary and concepts encountered in these science investigations. FOSS provides standardized computer-administered tests that are administered before and after students complete a science module, so teachers can measure students' learning.

We will ask teachers to have their students complete two MSBs per week until they have completed the 16 MSBs. The expected time on task for each MSB is expected to vary from 20 to 40 minutes; MSBs are designed to empower students to control the pace of each activity, so we expect significant variation in time on task for different students. Students will wear headphones with a noise-cancelling microphone. The MSB processes students' speech when they click on the record button on the screen. Students' head and eye movements will be processed from video collected webcams on the PCs. We will provide 6 laptops to each classroom, with the MSBs loaded on each computer.

The purpose of the pilot study is to assess the feasibility of integrating MSBs into regular, FOSS-based classroom instruction, and to assess the impact of the MSBs on students' attitudes, beliefs, and learning. The *feasibility* of the program (the sequence of MSBs) will be measured by the quality of teachers' and students' experiences with the books. Do teachers' find the program easy to integrate into classroom instruction, and believe it benefits their students? Would they like to adopt the program for future use? Would they recommend it to other teachers? We will measure this through classroom observations and semi-structured interviews with teachers and students. The *effectiveness* of the program will be measured by changes in students' attitudes and beliefs (e.g., motivation, excitement, and self-efficacy, students' estimates of their ability to undertake and complete tasks), and improved science understanding and oral reading fluency. Gains in science learning attributed to the MSBs will be assessed by comparing learning gains of students who use the MSBs during classroom science or literacy instruction to students in matched classrooms that do not use the MSBs. Performance of these two groups of students will be compared using the identical FOSS pretests and posttests. These assessments have strong arguments for validity and reliability. .

Hypothesized benefits of MSBs on oral reading fluency will be measured using DIBELS, a standardized test of oral reading fluency that measures the number of words that students read in one minute on grade-level tests. In addition, we will analyze students' session logs to measure expected improvements in oral reading fluency both within and across MSBs. We hypothesize that students will demonstrate improvements in oral reading fluency, as measured by their initial independent reading of successive books in the sequence. .

Qualitative Measures: Consistent with our prior research using the My Science Tutor system, we expect most students will report they were highly engaged in learning activities while using the MSBs and that they will feel that Marni was an effective teacher that helped them learn science, learn to reading, and that they have become more motivated to study science after working with Marni [56, 57]. We will revise student and teacher questionnaires used in our previous studies to assess teachers and students experiences, beliefs, and attitudes related to MSBS. We will also extend the questionnaires to gain insights into how students' perceived Marni's visually aware and expressive behaviors. We will design questions to help us understand whether students' believed that Marni was visually aware of them and responsive to their learning challenges and achievements.

Self-Efficacy Survey Items: We will use survey items that ask students about their self-efficacy in science. We will provide this self-efficacy survey before and after the treatment for students in the treatment and control classrooms. To construct our survey, we will adjust the existing self-efficacy scales provided by Andrew [58] and [55]. We will use factor analytic techniques to generate a composite score for analysis. *Science Motivation Questionnaire II (SMQ-II)* [59, 60]: The SMQ-II survey evaluates student attitudes toward learning science. It uses 25 Likert-type items and draws on classical test theory for validity and reliability arguments for 5 subscales: intrinsic motivation, self-determination, self-

efficacy, career motivation, and grade motivation. We will use it to gauge motivations to learn and attitudes toward future learning of science. It will be given as a pre and post-test for the treatment and control groups.

Part4: Commercial Potential

Market Opportunity

We believe there is a large global market for MindStars Books, and that the MSBs we envision (resulting from Phase II development efforts) will be unique and in great demand. The overarching reason is that, pending successful outcomes of our work, MSBs will offer an accessible, inexpensive and highly effective means for improving students' motivation, learning and achievement in both science and reading. As discussed below, MSBs are unique; no educational software on the market today combines science and reading instruction with character animation and human language technologies into a single program. In addition, MSBs are designed to provide a complete solution to science and reading instruction for elementary students, as a sequence of MSBs will be designed to cover science and reading goals aligned to national and state science and reading standards. Our discussions during the past two years with science and literacy curriculum directors in three Colorado school districts (Boulder Valley, Adams 12 and Thompson) highlighted the importance they all assign to combining science and literacy in a single program; the reality is that science instruction often receives short shrift in elementary schools because teachers must focus on (and are accountable for) students' reading and math achievement. For these reasons, we believe that, if our research produces strong evidence that MSBs engage and motivate students and improve their science achievement and reading proficiency, they will be in demand in schools throughout the U.S. For this reason, our initial focus is developing MSBs that can be integrated into elementary school classrooms in U.S. schools. We believe it is premature to contact publishers who might want to license MSBs and market them to schools, since the books are not yet a commercial product. However, we have an existing relationship with School Specialty Science, the company that publishes FOSS, and they have expressed interest in marketing the books (please see letter of support).

We also believe, and have initial evidence, that MindStars Books can be marketed globally. There is a tremendous demand for educational technology worldwide, as it offers the promise of accessible, low cost and effective learning tools. Marni currently speaks in English, Finnish, Polish, Italian, Spanish and Chinese, and new languages can be added relatively quickly. Our collaborators at the University of Jyvaskyla have embraced MSBs; they see great potential in using the books in Finland for teaching science in Finnish, and teaching reading in both Finnish and English. During the past year, we have had discussions with David Wisner, President and founder of Aston Education Group in China. David is very interested in integrating the books into the Aston Interactive English program in over 60 schools throughout China that teach English to Chinese children and adolescents, as well as marketing the MSBs to public schools throughout China.

The Company/Team

Boulder Language Technologies was founded by Ron Cole and Wayne Ward in 2007. In 1998, Ron and Wayne established the Center for Spoken Language Research (CSLR) at University of Colorado, where they worked as research professors. CSLR received over $20 million in research grants from NSF, NIH, DARPA and other sources. In February, 2007, Ron and Wayne left CU to work at BLT, although Wayne has maintained a research professorship at CU, and is involved in projects there with the computational semantics group. To date, BLT has been run as a research lab. Our mission has been to develop the technologies needed to create a new generation of intelligent tutoring systems that immerse students in multimedia environments in which learn science during spoken dialogs with empathic and effective virtual tutors. Our goal is to demonstrate the effectiveness of these systems, and to create and own the component technologies, so we can a) distribute the technologies and systems to the research community in order to accelerate research and development of next generation of intelligent tutoring systems, and b) be able to market these systems to educational institutions and the general public when they have proven to be stable, robust and effective. In its short history, the company has made excellent progress towards

these goals. BLT has received approximately $12 million in research grants from NSF, IES and NIH, and a $2 million contract from School Specialty Science to develop interactive tutorials to supplement the FOSS program. We have distributed our systems to researchers at universities in the U.S. (e.g., DU, SMU, and University of Portland) and to university researchers in Poland, Finland and Italy. The open source Bavieca speech recognizer has been put into the public domain (http://sourceforge.net/projects/bavieca/). The current SBIR proposal represents BLT's first attempt to move towards commercializing a product.

The research team has the expertise to develop the MSB innovation and market it to publishers, as discussed in the financial plan below. Wayne and Ron have over 20 years' experience managing medium to large scale research projects funded by NSF, NIH, IES and DARPA. Each of these projects has met or exceeded research goals and deliverables. The MSB system consists solely of technology components developed at BLT; the Bavieca speech recognizer, the Phoenix dialog manager, and the new BLT Avatar system. The MSBs are fully functional and have been tested in the laboratory. The listening comprehension component of the MSBs has been tested with children with good results. The oral reading fluency component has yet to be tested and refined with children; testing and refining ORF training through iterative design-test-refine cycles is one of the main goals of the SBIR project described in the Research Plan.

Product or Technology and Competition

We believe that BLT has a strong competitive advantage relative to other educational software. We conducted an extensive review of existing educational technology products marketed to schools or individuals as apps. We found no products that combine science and reading using speech recognition technologies. We found no science products that engage children in multimedia presentations and question-answer dialogs with a virtual tutor. Finally, we found no products that approach the range of technical capabilities used in MSBs to train oral reading fluency. For example, Read Naturally Live [61] has a successful product marketed to schools in which students read stories aloud. After each reading, a teacher must then provide each student with feedback on their oral reading fluency. Reading Champion is an excellent IPad app that enables children to listen to any story read aloud using text-to-speech synthesis as words are highlighted. The student can then record the story, and listen to their story as they read the text, and touch words they misread, after which they receive a score. However, the app does not highlight the reader's words on the page when the recording is played back, and the system does not automatically score and highlight words the student should practice.

In sum, we are confident that no products exist today that can compete with the proposed MSBs. Moreover, we believe it is unlikely that competing products with the functionalities of the proposed MSBs will be introduced into the educational software market in the near future. We make this claim because of the expertise, effort and expense required to support a) conversational interaction with a virtual tutor that can look at, talk to, and listen to the user, and b) provide immediate feedback to the user on how accurately, fluently and expressively a child has read a text passage. BLT has developed and validated the effectiveness of these technologies, and published results in major journals during the past two years that report the highest accuracies achieved to date for recognizing how accurately, fluently and expressively children read grade level texts [40, 41, 62].

Financing and Revenue Model

We have a simple model for generating revenue. We plan to work with publishers that have sales and marketing teams already in place. BLT will provide a number of options:

1) BLT will produce interactive books and license them to publishers for a royalty fee
2) BLT will contract with publishers to put the publishers' content into interactive books, or to develop new content to publisher's specifications. Our extended team, including our collaborator Doris Baker at SMU, has substantial experience creating science and reading content that incorporates media and conversational interactions with virtual tutors

3) BLT will license the MSB platform and authoring tools to publishers who can create or adapt their own content.

We have discussed this model with David Wisner at AEG and Mathew Bacon at School Specialty Inc., and both believe it is a viable model.

Part 5: Consultants

Dr. Mohammad Mahoor at University of Denver and Dr. Doris Baker at SMU will serve as consultants on the project. Dr. Mahoor and Dr. Baker have collaborated with Drs. Cole and Wayne on previous NSF-funded research projects. Their expertise is critical to the project.

Dr. Mahoor is an expert in computer vision and robotics. His research focuses on automatic recognition of individuals' facial expressions and synthesis of facial expressions on 3-D computer characters and robotic heads. This past summer Dr. Mahoor and a team of three students collaborated with Mr. Eric Borts, developer of the BLT avatar system and MSB Toolkit, to synthesize natural and realistic facial expressions while Marni speaks. In the SBIR project, he will collaborate with Dr. Cole and Mr. Borts to integrate an open source head and eye tracking algorithm into the MSB system. When this task is completed, our research will focus on using information about users' head pose and gaze to control Marni's head movements and gaze while talking to, listening to, or observing users as they consider answers to questions or practice reading texts. Dr. Mahoor has agreed to consult for a total of 24 days (average of 4 days per month) at the rate of $600 per day. Dr. Doris Baker conducts research on English learners' development of language and reading skills in different instructional contexts. Dr. Baker collaborated with Dr. Cole and his colleagues at BLT during development of the initial set of MSBs. Dr. Baker will work with English learners in Dallas to revise and refine Marni's English and Spanish language prompts (e.g., explanations, questions, feedback) to optimize children's understanding of Marni's speech. Dr. Baker has agreed to consult for 12 days during the first three to four months of the project at the rate of $600 per day.

Part 6: Equivalent or Overlapping Proposals or Awards to/from Other Federal Agencies

BLT has submitted an NSF EAGER grant for $300,000 for 18 months to enhance and test the MindStars Books Toolkit. It is currently under review by Dr. Julio Lopez-Ferraro in the NSF EHR division. The EAGER project, if funded, will focus on completing the goals of the SAVI project, which was envisioned and planned as a two-year project with those in Jyvaskyla, Finland. It has 3 tentative goals:

1. Support development of Finnish MSBs, including collection of a speech corpus of Finnish children, so that Finnish MSBs can support oral reading fluency training with Finnish children.
2. Document and distribute an open source version of the MBS toolkit to the research community for research use, with the goal of accelerating research and development of intelligent tutoring systems for children.
3. Conduct a summative evaluation of the MSBs to determine their feasibility and promise. If funded, the evaluation will be conducted in second grade classrooms in Dallas TX by Dr. Doris Baker, who is a consultant on the SBIR project.

We note that goal 3 of the EAGER overlaps specific aim 3 of the proposed SBIR Phase 1 project. Since we do not know if the EAGER project will be funded, and since is critical to provide scientific evidence of the feasibility and effectiveness of the MSBs innovation to demonstrate their commercial potential, we have included summative evaluation of the MSBs in this SBIR proposal.

If the EAGER grant is awarded, we will conduct the evaluation study in Dallas, with the MSBs incorporating the proposed technical innovations supported by the SBIR project—i.e., providing the virtual tutor with computer vision and expressive behaviors during interaction with children, and improving oral reading fluency training. The effort currently allocated to the summative evaluation in the SBIR project will be devoted to additional iterative design-test-refine cycles for specific aims 1 and 2 in the proposal; these aims seek to understand how to optimize children's engagement and learning with a visually perceptive and expressive virtual tutor, especially during oral reading fluency training.

Part 7. Lineage of the Innovation.

NSF Challenge Grant: CDA-9726363, Challenges in CISE: Creating Conversational Agents for Language Training: Technologies for the Next Generation of Interactive Systems, (1997-2000; $1,800,000) PIs Ron Cole & Mike Macon, Oregon Graduate Institute & CU Boulder). This project led to development of a Vocabulary Wizard that was used to develop applications in which K-5 students at an oral deaf school learned vocabulary related to classroom subjects during interactions with a 3-D computer character. *Intellectual Merit:* Children learned to recognize and use new vocabulary during classroom discussions, and their speech intelligibility improved significantly [63, 64]. The research project was featured at a special session of the International Conference of Phonetic Sciences [65-67]. *Broader Impact:* The project was featured on ABC TV's Primetime and the NSF home page. The CSLU Toolkit's Vocabulary Wizard has been widely used by the research community (e.g., [68]).

NSF CISE CARE Grant: EIA-9870916, Accessible Language Resources for Research and Education. (1998-2002, $1,200,000; PI: Ron Cole, CU Boulder). This grant supported development of the CSLU Toolkit, a free software platform designed to support research and development of intelligent tutoring systems in which users interact with lifelike conversational agents. *Intellectual Merit and Broader Impact:* The CSLU Toolkit has been installed in over 30,000 sites in over 110 countries, servving as a platform for research and education worldwide. For example, *Wired for Speech: How Voice Activates and Advances the Human-Computer Relationship*, by Cliff Nass and Scott Brave[69] describes over a dozen experiments using the CSLU Toolkit. In his review of the book, Eden [70] wrote: "Voice-interface technology had numerous problems before 2000, when the open source CSLU Toolkit appeared on the scene".

NSF ITR Grant: 0086107, Creating the Next Generation of Intelligent Animated Conversational Agents, (2000-2005, $1,800,000; PIs: Ron Cole & Wayne Ward, BLT): We developed a system for automatically generating and modifying verbal and visual behaviors of lifelike computer characters that could be integrated into learning applications. *Intellectual Merit:* A major outcome was the CU Animate system [71-73] which produced 5 ethnically diverse 3D models that produce accurate visual speech, emotions, and graceful head and face movements synchronized with either recorded utterances or synthetic speech. *Broader Impact:* The CU Animate system has been used in reading tutors and science tutors for children [57, 74, 75] and speech and language therapy systems for adults with Parkinson disease or aphasia [56, 76-78].

NSF Grant DRK-12: DRL-0733323, Collaborative Research: Improving Science Learning in Inquiry-based Programs, (2007-2013; $2,100,000, PIs: Wayne Ward & Ron Cole, BLT): My Science Tutor (MyST) is an intelligent tutoring system designed to improve third, fourth, and fifth grade students' science learning by providing individualized instruction similar to that of expert human tutors. *Intellectual merit*: MyST is the first intelligent tutoring system to support natural spoken dialogs with children. A summative evaluation revealed moderate to large learning gains for students who used MyST ($d = 0.53$), and students who received human tutoring ($d = 0.68$), relative to students who did not receive tutoring. *Broader impacts*: The positive learning gain results suggest that this type of virtual tutor can provide an effective and low-cost intervention for young students struggling in science. Results of the MyST project led to grant from the Institute of Education Sciences to replicate and demonstrate efficacy of MyST for a broad population of students [56, 57].

NSF PRIME: DRL-1228996, Understanding the Transformative Potential of Spoken Assessments of Science, (9/2012 – 08/2014); $249,568; PI: Wayne Ward & Ron Cole, BLT): The goal of this project is to evaluate the use of computer-based conversational agents for assessing science knowledge for elementary school students. *Intellectual merit*: The project attempts to separate the confound between students' reading ability and their knowledge of science topics as expressed on written assessments. *Broader impacts*: Success in this project can lead to more accurate assessments of students' science knowledge, especially for poor readers.

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