NSF Project Report:

Teachers' and Children's Experiences with MindStars Books

This report summarizes the NSF SBIR Phase 1 research and development effort that led to an integrated first and second life grade science curriculum designed to supplement classrooms science instruction using an intelligent tutoring system called MindStars Books. The R&D effort produced successful outcomes based on students' opinions about the program, teachers' impressions of their students' excitement and learning, and student performance within the MindStars Books.

The main work products resulting from the Phase 1 R&D effort included:

1. Development of the MindStars Books authoring tool (the MSB Editor), a stable, flexible and easy-to-use authoring environment that was used to design, test, and publish 14 MindStars Books for use in schools, and the associated MindStars Books Reader that provided students access to the library of MindStars books students used in two schools during the pilot study.

2. Evaluating the feasibility and promise of the MindStars books for deployment in real world educational contexts to improve science learning and reading, based on first and second grade children's experiences and performance during and following use of the books.

The remainder of this section describes the R&D effort and outcomes associated with these three work products.

1. Developing and Testing the MindStars Authoring Tool (MSB Editor) and Published Interactive Books (MSB Reader)

This section describes the MindStars Books Editor, the authoring tool that was used to create, test and refine the 16 MSBs developed over the course of the Phase I project. Significant effort was devoted to developing an intuitive, flexible and powerful tool that could be used by

individuals with no programming experience for creating, testing and publishing MSBs. Creation of a book within the MSB Editor resulted in a published book that supported all the interactive science learning and reading activities, which included automatic feedback to students on their oral reading fluency. The MSB Editor was developed, through iterative design and testing, to enable an author, working from a completed script, to develop and publish an MSB in a one to two days. This goal was met consistently during development of first versions of MSBs within the project.

We note that several weeks of research were required to plan and create each MindStars Book. Scripts were created and aligned to the US Next Generation Science Standards for first and second grades. Media (pictures) were located for each book, with objects highlighted within the pictures. Spoken multiple choice questions were designed with spoken answer choices and/or pictures, with feedback provided following correct answers, and hints following incorrect answers. Reading passages were designed that incorporated the vocabulary, concepts and pictures taught in the book. Once a book was authored and published, it was tested and refined over the course of several design cycles, first by members of the project team, and finally during pilot testing in classrooms. Throughout this iterative design-test-refine process, the MSB Editor was used to implement changes in each book, based on observations of students using the books, and subsequent analysis of student behaviors within each book. For example, analysis of student responses to multiple choice questions was used to refine the questions and answer choices, and in some cases, improve the multimedia presentation that preceded a subsequent multiple-choice question.

Each MSB consisted of three independent activities:

1. narrated multimedia science explanations,
2. multiple choice questions for assessing students' knowledge and providing them with immediate feedback on their answer choices, with the goal of helping students master vocabulary and concepts, and
3. reading practice, which used automatic recognition of children's speech while reading aloud to provide them with feedback on their reading.

The MSB Editor was used to create each of these activities. Compiling the completed MindStars Book produced a published book that supported all of the interactions between students within a MindStars Book, described below.

1.1 Narrated Multimedia Science Presentations

Research reviewed in the SBIR Phase 1 proposal indicates that narrated multimedia presentations of science produce optimal learning, as measured by both short-term retention of information and by transfer of learning to new tasks. During narrated science explanations, each "page" of a book is presented to a student as a sequence of pictures. The student looks at each picture (or a collage of pictures) while the voice of the intelligent agent presents information related to the picture. Figure 1a shows a single page of an MSB in the Editor. Figure 1b shows the first two screens presented to the student, corresponding to the first two lines of the page in the Editor.

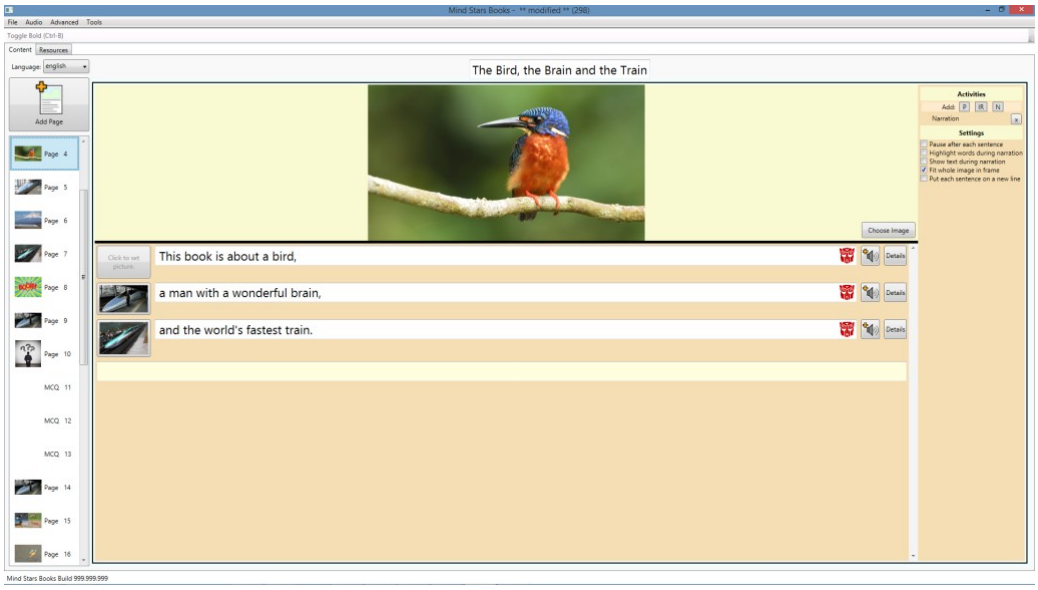


Figure 1a. *Screen shot in MSB Editor of the first page of "The Bird, The Brain and The Train." The Picture at the top of the page is associated with the first sentence. The pictures associated with the second and third sentence are shown before these sentences.*

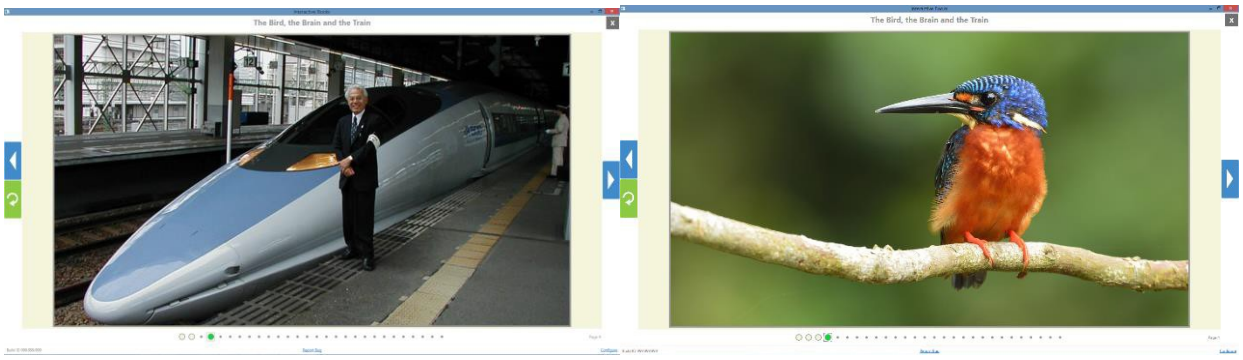


Figure 1b. *Screen shots of first two pages for students. Students see pictures while the virtual agent narrates the sentences shown in the MSB Editor shown in Figure 1a. A female voice talent narrated each of the stories.*

We emphasize that *words were not displayed on screen during narrated multimedia presentations*, as the goal is to have students listen to the agent's voice while looking at the pictures, enabling them to construct rich multimodal mental representations of the science. Research has shown that putting words on the screen during a narrated multimedia presentation impedes learning (relative to not having words on the screen), as students will switch attention between the printed words and the pictures, resulting in poorer recall of the presented information.

Within the Editor, the author can "play" the book at any time to review the narrated science explanation. After typing the sentences on a page of an MSB in the Editor and importing the pictures into the page (which are downloaded from Shutterstock), the author can save the page,

and then immediately listen to the narration with the pictures displayed. The narration is initially produced using synthetic speech. Once the author is satisfied with the narration, he or she can then record the narration using the recording tool within the Editor.

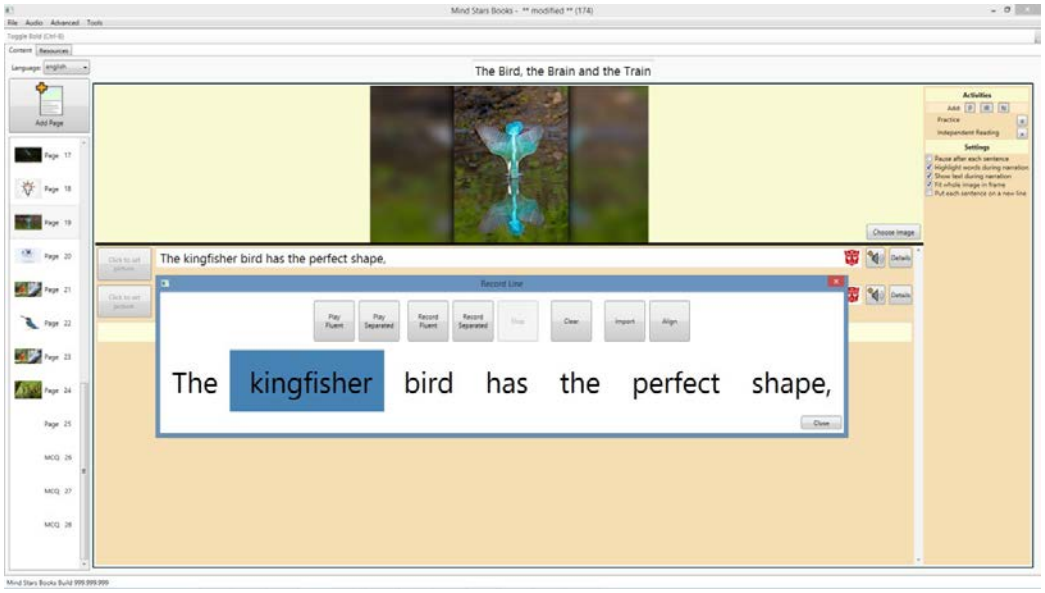


Figure 2. *Recording function within MSB editor. The author has recorded the sentence that will be spoken to the student while looking at a picture on a page and is watching the words highlight during playback of the recording to assure accurate synchronization of her speech to each highlighted word.*

As discussed in the SBIR Phase 1 proposal, the design of narrated multimedia science explanations was informed by a set of established principles based on research in the area of multimedia learning. Basic principles used in the books included: a) parsing each 10 to 15 minute books into a sequence of short narrated science explanations, so students could learn and master sub-concepts that build on each other, b) making all activities self-paced, so students are in complete control of the book, and c) ensuring that during a narrated science explanation, the student can repeat the utterances just produced by the agent, or proceed to the next screen.

1.2 Multiple Choice Questions with Immediate Formative Feedback

Multiple choice questions (MCQs) were presented at logical stopping points within the book to assess students' understanding of science presented in the preceding several pages, and to provide students with feedback on their answer choices. Each multiple-choice question concluded with an expansion of the correct answer choice, with the goal of helping students master concepts and build on them during the remainder of the book. Questions were always spoken to the student. If the question was: "Which picture shows a living thing?" the question, printed at the top of the screen, was always read aloud to the student. Students could listen to the spoken question as often

as desired by clicking on it. Each spoken question was followed by four answer choices. If the answer choices consisted of pictures, the student clicked two times to select the picture. The first click highlighted the picture. A second click on the highlighted picture selected it as the answer choice. When answer choices were printed, students could listen to each answer choice by clicking on it. The answer choice was then highlighted. If the student clicked on the highlighted text, it was selected as the answer choice. Thus, for printed answers, all students had to listen to the printed answer spoken aloud before they could select it. Students who were proficient readers could read the answer choices, then select one and click on it twice. Students who could not read well could click on answer choices they could not read to hear them spoken aloud. The interface was efficient, and all students were able to use it.

A key feature of multiple-choice questions is that they were designed to help students master the vocabulary and concepts in the narrated multimedia presentations. If the student selected a correct answer on their first choice, the agent provided verbal reinforcement (e.g., "Good thinking") and briefly expanded on the correct answer. If the student selected an incorrect answer on their first choice, they were given a hint, and a second try. If they selected an incorrect answer on their second choice, the agent said: "The question was (and repeated the question)"; followed by: "The correct answer is (and provided the correct answer and its expansion). As discussed below, the use of hints was highly effective, student averaged ~75% correct first choices; after receiving a hint, correct first plus second choices rose to 98%.

The MindStars Books Editor enabled us to author MCQs designed to a) assess students' understanding of the science vocabulary and concepts presented in the MCQs, b) stimulate reasoning about the science by enabling them to read or listen to responses before choosing one, c) provide a hint following an incorrect first choice, to stimulate reasoning and scaffold learning, and d) provide <u>all</u> students with the correct answer and its expansion before completing the MCQ activity. The results of the pilot studies indicated that together, narrated multimedia science presentations and multiple-choice questions with feedback facilitated deep learning of science vocabulary and concepts.

Figure 3 displays the Editor interface for developing multiple choice questions. It shows slots for typing or importing questions, pictures, answer choices, and feedback on answer choices. The Editor uses the recording tool for recording each question and spoken answer choices.

1.3 Reading Practice

The goal of reading practice in MSBs was to improve students' confidence in their ability to read text passages about science, by enabling them to practice reading them fluently, with both support and feedback on their oral reading fluency. Creating a reading passage in the MSB Editor consists of the author a) typing the text passage into the Editor, b) recorded each sentence in the text, c)

recording each word in the sentence individually, and d) optionally importing a picture associated with each sentence. When the author "builds" or publishes the book, the typed and recorded text is automatically transformed into the complete set of oral reading fluency activities students can do within the MindStars Book.

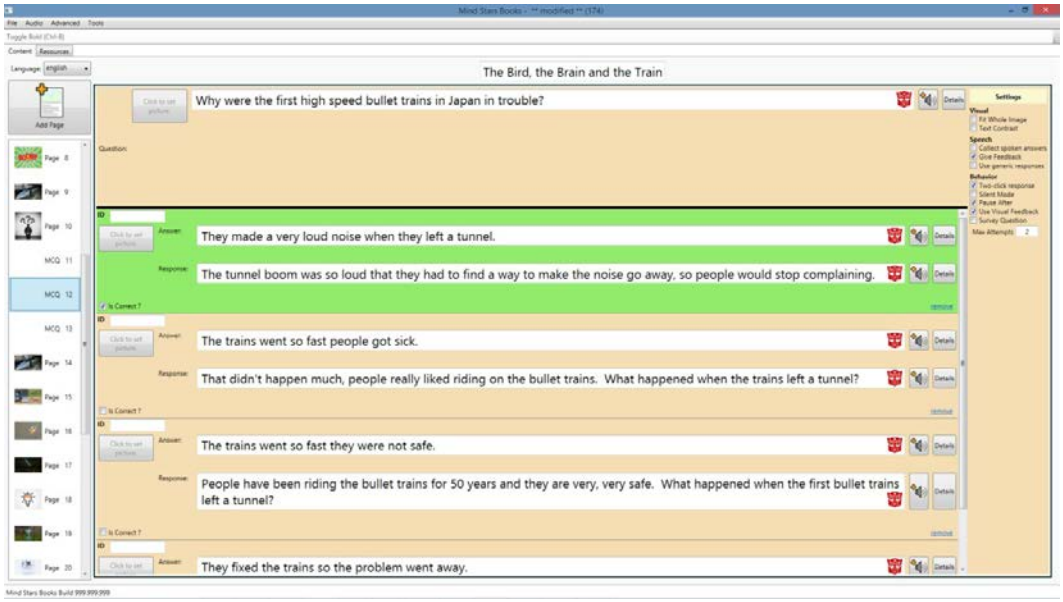


Figure 3a. *Editor for Multiple Choice Questions in the MSB Editor. The top of the page shows the question; the first line is the answer choice and feedback. The pairs of sentences, more broadly, show answer choices to the MCQ's followed by feedback after selection of the answer.*

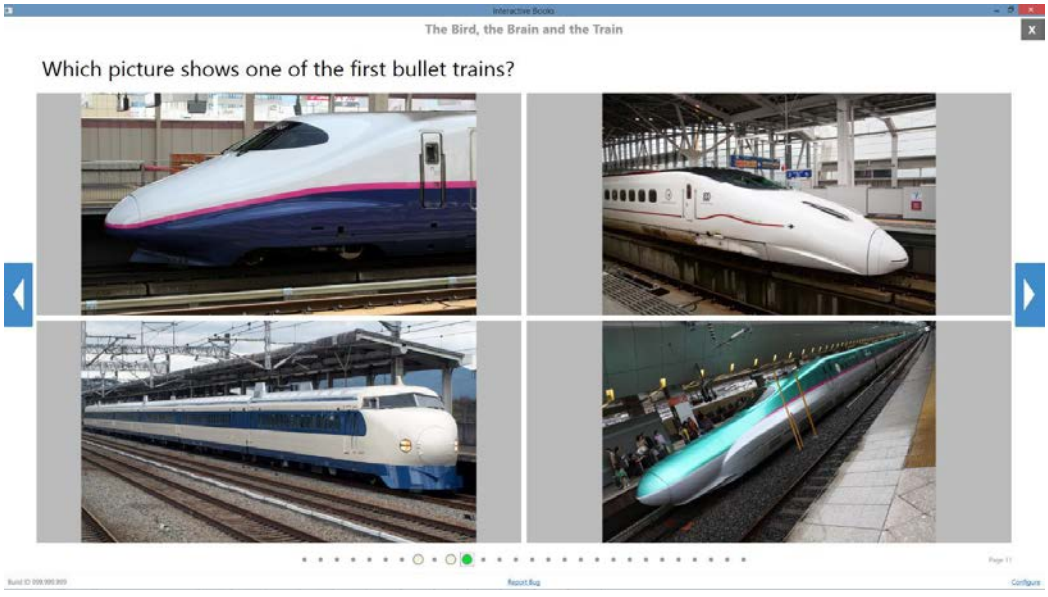


Figure 3b. *Screenshot of multiple-choice question followed by four pictures. The train with the flat nose cone is the correct answer. Answer choices are randomly placed on the screen each time a question is presented.*

These activities include: a) listening to the entire passage read aloud by the agent, while each word on the screen is highlighted as it is spoken and b) clicking on the arrow before a sentence to activate it, allowing the student to listen to and practice reading the sentence in various ways. When a sentence is activated, the picture associated with the sentence is displayed on the screen. The student can do any of the following activities: i) click on the arrow again to listen to the entire sentence read by the agent, with each word highlighted, ii) click on individual words in the sentence to hear them pronounced, and iii) record the sentence by holding down the space bar and reading the sentence aloud. When the student releases the space bar, the student listens to the sentence they just recorded played back to them while watching the printed words on-screen highlight when they were spoken. This last activity, recording and receiving feedback on their reading practice, delighted students. Survey responses indicated that both students and teachers believed that reading practice improved students' reading skills.

All students engaged in this activity (which was optional, as students had complete control of the functions on the reading practice page), and quickly became adept at self-assessing their oral reading performance. For example, if they skipped a word while reading the sentence, they heard silence when the word was highlighted. If they misread a word, they could hear that they misread it. They would often click on the misread word to listen to it, and then rerecord the sentence. Figure 4a displays a reading practice page in the MSB Editor. Figure 4b shows how the reading practice in the published MSB was used by a student who is watching words highlight while listening to a sentence they recorded.

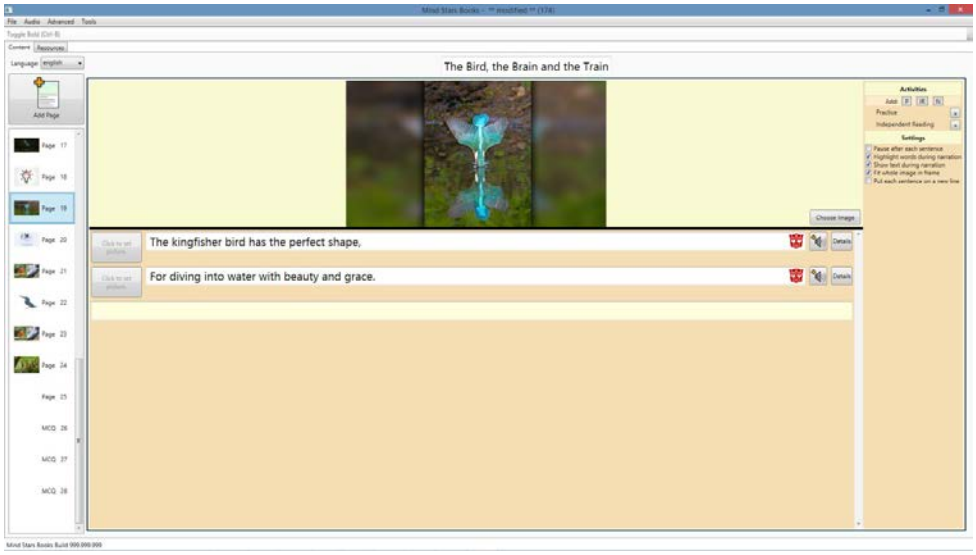


Figure 4a. *Screenshot of oral reading fluency passage in the MSB Editor. In this example, the same picture, shown at the top of the page, is presented along with the text that the student practices in the published book.*

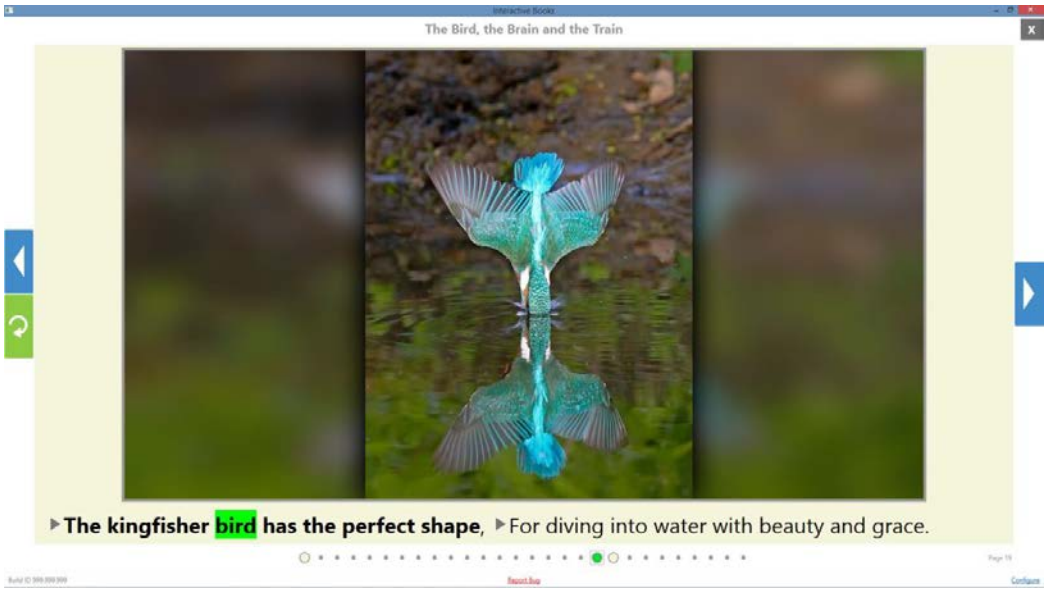


Figure 4b. *Screenshots of oral reading practice page in the MindStars Book. The bold sentence is active (has been activated by the student). The student has just recorded the sentence and is listening to playback of 'bird' as the word is highlighted on the screen.*

2. Developing and Publishing MindStars Books

2.1 Developing MSB Scripts

During the first four months of the project, the MSB Editor was completely redesigned to provide a more flexible and scalable authoring environment. During this period, we developed detailed scripts for an initial 12 books that were tested in the first pilot study in February and March, 2016. Because development of the MSB Editor took longer than expected (5 months, rather than 2 months), a no-cost extension to the SBIR grant was requested and approved by Dr. Glenn Larsen, the Program Officer of our project. While waiting for the MSB Editor and Reader to be released, the PI and his team created detailed multimedia scripts, with each page of a to-be-developed MSB described in a word file, including a) the sentences to be narrated, pictures or descriptions of the pictures to be associated with the sentence, b) multiple choice questions, including the questions, answer choices, and feedback to each answer choice, and c) the short text passages (which always rhymed) for oral reading fluency practice.

2.2 Developing an Initial Set of 12 MSBs in the MSB Editor

During January and February 2015 the MSB Editor and Reader were released, and the new Editor was used to develop, test, and refine a set of 12 books. This process resulted in numerous change requests to the software developer to fix or change the MSB Editor to eliminate problems, improve

the interface, or change the interactions with students in the published books. These problems were addressed over a period of about six weeks, until the initial set of books appeared to be stable based on testing in the laboratory.

2.3 First Pilot Study: February & March 2015

We then recruited kindergarten, first and second grade students from a low-performing elementary school that agreed to participate in our study. We first met with the principal of the school, and then with the teachers to review the books and answer their questions. Three teachers agreed to participate, one from kindergarten, 1 from first grade, and 1 from second grade. We distributed consent forms to the parents of their students and received informed assent from about 30 students whose parents had signed the consent forms.

The study was conducted in a large room, the school's science lab. Because the room was spacious, students were able to sit at separate tables, with plenty of space between the tables, and lots of room between the students. Our project provided laptops running Windows, and headsets with noise-cancelling microphones that each used during reading practice to record their speech. Two or 3 project staff were present each day of the study, with students using 3 to 4 books each week. Over the course of the 6-week study, at least 12 different problems were detected while students used the books. Students were instructed to raise their hands whenever they detected a problem, or they got "stuck" on a page. Project staff immediately filed a bug report on their computer (which saved all relevant information into a log file), and project staff were typically able to advance the book manually to a previous page (to see if the problem was replicable when they reached the page where the problem occurred), or to skip to the next page when necessary. On a few occasions, the computer had to be rebooted, or replaced with a spare. At the end of each week, all of the computers were returned to our laboratory to analyze and address problems reported, and to load a new set of books for the next week.

By the end of the first pilot study, few problems occurred. Throughout the study, students were incredibly patient and highly engaged. This was likely because we were careful to explain to students at the onset of the study that they were participating in a research study, and they could help us by reporting any problems as soon they appeared.

We note that teachers in the first pilot study did not observe their students using the MSBs. We brought their students to the science lab where the study was conducted, while the teachers stayed in their classrooms with the students who did not receive parental consent.

2.4 Second Pilot Study: April & May 2015

Each of the 12 books used in the first pilot study was reviewed and revised. Revisions were informed, in part, on observations of project staff while children used each of the books during the

first pilot study. In addition, four new books were developed, to provide comprehensive coverage of the main science concepts taught in first and second grade life science in Colorado schools.

The second pilot study was conducted in a high performing school. The students were recruited from 4 second grade classrooms, and 1 first grade classroom. The study was conducted in the second grade "Tech Pod," a central area surrounded by the 4 second grade classrooms. Thus, the 4 second grade teachers could view their students using the computers, and occasionally watched students interacting with the MSBs when they walked in and out of their classrooms.

The Tech Pod provided a legitimate "stress test" of the MSBs in a real-world educational environment. Space in the Tech Pod was limited, and students were required to sit around two tables. Eight students sat around each table, 2 per side, with just enough room to sit in front of their computer and use a mouse and mouse pad. Often, 3 or 4 students at the same table would be practicing reading (out loud) at the same time. Nevertheless, it was clear that students were focused on their MSB activities and did not appear to be distracted or even aware of what their neighbors. A notable exception was two children who always sat side by side, made sure they were on the same page, and occasionally discussed what they were learning. We decided to allow them to work this way, as they clearly enjoyed their collaboration.

Students and teachers in the second pilot study were given the identical surveys as students and teachers in the first pilot study. Figures 7 and 8, respectively (See Appendix), display students' and teachers' experiences with and opinions about the program. It can be seen that, in general, students had strong positive opinions about the MindStars Books. Most believed the program was great fun, that they learned many new and interesting things about science, and that they were more excited about studying science after using them. Teachers also had strong positive opinions about the value of the books. All teachers said they would like to use them in the future, and that they would recommend them to other students. The teachers made it clear that they would like us to return in the fall so their students could use the MSBs.

Students in the second pilot study attended a high performing school, had infrequent problems with the books, and were packed into a relatively small area with many possible distractions. Despite these differences, students' impressions of the program were quite similar, as shown in the figures in the Appendix. In general, students in the lower performing school reported greater science learning and reading improvement; we attribute this to the possibility that these students had lower initial science knowledge and reading proficiency and were therefore pleased and motivated to receive individualized instruction in the books. We will test this hypothesis in future work.

2.5 Science Learning in MSBs

We analyzed students' responses to the 3012 multiple choice questions (MCQs) they responded to in the MSBs to gain insights into their understanding of facts, vocabulary and concepts presented in the narrated multimedia science explanations. These analyses revealed that, across all books, students in the second pilot study answered over 78% of all MCQs correctly on their first choice, with an additional 16% answered correctly on their second choice (after listening to a hint). Thus, students answered 94% of questions correctly on their first or second choice, with 6% of all questions answered incorrectly after two choices. These results suggest that students understood vocabulary and concepts presented in the narrated presentations, and that the hints following incorrect first choices were helpful to students.

We conclude that, since the content of the MSBs were aligned to Colorado and Next Generation Science Standards, that MSBs show strong potential for helping students learn vocabulary and concepts related to classroom instruction and both state and national standards. Students' ability to transfer learning to new contexts has not yet been demonstrated and will be a focus of future work.

2.6 Summary of Pilot Studies

Iterative testing and refinement of the books led to robust and stable performance of the MSBs in real world educational environments. Overall, both students and teachers provided positive feedback about their experiences with the books. Initial evidence suggests that students learned science while using them, and that most students increased their general excitement about and motivation to learn science. In addition, the majority of students were fully engaged in reading practice and reported that practicing reading improved their ability to read sentences. In a Phase 2 project, we will administer student self-efficacy instruments before and after using the MSBs to test the hypothesis that using them improves students' self-efficacy.

A second major outcome of the pilot studies, based on teachers' survey responses and written comments, and opinions shared by teachers during informal conversations with the PI and project staff, *was their unanimous and enthusiastic support for combining science learning and reading practice in the MSBs.* Teachers shared that they (and their schools) are accountable for their students' achievement in math and reading. As a result, math and reading instruction has become an overarching priority, with less classroom instruction and professional development devoted to science. The teachers viewed the MindStars books as a potentially valuable resource for improving both science and reading achievement, and one they could readily integrate into their classroom instruction, *since students could use the program during classroom time devoted to either science or language arts.*

4. Summary of Phase 1 R&D Outcomes

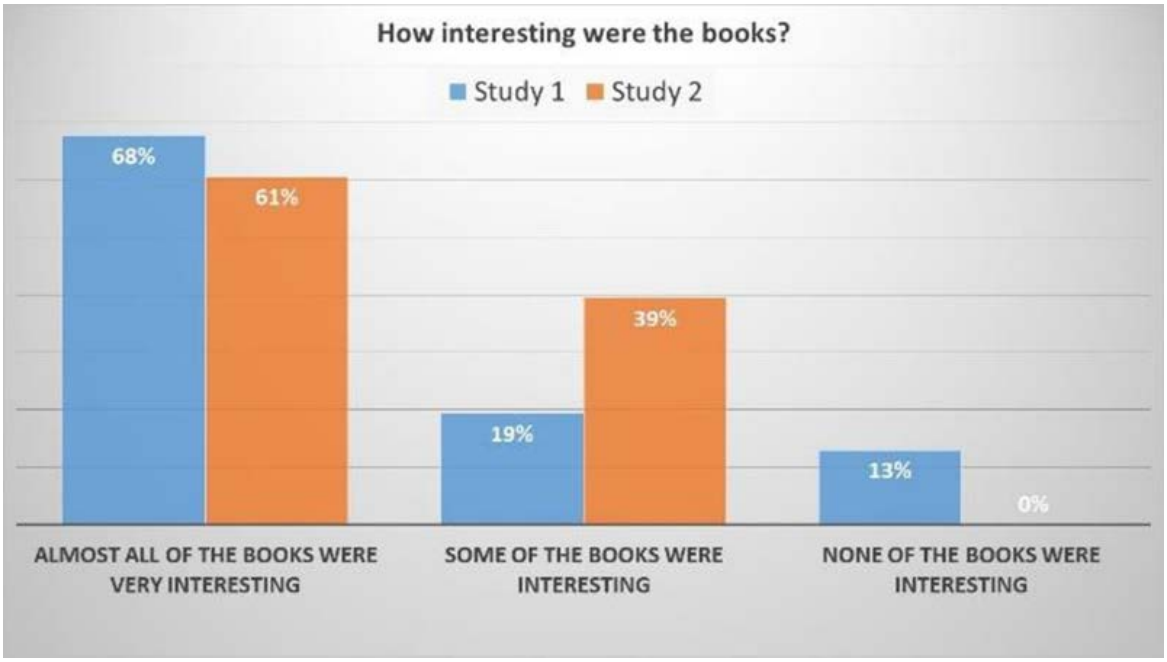
The research and development effort indicated that:

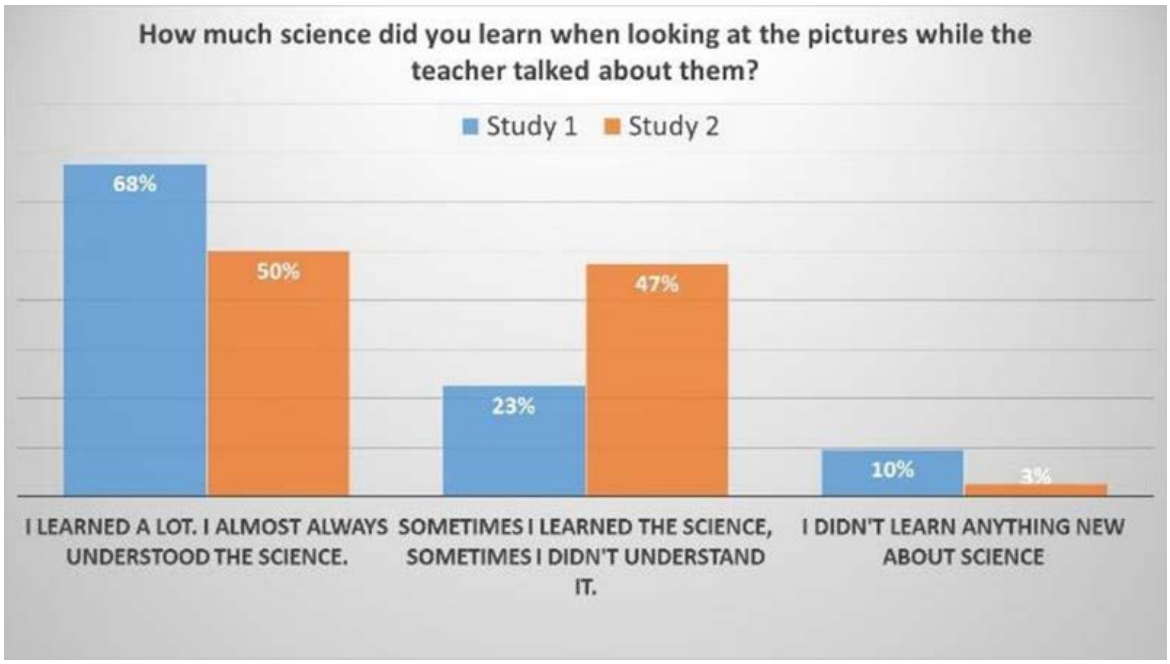
1) The MindStars Books Editor can be used to develop, test and publish books that support science learning and reading practice. The MSB Editor can be used to create MSBs, by individuals without programming experience, to engage students in narrated multimedia science explanations, assessments of their understanding of the science, and practice reading science texts.

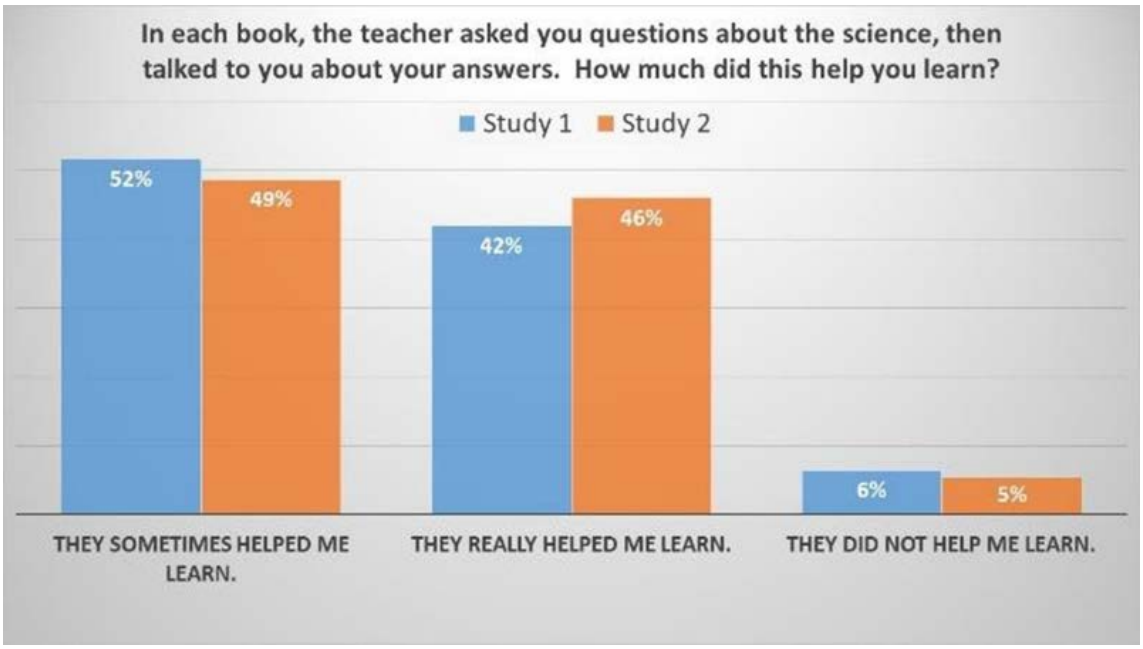
2) Initial experiences with students and teachers indicate the feasibility and promise of integrating MSBs into elementary school classrooms to learn science and reading. Students and teachers had strong positive impressions of the books, and students demonstrated learning of science vocabulary and concepts taught in the books based on answers to multiple choice questions. Students reported increased excitement about both science learning and reading after using them.

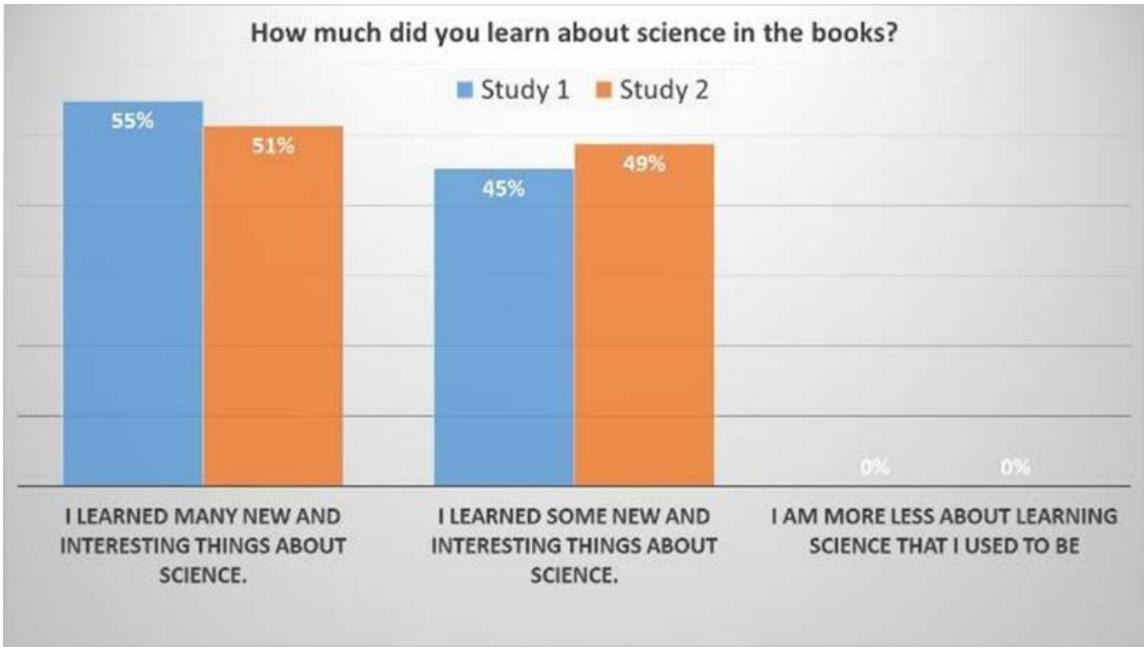
Appendix A

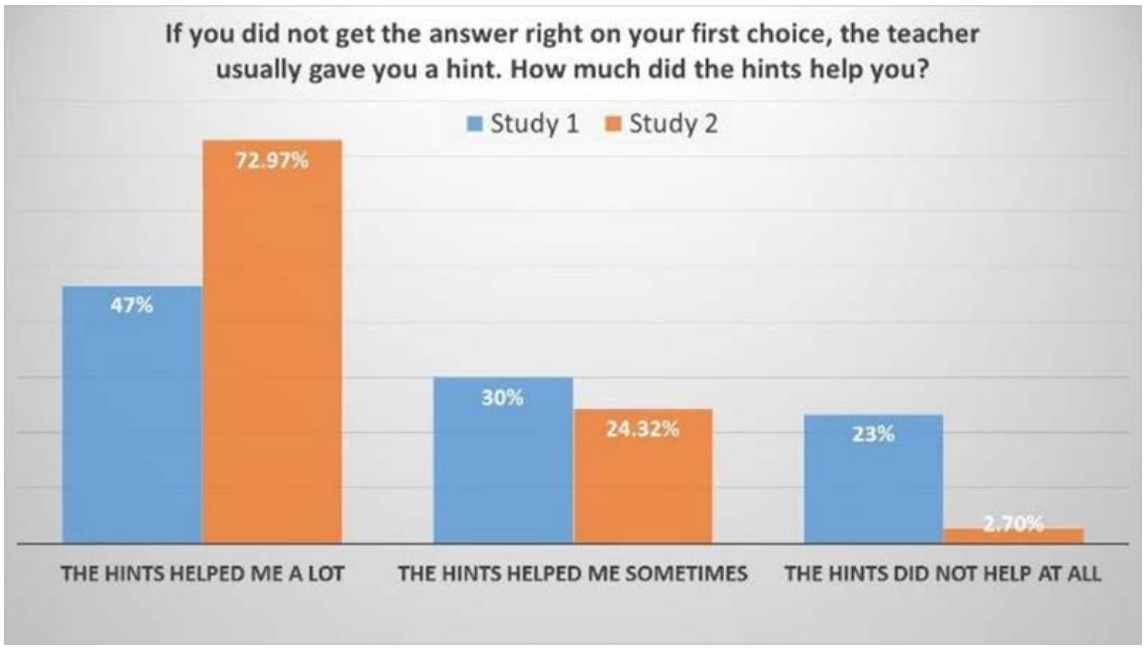
The Appendix presents a summary of teachers' and students' impressions of the study. Students in both pilot studies were presented with computer-administered questionnaire. Students had the choice of reading the questions and response choices or clicking on them to hear them read aloud. Those responses are included in the Figures below (unnumbered).

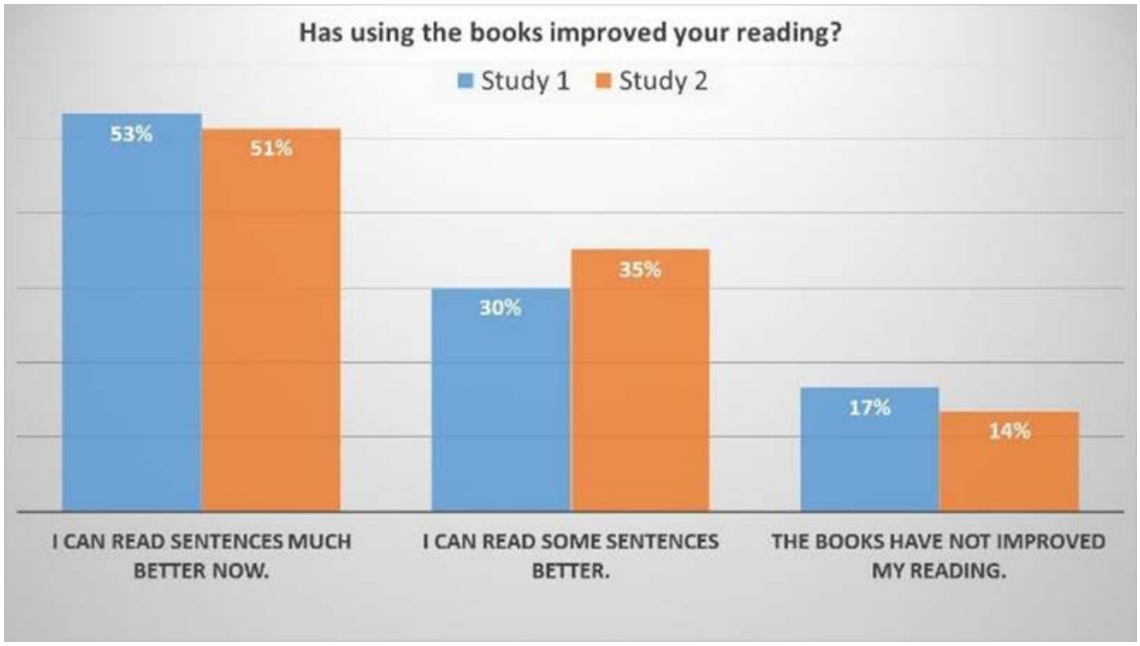


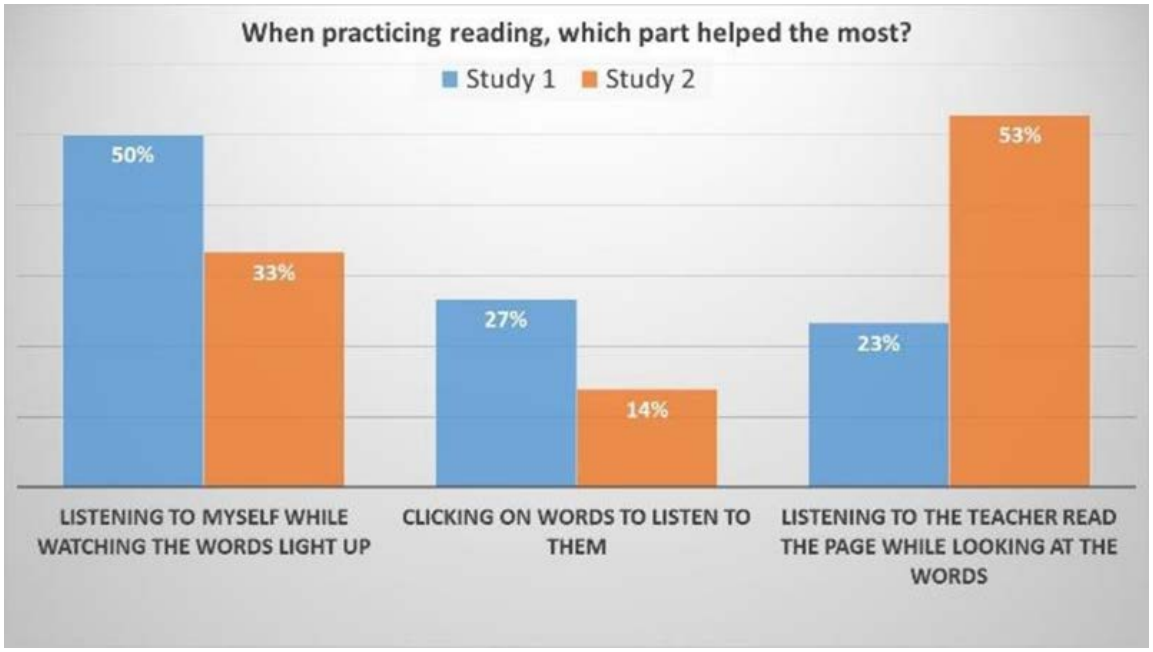


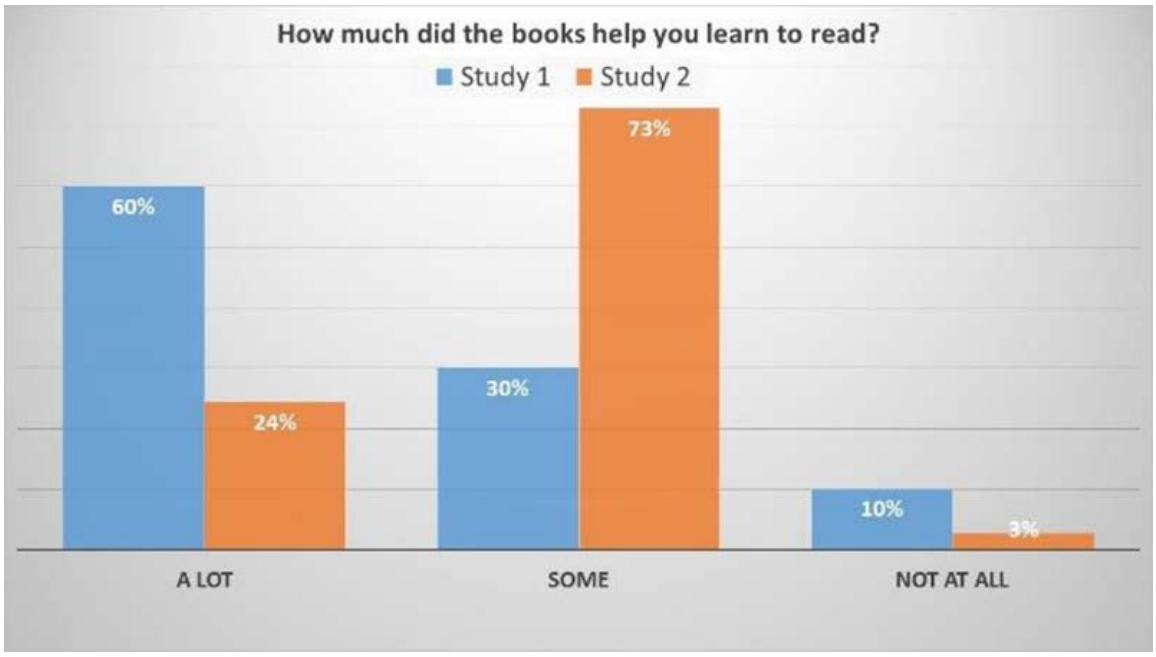

In each book, the teacher asked you questions about the science, then talked to you about your answers. How much did this help you learn?
Study 1
Study 2
52%
49%
42%
46%
6%
5%
THEY SOMETIMES HELPED ME LEARN.
THEY REALLY HELPED ME LEARN.
THEY DID NOT HELP ME LEARN.

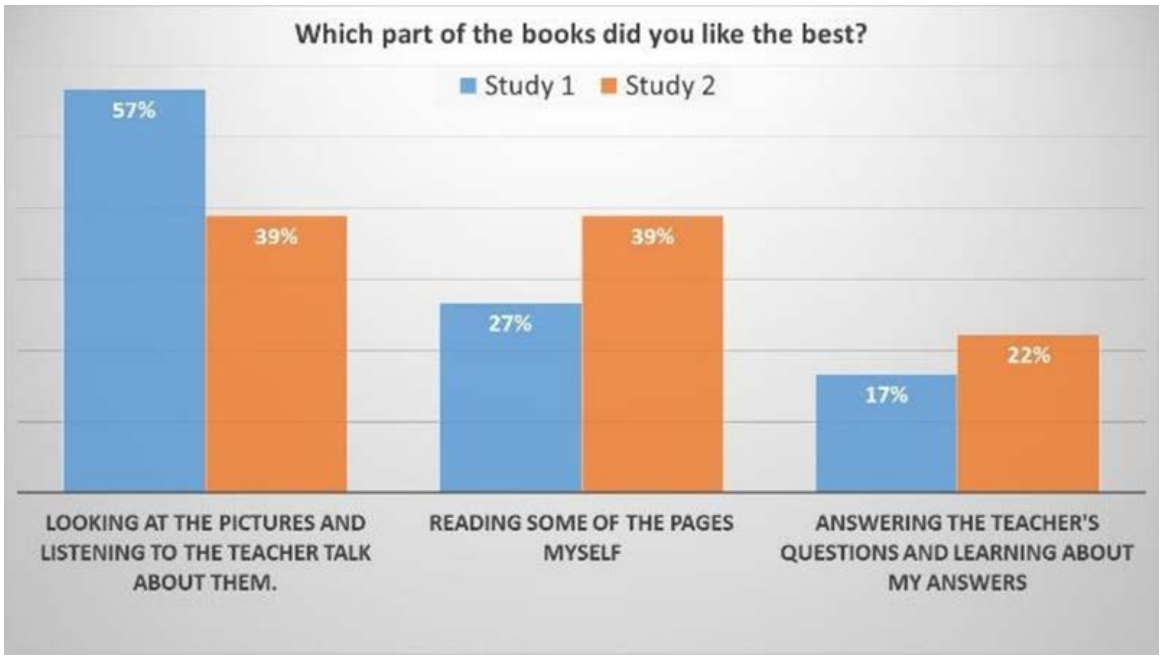

How much did you learn about science in the books?
Study 1
Study 2
55%
51%
45%
49%
0%
0%
I LEARNED MANY NEW AND INTERESTING THINGS ABOUT SCIENCE.
I LEARNED SOME NEW AND INTERESTING THINGS ABOUT SCIENCE.
I AM MORE LESS ABOUT LEARNING SCIENCE THAT I USED TO BE

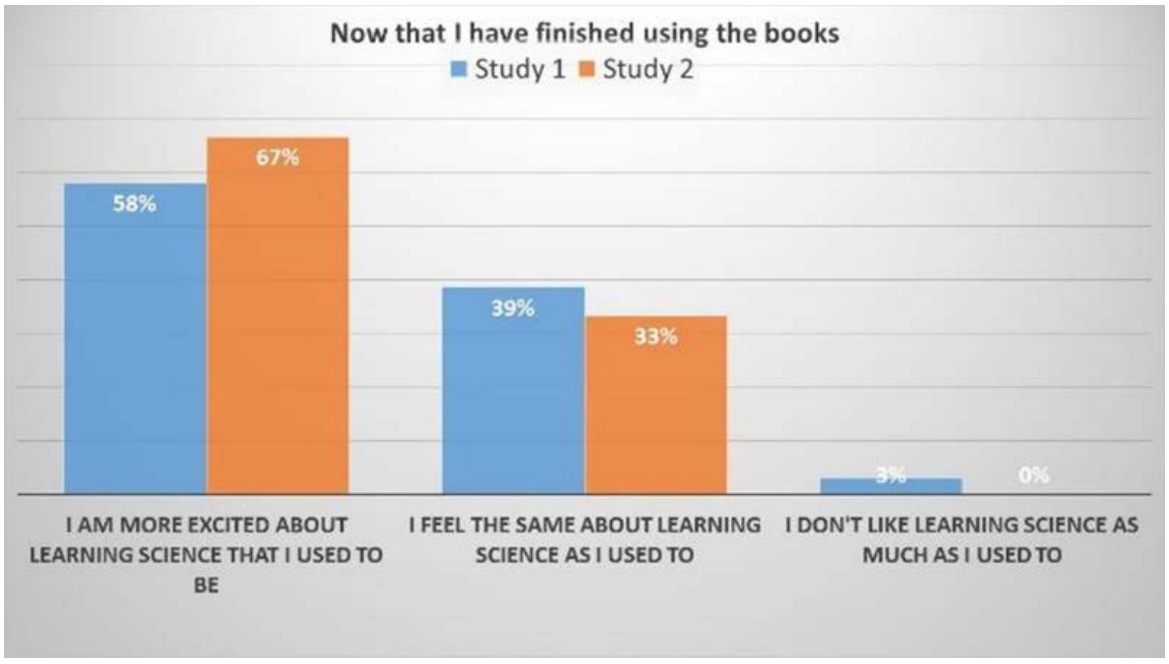

If you did not get the answer right on your first choice, the teacher usually gave you a hint. How much did the hints help you?
Study 1
Study 2
47%
72.97%
30%
24.32%
23%
2.70%
THE HINTS HELPED ME A LOT
THE HINTS HELPED ME SOMETIMES
THE HINTS DID NOT HELP AT ALL

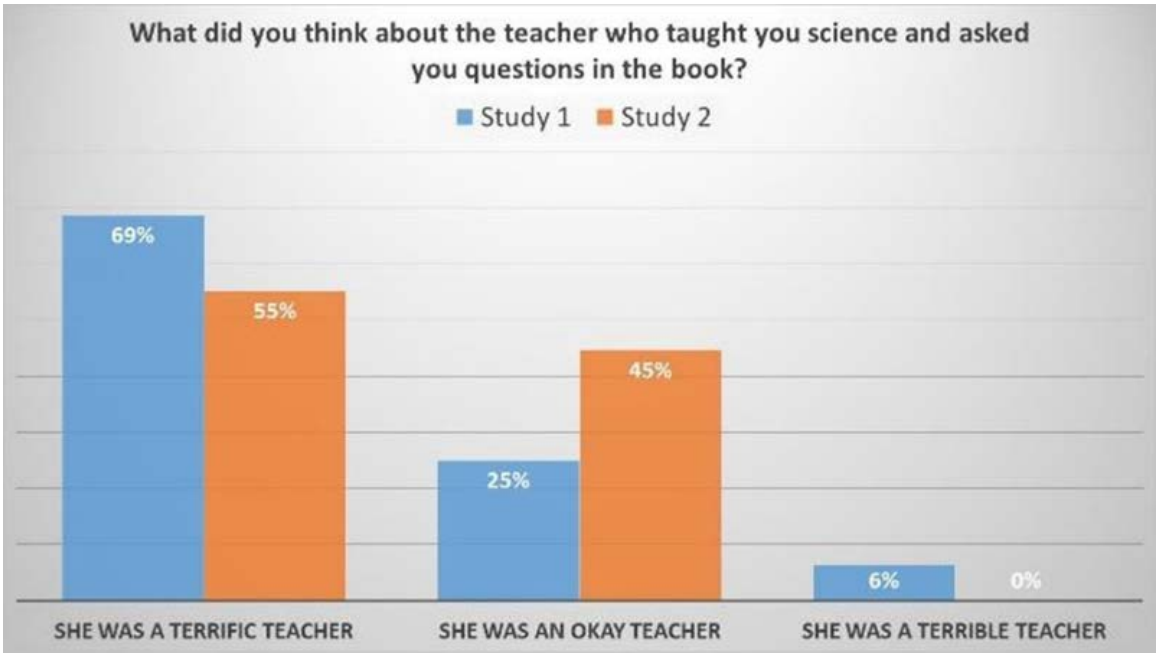

Has using the books improved your reading?
Study 1
Study 2
53%
51%
30%
35%
17%
14%
I CAN READ SENTENCES MUCH BETTER NOW.
I CAN READ SOME SENTENCES BETTER.
THE BOOKS HAVE NOT IMPROVED MY READING.

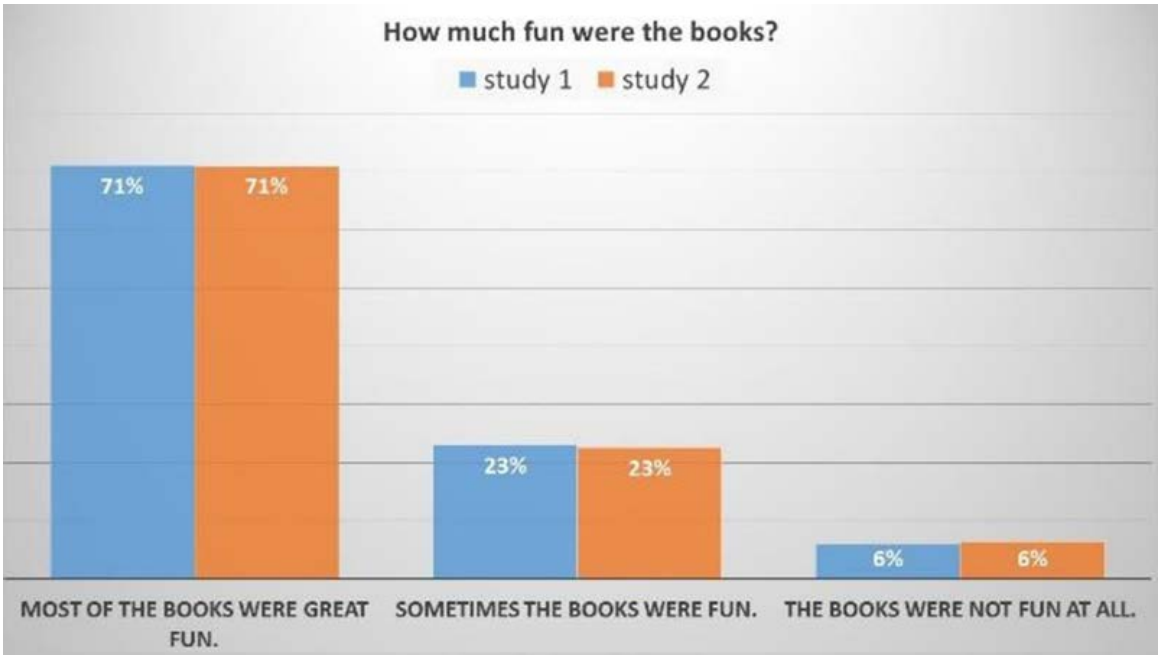

When practicing reading, which part helped the most?
Study 1
Study 2
50%
33%
27%
14%
23%
53%
LISTENING TO MYSELF WHILE WATCHING THE WORDS LIGHT UP
CLICKING ON WORDS TO LISTEN TO THEM
LISTENING TO THE TEACHER READ THE PAGE WHILE LOOKING AT THE WORDS


How much did the books help you learn to read?
Study 1
Study 2
60%
24%
30%
73%
10%
3%
A LOT
SOME
NOT AT ALL


Which part of the books did you like the best?
Study 1
Study 2
57%
39%
27%
39%
17%
22%
LOOKING AT THE PICTURES AND LISTENING TO THE TEACHER TALK ABOUT THEM.
READING SOME OF THE PAGES MYSELF
ANSWERING THE TEACHER'S QUESTIONS AND LEARNING ABOUT MY ANSWERS

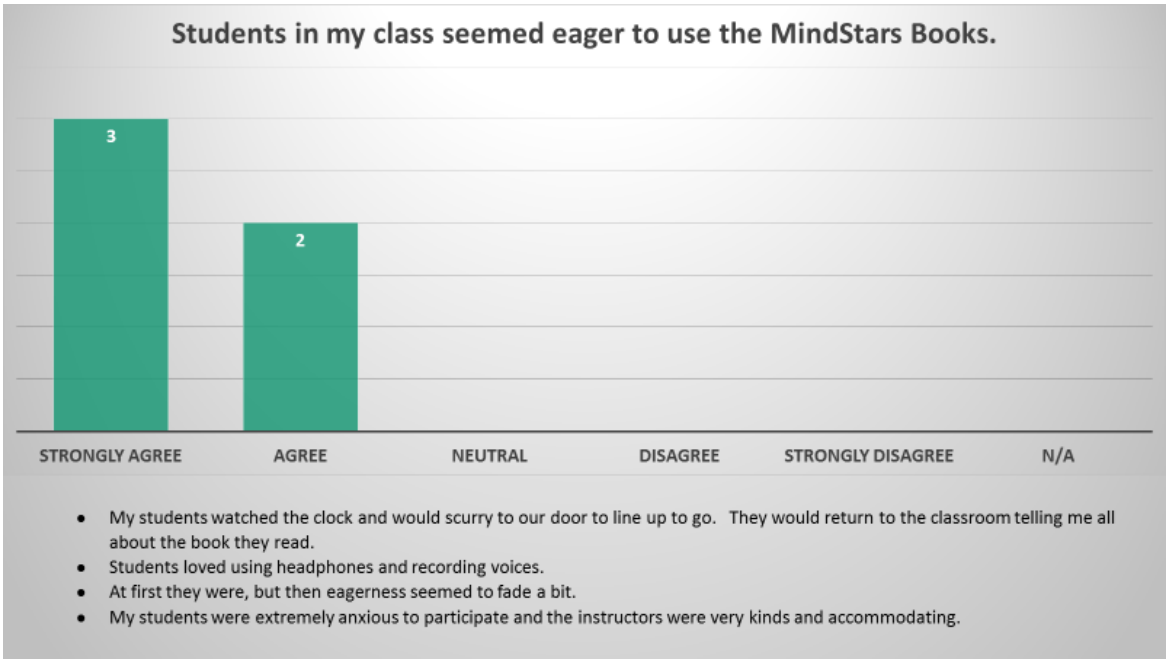

Now that I have finished using the books
Study 1
Study 2
58%
67%
39%
33%
3%
0%
I AM MORE EXCITED ABOUT LEARNING SCIENCE THAT I USED TO BE
I FEEL THE SAME ABOUT LEARNING SCIENCE AS I USED TO
I DON'T LIKE LEARNING SCIENCE AS MUCH AS I USED TO

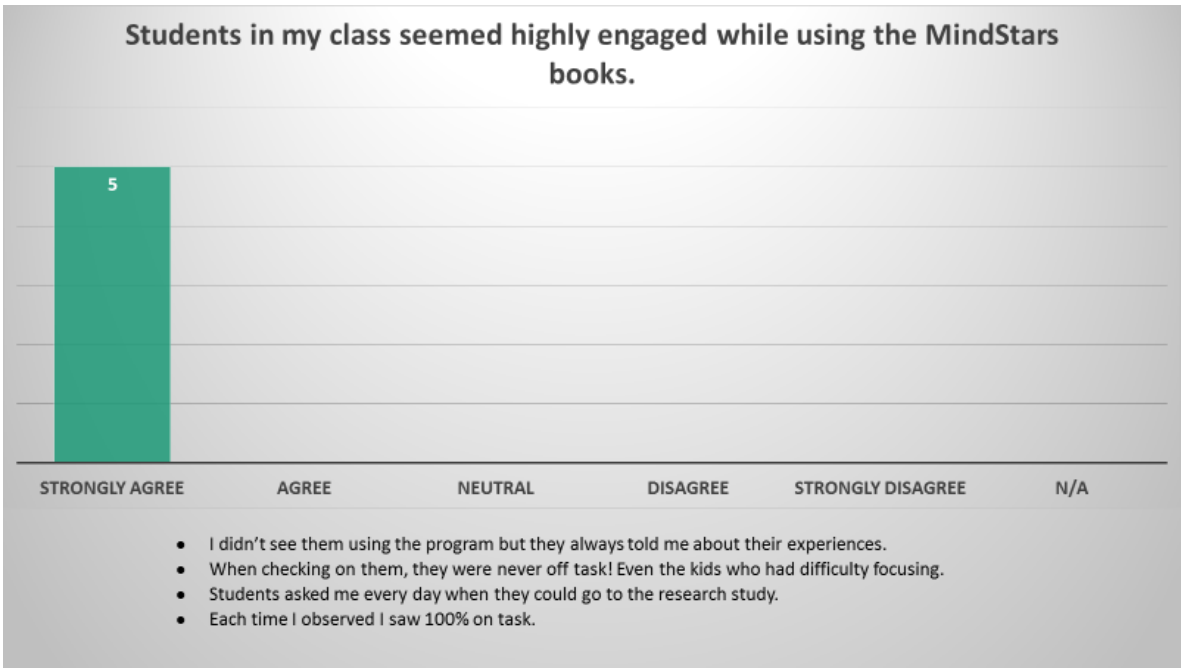

What did you think about the teacher who taught you science and asked you questions in the book?
Study 1
Study 2
69%
55%
25%
45%
6%
0%
SHE WAS A TERRIFIC TEACHER
SHE WAS AN OKAY TEACHER
SHE WAS A TERRIBLE TEACHER

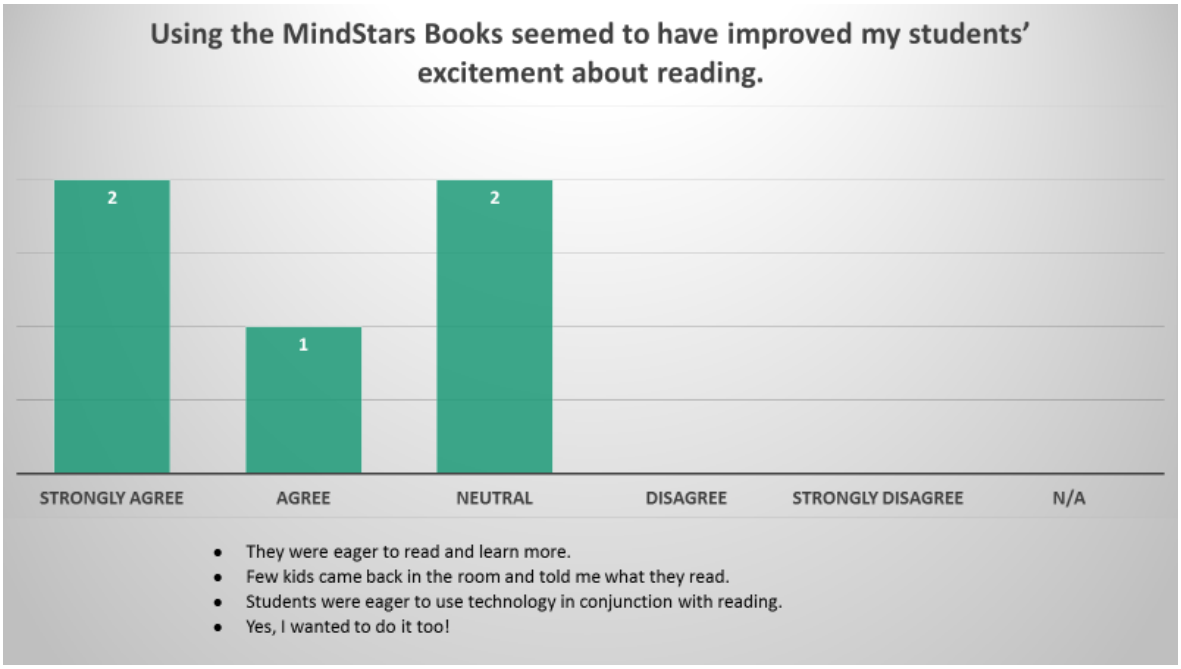

How much fun were the books?
study 1
study 2
71%
71%
23%
23%
6%
6%
MOST OF THE BOOKS WERE GREAT FUN.
SOMETIMES THE BOOKS WERE FUN.
THE BOOKS WERE NOT FUN AT ALL.

Appendix B

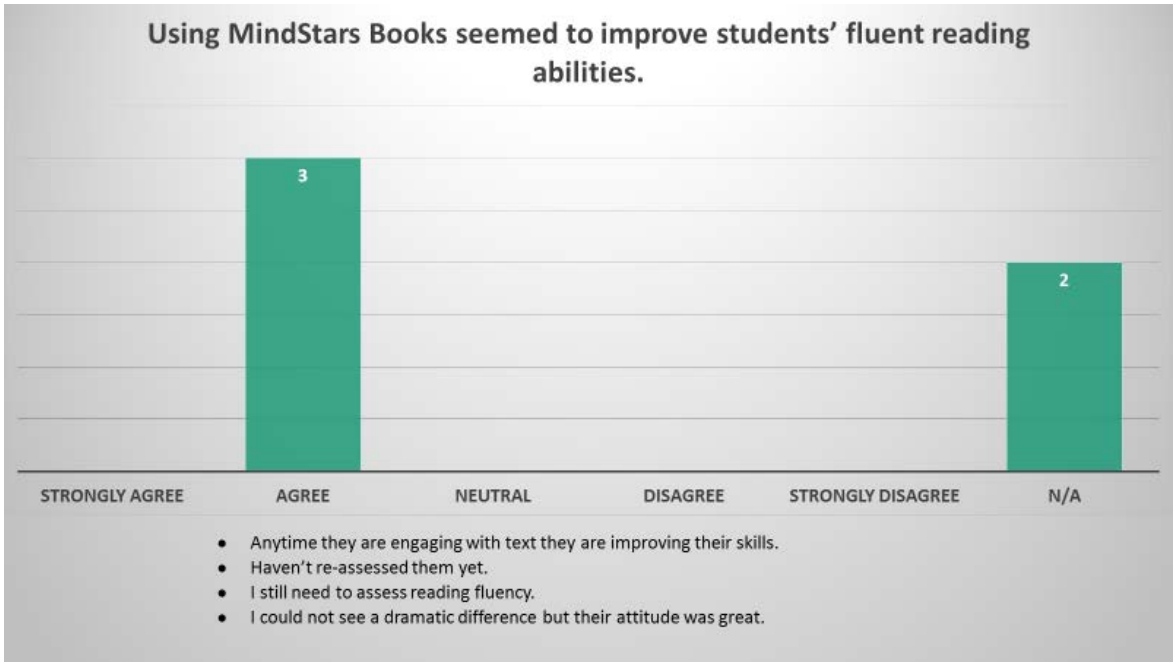
The 5 teachers who participated in the second pilot study responded to a printed questionnaire. The questionnaire consisted of a set of statements about the study. Teachers selected one of the following Likert-scale responses: Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree, N/A (Not Applicable). Teachers were encouraged to provide written comments after selecting among the response choices in the questionnaire. Those teacher responses are provided in the Figures below (unnumbered).





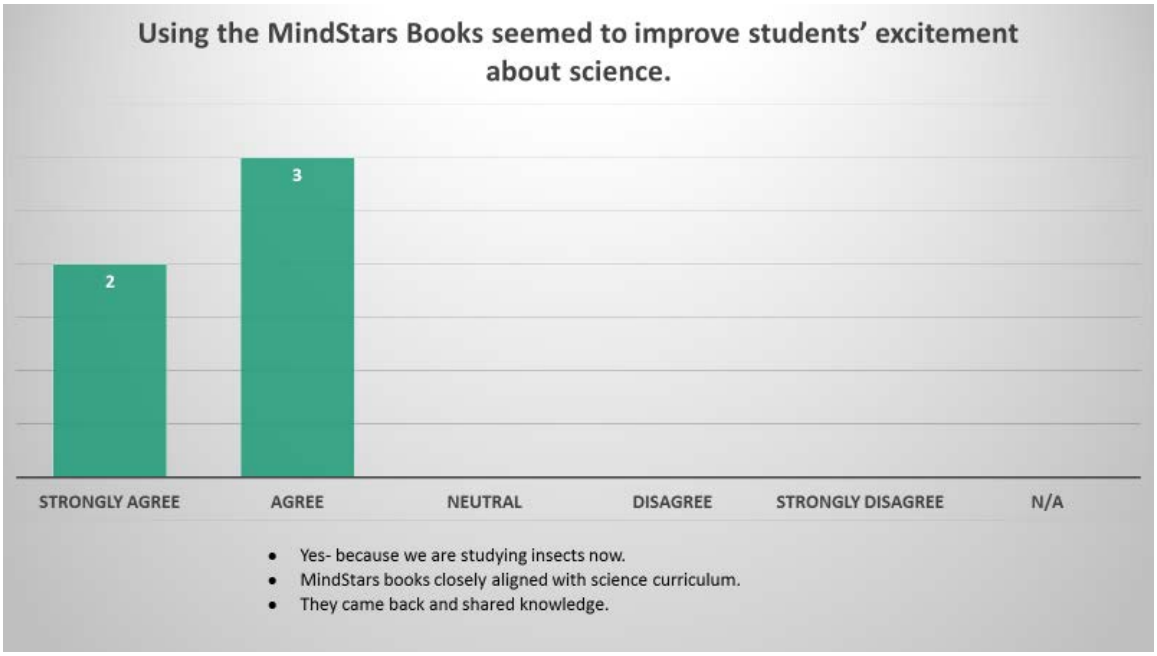


- They were eager to read and learn more.
- Few kids came back in the room and told me what they read.
- Students were eager to use technology in conjunction with reading.
- Yes, I wanted to do it too!

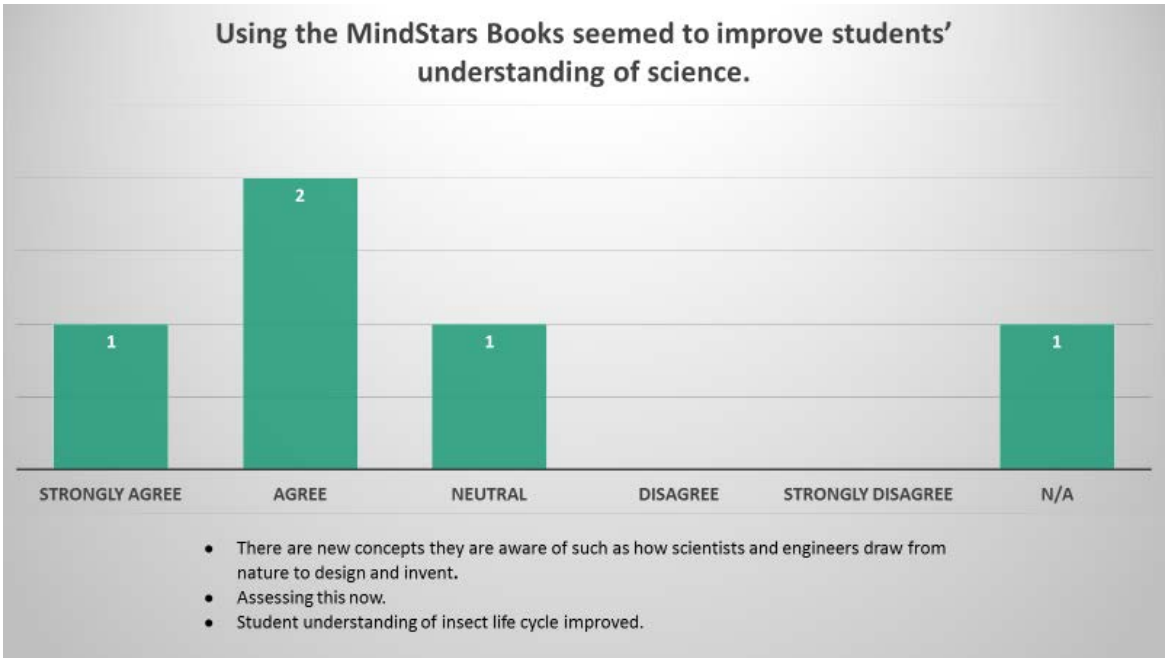


- Anytime they are engaging with text they are improving their skills.
- Haven't re-assessed them yet.
- I still need to assess reading fluency.
- I could not see a dramatic difference but their attitude was great.

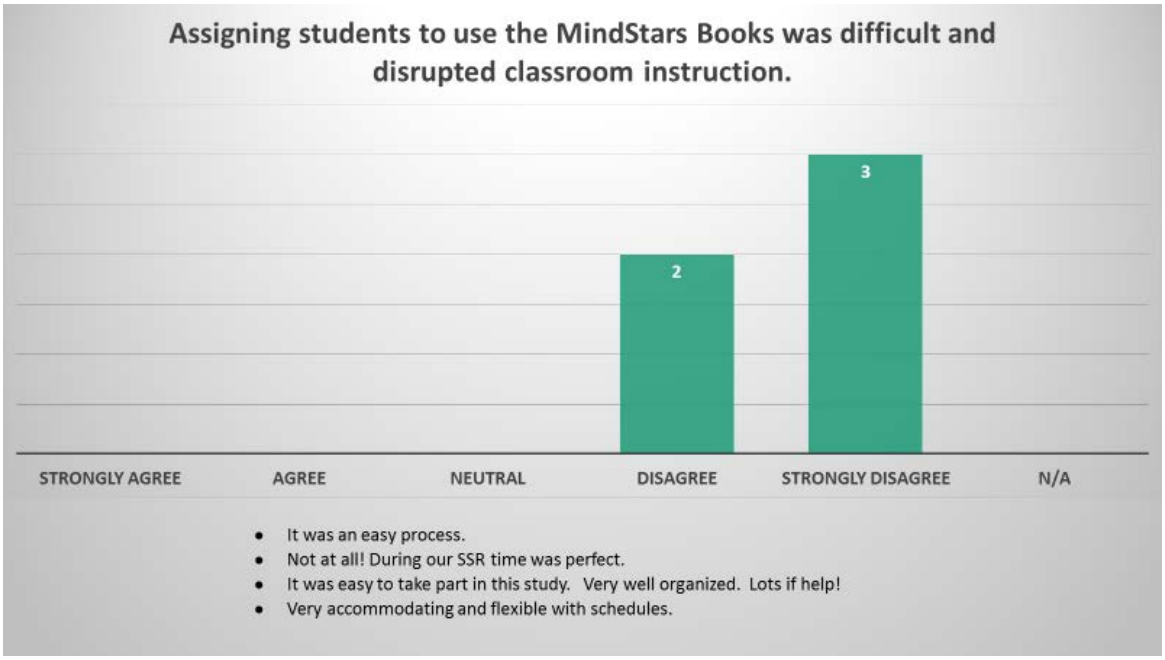
Teachers' and Children's Experiences with MindStars Books



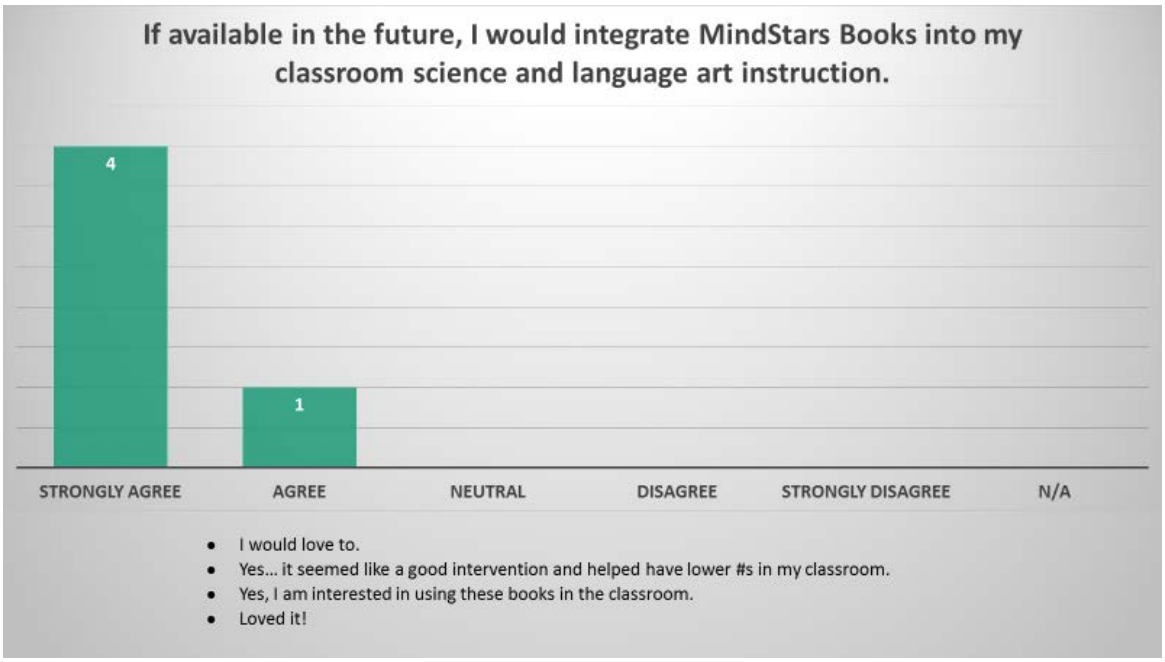
- Yes- because we are studying insects now.
- MindStars books closely aligned with science curriculum.
- They came back and shared knowledge.



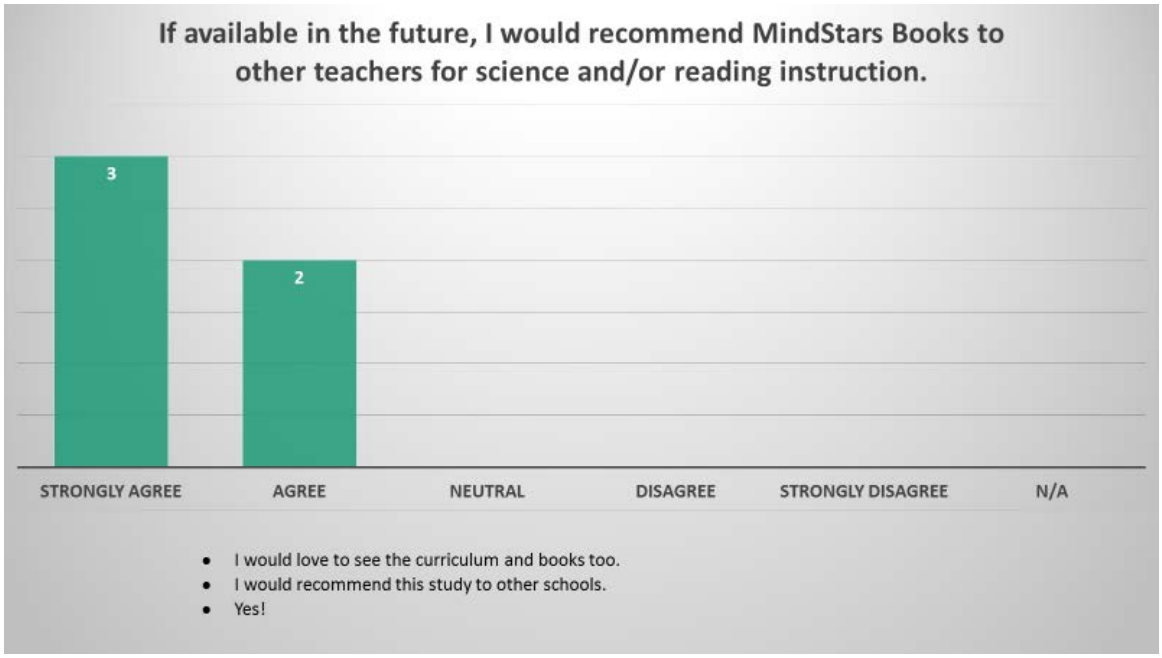
- There are new concepts they are aware of such as how scientists and engineers draw from nature to design and invent.
- Assessing this now.
- Student understanding of insect life cycle improved.



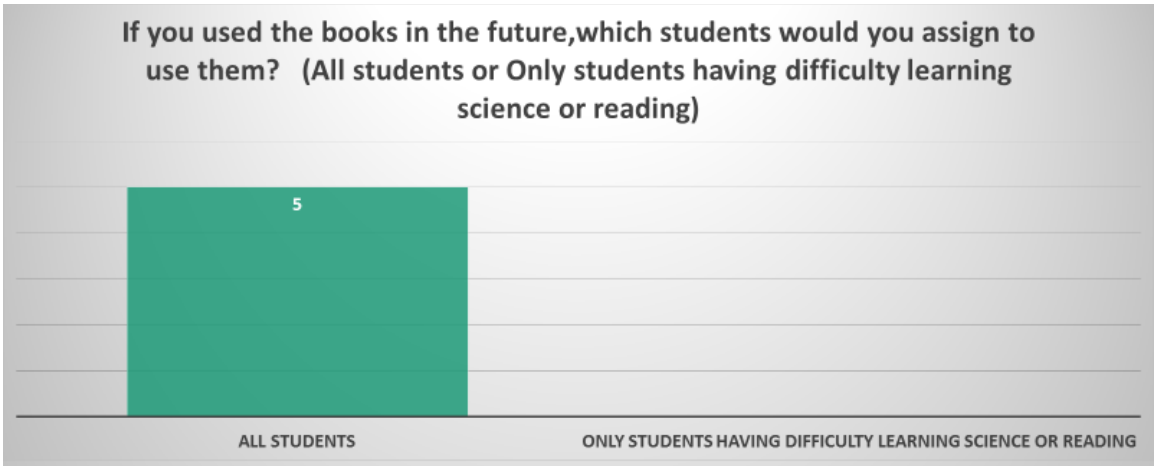
- It was an easy process.
- Not at all! During our SSR time was perfect.
- It was easy to take part in this study. Very well organized. Lots if help!
- Very accommodating and flexible with schedules.



- I would love to.
- Yes… it seemed like a good intervention and helped have lower #s in my classroom.
- Yes, I am interested in using these books in the classroom.
- Loved it!



- I would love to see the curriculum and books too.
- I would recommend this study to other schools.
- Yes!



- I think all students can benefit from the program. It's more time with text for struggling readers and emphasizing gaining meaning for more fluent students – win-win.
- Some kids were jealous that their parents did not sign them up. Good integration of tech + reading skills to practice for state / district tests that are administered on computers! Thanks!
- I feel my entire class would have benefitted from instruction /participation.