INK-12: Interactive Ink Inscriptions in K-12
Final Report

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1. Introduction

INK-12: Interactive Ink Inscriptions in K-12 was an exploratory project that investigated the use of a set of *wirelessly connected tablet computers* in elementary and middle school math and science classrooms [1]. We examined, and are continuing to examine via a four-year DRK-12 follow-on grant of the same name, two innovations that we believe will enhance STEM teaching and learning in K-12 classrooms: 1) because a tablet has a *pen-based interface*, students and teachers can draw and write on the tablet's screen (create "ink" inscriptions), e.g., to annotate text, indicate locations on maps, draw graphs and other scientific and mathematical representations critical in STEM fields; and 2) because the tablets are connected via a *wireless network*, teachers and students can easily send such ink inscriptions to one another. This wireless communication provides teachers the opportunity to look at all the students' work at the same time on his or her tablet computer, choose several to look at in more detail and have those appear anonymously on a public classroom screen or on every student's screen. Such publicly displayed work provides a forum for classroom discussion of alternate representations and problem-solving methods.

In the sections that follow, we detail the project's software development, classroom trials, curriculum adaptation, and findings.

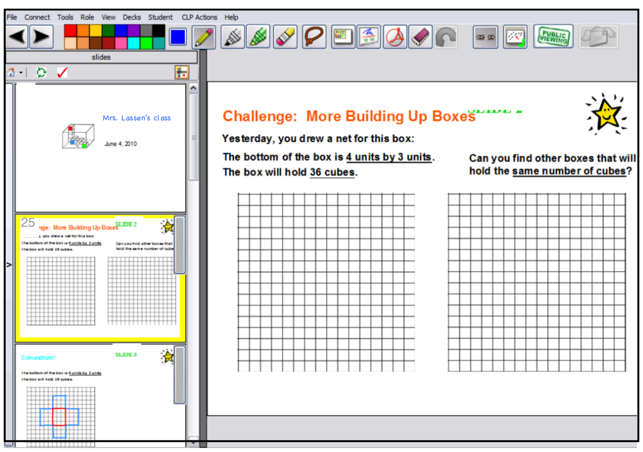
2. Software Development

For the INK-12 project, we enhanced tablet-pc-based software called Classroom Learning Partner (CLP), which had been developed by Kimberle Koile's research group for use in undergraduate education [2-5]. To use CLP in a classroom, the teacher and each student have a tablet computer, and a tablet computer is connected to a projector, creating a public display. The student machines are in "tablet mode", with the screen swiveled to cover the keyboard. At the beginning of class, each student logs into a tablet by choosing his or her name from a class list, and the lesson's slides are automatically loaded from a classroom server onto the tablet. The teacher controls via her tablet which slide is visible on the public machine and on the student machines. She can "link" the students in order to have the student machines display the same slides as hers or "unlink" the students and allow them to freely navigate through the lesson's slides at their own pace. Using the tablet computer's pen, each student "writes" on his or her tablet screen, e.g., answers to problems posed on the slide, then wirelessly sends his or her "digital ink" inscription to the teacher. The teacher then can choose several student submissions to display anonymously on a public screen and discuss with the class.

During the project we added software features that we deemed important based on classroom observations and interactions with teachers and students. Below are descriptions of the features and their use.

Display of student submissions. We made two important changes to the CLP user interface that enable teachers to display student submissions on the public display. First, we provided easy access to the submissions, allowing teachers to view student submissions with one tap of the pen. Student submissions are organized by slide on the teacher's machine, with one submission "deck" per slide. The teacher has access to a submission deck via a tab associated with her version of each slide. Figure 1a shows a teacher's screen, with her lesson slides in the vertical filmstrip on the left; the gray tab on the right of a slide indicates the presence of submissions, and the number on the left indicates the number of students who have sent submissions—information that teachers use to gauge student progress through a lesson. Tapping on the tab displays the student submissions for that slide in the filmstrip; tapping on a particular submission slide in the filmstrip displays it on both the teacher and public machines. Second, we added a "multi-display" interface, which allows teachers to select multiple submissions to be viewed simultaneously on the public display—a feature that teachers found enhanced their ability to hold class conversations about different representations and problem-solving approaches.

An example of creating a multi-display is shown below in Figure 1.b-d: Tapping on the "multi-display" icon  at the top of the filmstrip enables the teacher to select submissions to display. On the teacher's machine, student work is displayed in a filmstrip on the left, one "stack" per student. Each stack contains all submissions from a single student. The teacher expands stacks as desired, by clicking on the student nametag on each stack, e.g., Avery; drags submissions onto a "stage"; then selects column or grid view for the display. Column view allows teachers to zoom in on a particular selection, annotating it with digital ink if desired. Grid view expands the chosen submissions to fill the screen.



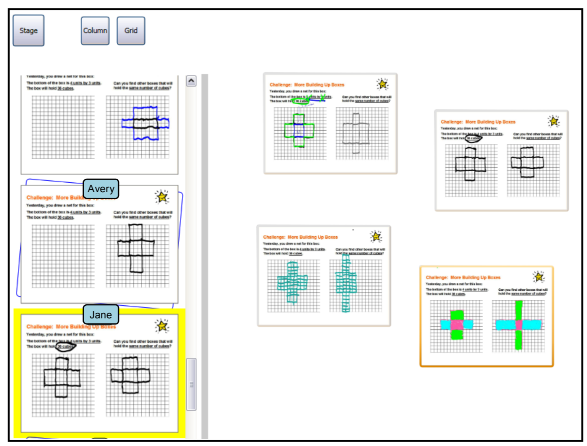
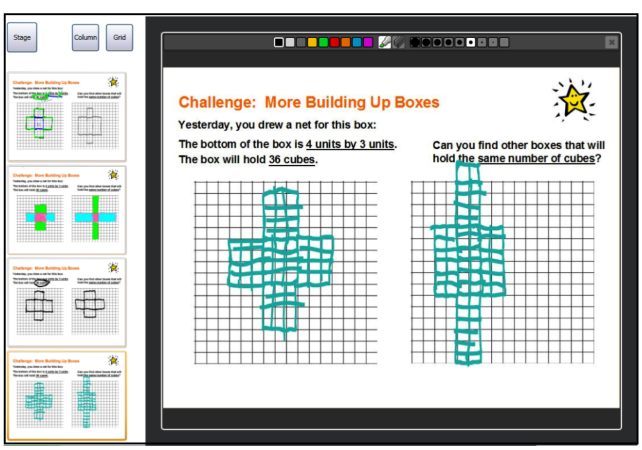
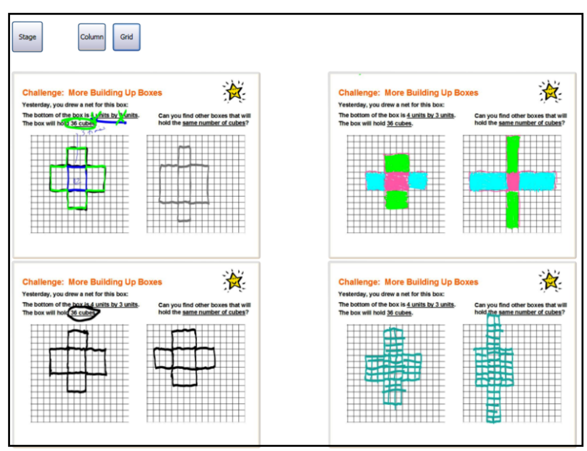


Figure 1. a. Teacher selects slide, then taps multi -display icon at top of filmstrip

b. Teacher drags submissions; yellow highlight shows one that has been dragged to "stage"





c. Teacher can select Column and "zoom" in on work

d. Teacher can select Grid to display all

This “multi-display” feature was implemented late in the second year of the project, and two teachers had the opportunity to use it, one for one three-day session, one for two three-day sessions. Those two teachers found the feature extremely useful and especially liked to toggle between looking at many pieces of student work at once, as shown in Figure 1d; and “zooming in” on particular pieces of student work, as shown in Figure 1c. The teachers found the interface easy to use and far superior to methods for displaying student work done on paper, e.g., via students copying their work on the board, especially when the goal was to compare and contrast several different answers simultaneously. Not surprisingly, however, this feature increased the cognitive load for the teacher, as she needed to select a set of student submissions to display, rather than just scrolling through a list of student submissions choosing one at a time. We will have to wait until teachers can use the multi-display feature over longer periods of time to observe how their use of it changes over time.

Private communication channel for teacher. We added a feature that enables the teacher to send ink only to the projector, not to student machines—students wanted to see the teacher’s annotations on the public screen, but most students became incensed when the teacher’s ink showed up on their slides![1] We also added features that enable the teacher to privately view and annotate an individual student submission, then return the annotated submission to the student without other students being aware of the interaction. Below is the top command bar, showing the public and private mode indicators. In public mode, the teacher’s ink shows up on student machines and/or the projector; in private mode, the ink only shows up on the teacher’s machine. The teacher enters private mode by tapping on the Public Viewing icon to switch the designation to Private. The teacher sends a note to a student by tapping on the envelope with wings icon. The annotated slide is then visible on the student’s machine.

Figure 2. The teacher can toggle between public and private modes via the top command bar.

We observed two contrasting uses of this potential for one-on-one communication. One teacher circulated around the room looking at student work, then wrote short notes to individual students, providing encouragement and suggestions for alternate approaches. The other teacher wrote longer, more substantive notes, but at the expense of interacting with the students—she stayed in one location in the room, using her tablet rather than walking around to talk with students. As with the multi-display feature, we expect that teachers’ use of this feature will evolve over time, and we intend to study this evolution in our follow-on grant.

Support for differentiated instruction. Teachers were interested in differentiating instruction by providing problems with differing levels of difficulty, and we were interested in investigating the affordances of the tablet system for providing such instruction. We implemented two mechanisms for accomplishing the differentiation. In one case, we prepared three separate slide decks, each of which contained problems with difficulty levels geared to particular groups of students. A file on the classroom server contained the level of difficulty assigned to each student by the teacher, and the software automatically loaded the appropriate slide deck onto each student’s machine at the start of class. In the other case, we prepared only one slide deck containing three versions of each of the differentiated problems, explicitly labeled as A, B, or C. The teacher placed a post-it note with one of these three letters in each student’s math notebook. (We rotated the letter designation so that the letters did not mean “easiest” or “hardest.”)

[1] This reaction was not seen in classes of undergraduates, who viewed the teacher ink on their screens as extra class notes that they didn’t have to write themselves.

These two mechanisms worked equally well in terms of specifying the problems different groups of students received. The teacher speculated that the best mechanism would be to show students only a single problem, thinking that the scheme deemphasized the separation of students into different skill groups. We found, however, that the students were very well aware of having different levels of skill and that the teacher had been so successful at creating a classroom culture in which different levels were accepted as the norm, that students didn't mind knowing they were working on different problems. Several students in fact said they preferred having a deck with all three problems in it so that they could figure out who else had the problem or a harder one because they wanted to ask another student for help before asking the teacher for help. Several other students said they liked having extra problems to work if they finished theirs early; others said they liked to choose their own problem. (Note that letting a student choose a problem relieves the teacher of the burden of assigning levels to students, with the possible disadvantage that a student may not know which problem best matches his or her skill level.) Another student said she liked to see all the problems because it let her know that the teacher had chosen a problem matched to her level of knowledge; she had no evidence of this explicit matching when only one problem was present. We will continue our investigation of differentiated instruction in our next grant.

"Shuffle" and peer grading of student work. We added a mechanism for teachers that enables students to grade each others' work. This feature took all students' responses to a particular problem, shuffled them, and distributed them randomly to other students to "grade." In our one classroom use, we found that, while the technology performed well, students couldn't use it effectively unless they had had experience in giving helpful feedback to other students. Many students, for example, simply wrote a letter grade. This feature will require more use in individual classrooms to evaluate its effectiveness.

Student-viewable submission history. In order for students to be able to compare what they wanted to submit with something they had submitted before, we implemented along the bottom of the screen a history "film strip", which they can hide or reveal. (See Figure 3.) The history displays small versions of the screen images of a student's previous submissions, along with the current version of their slide. The history panel enables students to review their previous answers and to restore and modify a particular answer should they want to resubmit an answer after they have understood a concept. The history panel also provides a place for a student to view private messages that a teacher may have written on a student's submission and sent back to the student. An example teacher message, "Very good!", is shown in yellow ink at the top of the rightmost slide in the history shown in Figure 3.

The interface we designed appeared to be easy for students to understand and use: They liked seeing what they'd sent so that it didn't "disappear" when they sent it to the teacher. They had no trouble distinguishing between their own submissions and those that were returned to them with teacher annotations. One student asked if she could send a message to another student, and when asked if the message was about the lesson, she admitted that it was not. The issue of who sends messages to whom is one that we will investigate in our follow-on grant.

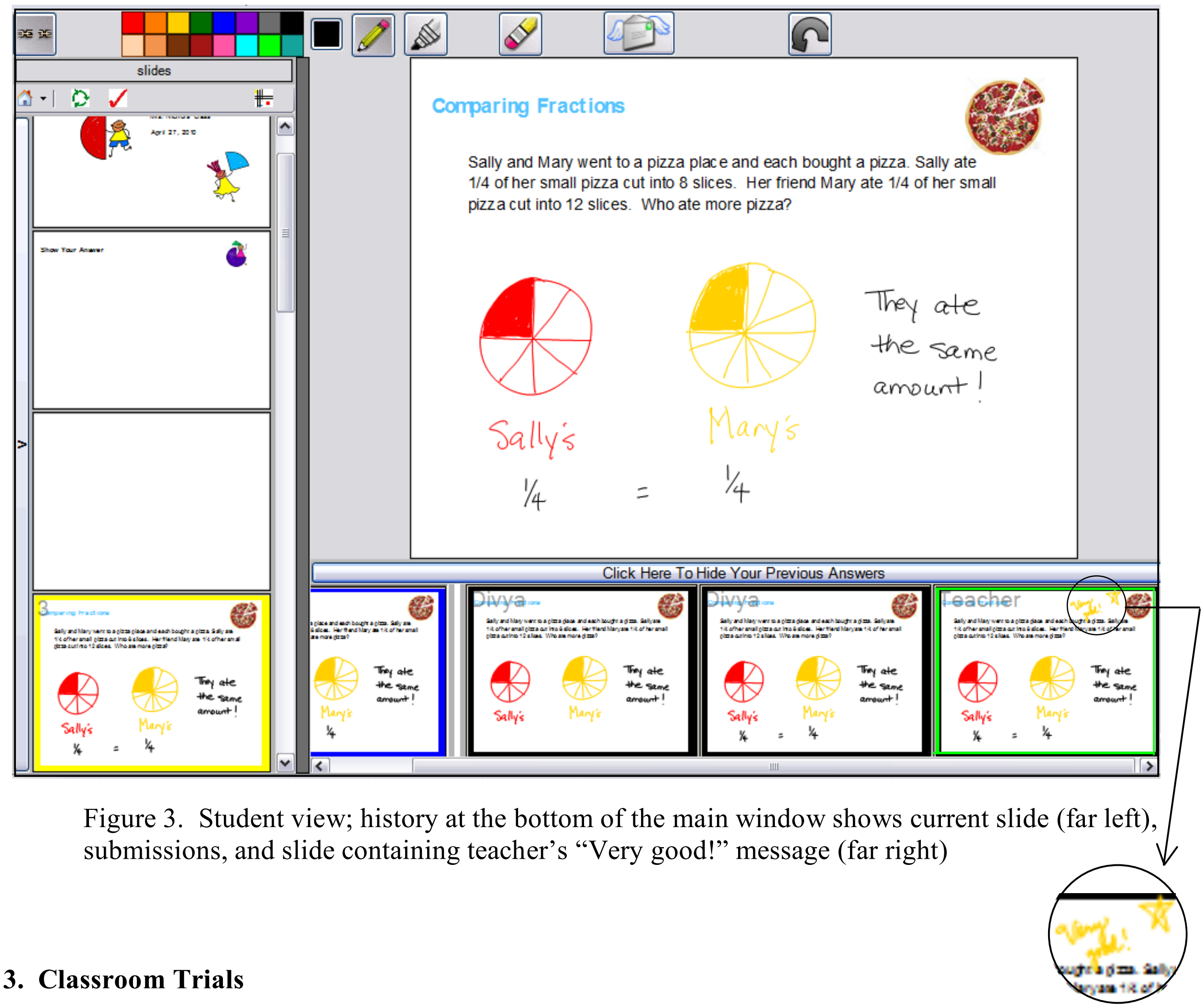


Figure 3. Student view; history at the bottom of the main window shows current slide (far left), submissions, and slide containing teacher's "Very good!" message (far right)

3. Classroom Trials

Year 1: The trials began with two single-day trials, of approximately two hours each, in two different Lexington (MA) fourth-grade classrooms in Fall, 2008:

1. Bridge School, Lexington, Grade 4 students. One classroom; emphasis on graphing scientific data. Class size 22.
2. Fiske School, Lexington, Grade 4 students. One classroom; emphasis on graphing scientific data. Class size 23.

During the spring of 2009, three multiple-day tablet trials were conducted in three schools:

3. Baldwin School, Cambridge, Grade 4 students. Two classrooms; four-day residency, emphasis on mathematics, MCAS (MA State standardized test) math preparation, MCAS long composition (English Language Arts) preparation, MCAS reading comprehension preparation. Average class size 18 students.
4. Clarke School, Lexington, Grade 8 students. Two classrooms, five classes each; five-day residency, emphasis on science (physics) and math. Both classrooms included MCAS preparation content. Average class size 20 students; total of 200 students.
5. Amigos School, Cambridge, Grade 8 students. One classroom; three-day residency, math class. Class size 22 students.

Year 2: During the spring of 2010, four multiple-day tablet trials were conducted in three schools:

6. Northeast Elementary School, Waltham, Grade 4 students. One classroom; three-day residency, emphasis on mathematics and science; three-day residency, emphasis on math. Class size 20 students.
7. John F. Kennedy Middle School, Waltham, Grade 6 students. One classroom, four classes; three-day residency, science class. Average class size 21 students; total of 84 students.
8. Cabot School, Newton, Grade 4 students. One classroom; three-day residency, emphasis on mathematics. Class size 23 students.

Below are examples of student work from the trials.

3.1 Year 1 Classroom Trials

Fourth grade science. In two fourth grade classrooms in Lexington, MA, teachers and students used the tablets for a science lesson. In both classrooms, we first observed the teachers without technology, to get a sense of their teaching styles, then we observed them using the tablets with their students. Both teachers were teaching a crayfish unit, having the students collect data about crayfish weight and length. Below is a photograph of one class in which students shared their data with the class by posting "post-it" notes on a classroom wall. Also below is a photograph of the teacher sharing student graphs of the data by holding up a student's notebook.

Figure 4. 4th grade students sharing data with the class, teacher sharing student work

In contrast, below is a photograph of the students submitting their work to the teacher via their tablets, and the teacher choosing student work to display on the public screen and discuss with the class. Also shown are two examples of submitted student work.

Figure 5. 4th grade teacher sharing student work with the class using the tablets

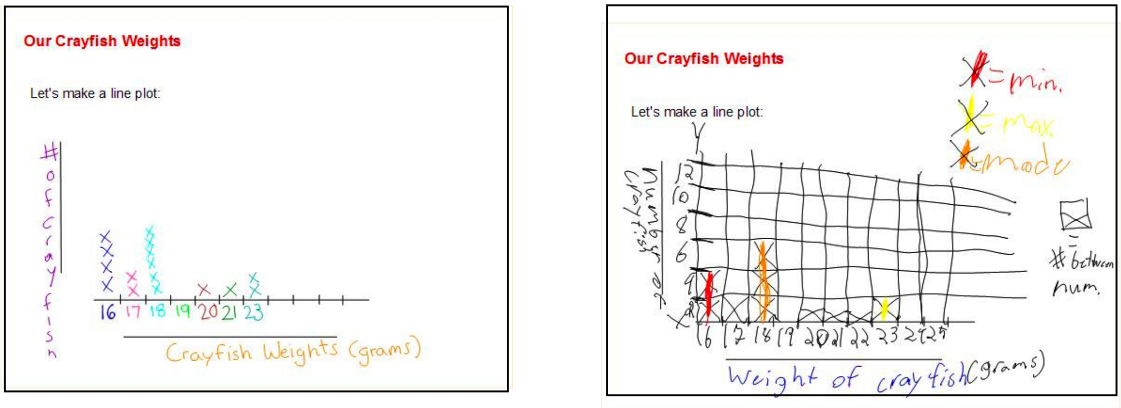


Figure 6. Examples of student work in the crayfish project

Fourth grade math, science, and language arts. The two fourth grade teachers in Cambridge, MA, used the tablets in a variety of subjects: composition, reading, math, and science. Below are photographs of a teacher and students using the tablets. Also below are examples of student work in each of the subject areas.

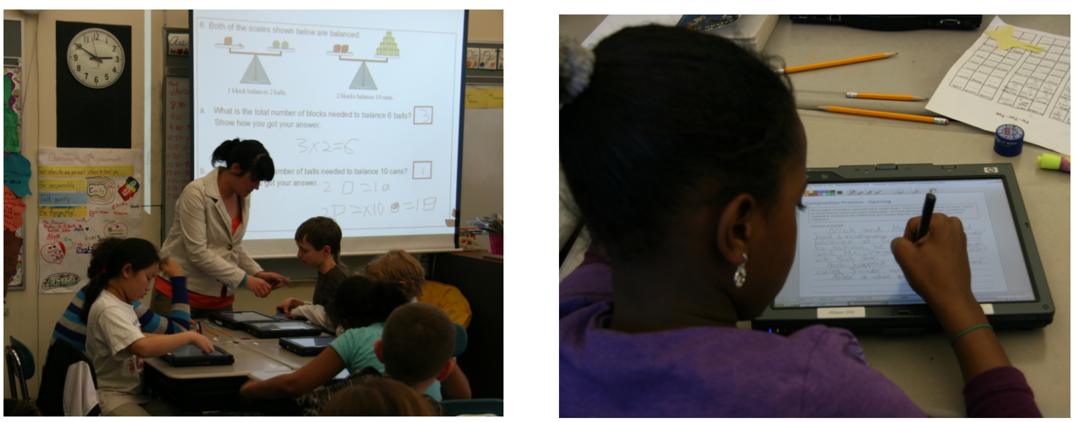


Figure 7. 4th grade teacher and students using the tablets

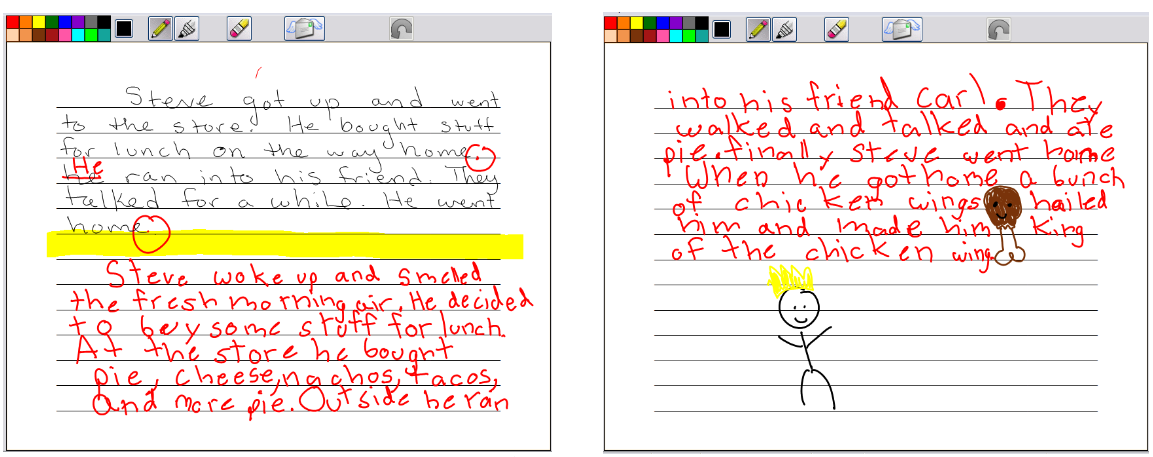
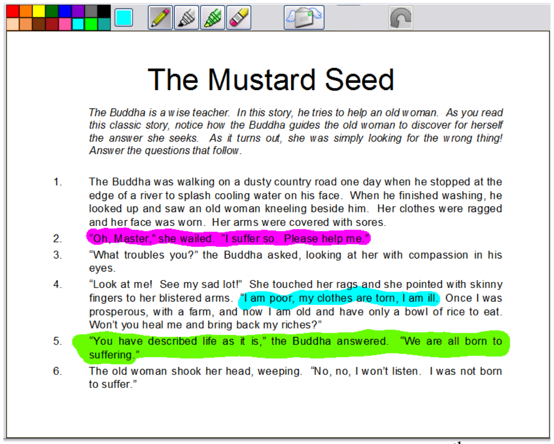


Figure 8. 4th grade composition work



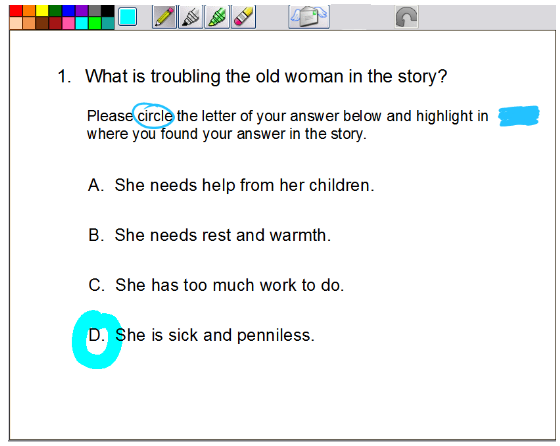
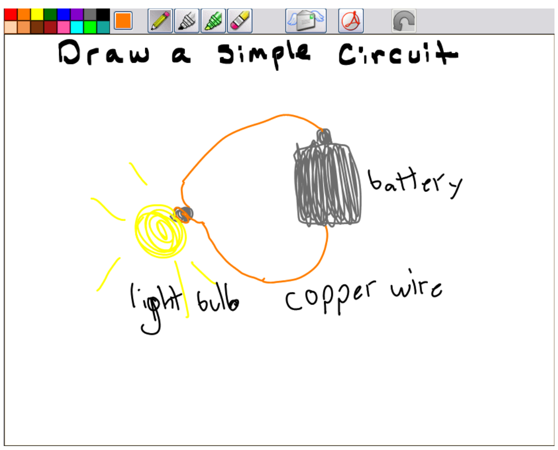


Figure 9. 4th grade reading comprehension work



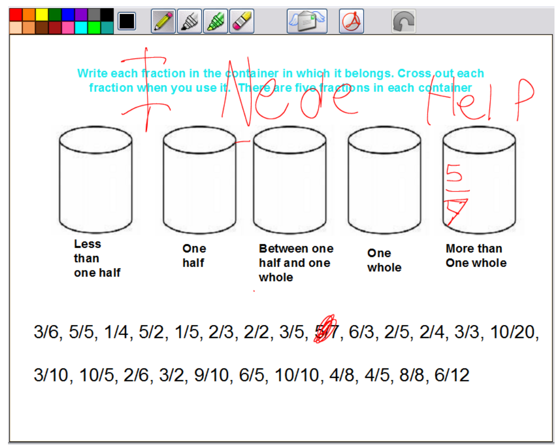
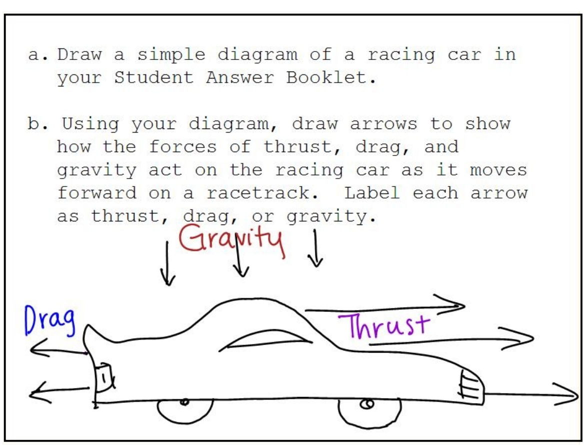


Figure 10. 4th grade science and math work; the student whose work is on the right discovered on his own that he could use his submission to communicate to his teacher that he needed help

Eighth grade science and math. We worked with three eighth grade teachers at two different schools in Lexington, MA—one science teacher and two math teachers. Shown in Figures 11, 12, and 13 are examples of student work from the science class and one of the math classes.



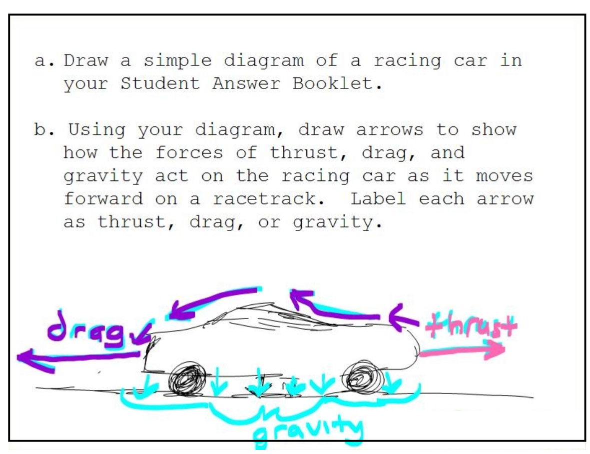


Figure11. 8th grade science work on forces

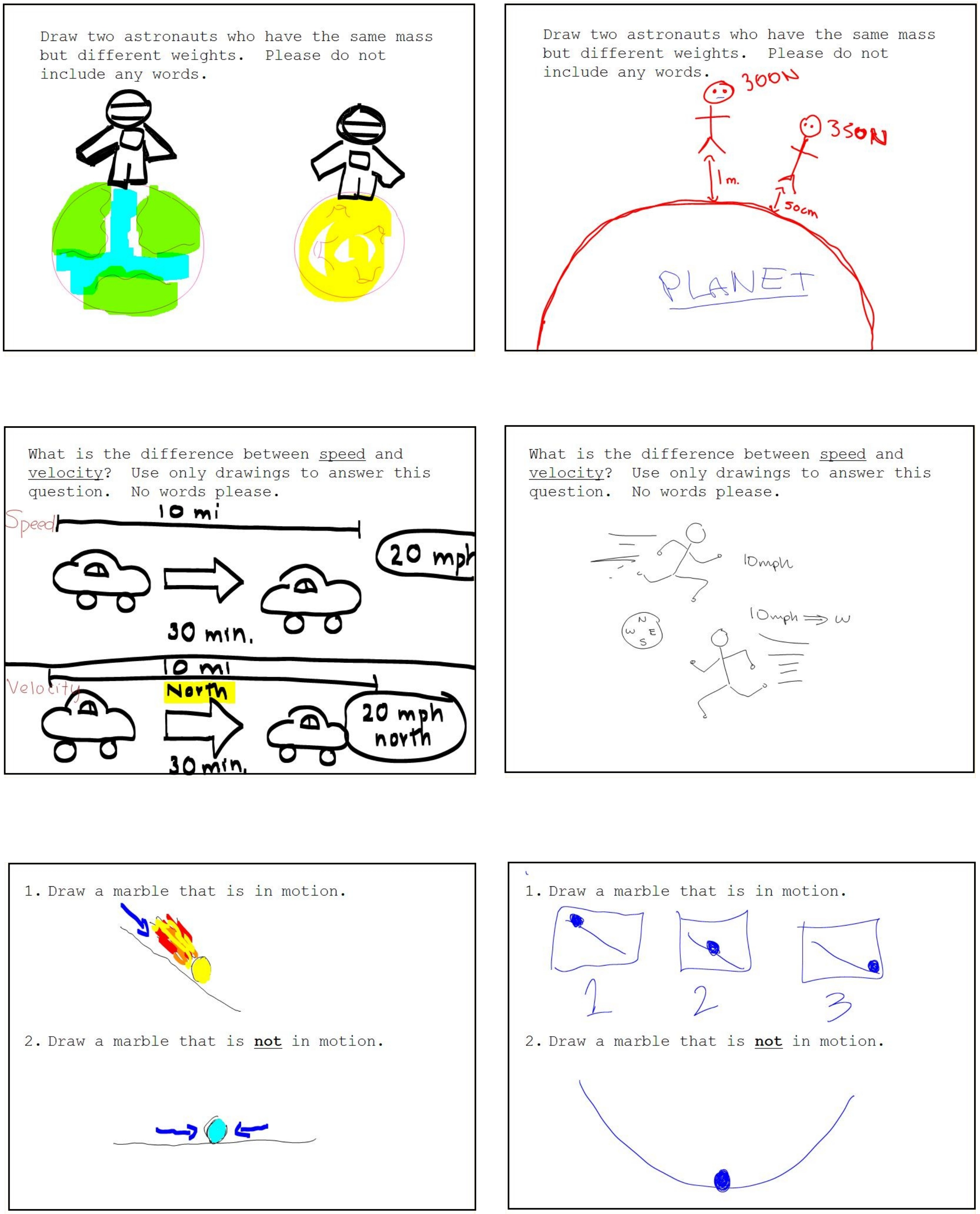


Figure 12. 8th grade science work on mass vs weight, speed vs velocity, and motion

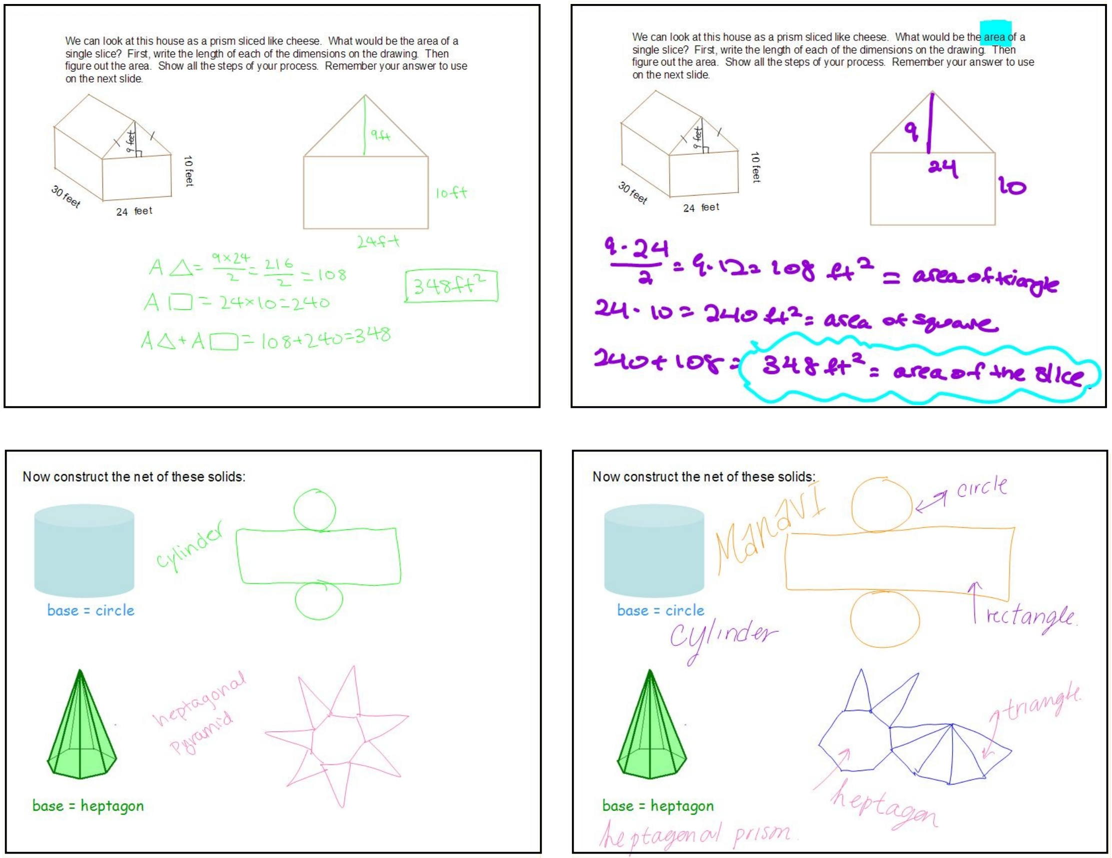


Figure 13. 8th grade math work in geometry

3.2 Year 2 Classroom Trials

Fourth grade math and science. We worked with a fourth grade teacher in Waltham who used the tablets for math and science. Below are examples of her students working with number lines, graphs, and electricity.

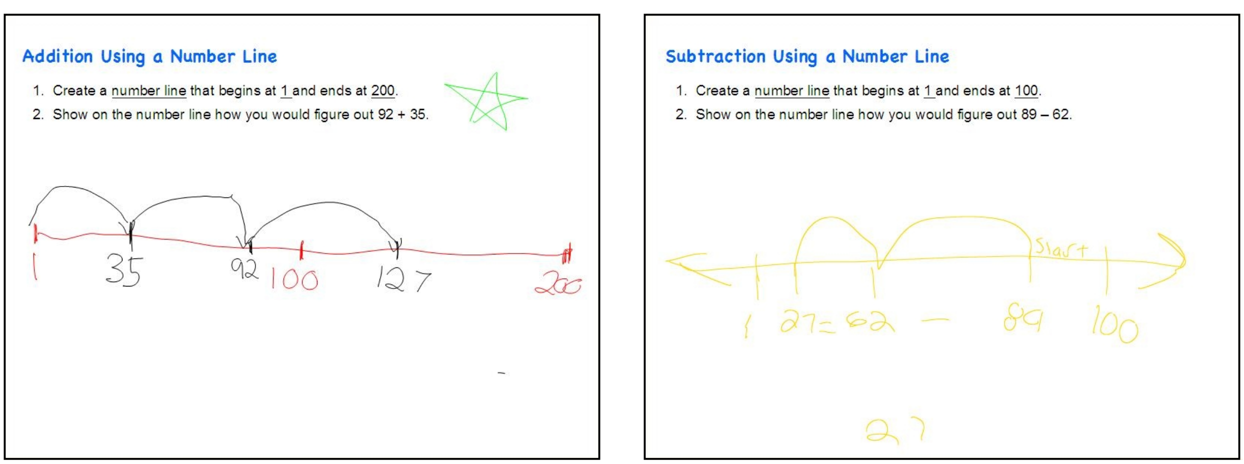


Figure 14. 4th grade math work on number lines

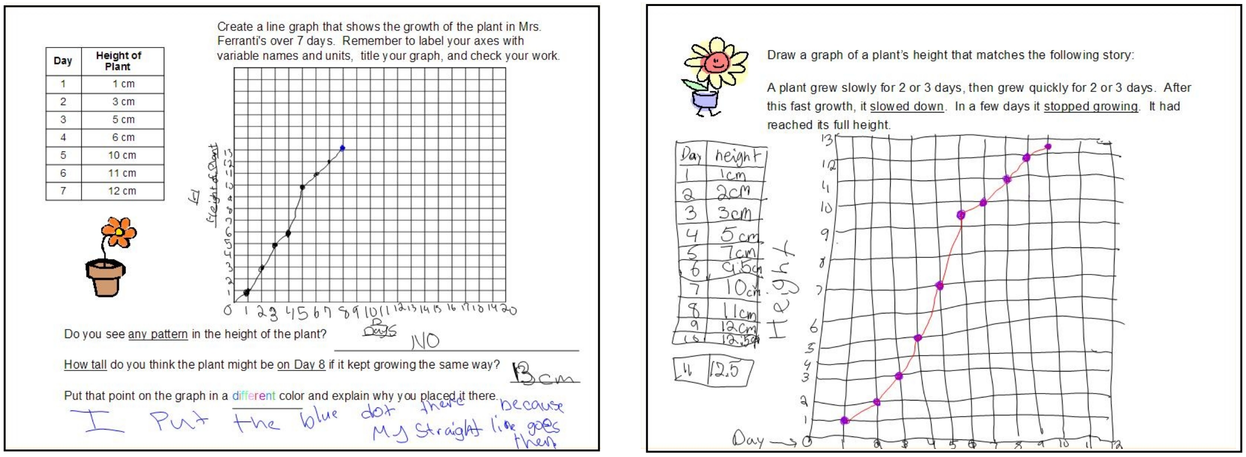


Figure 15. 4th grade math work on graphing data

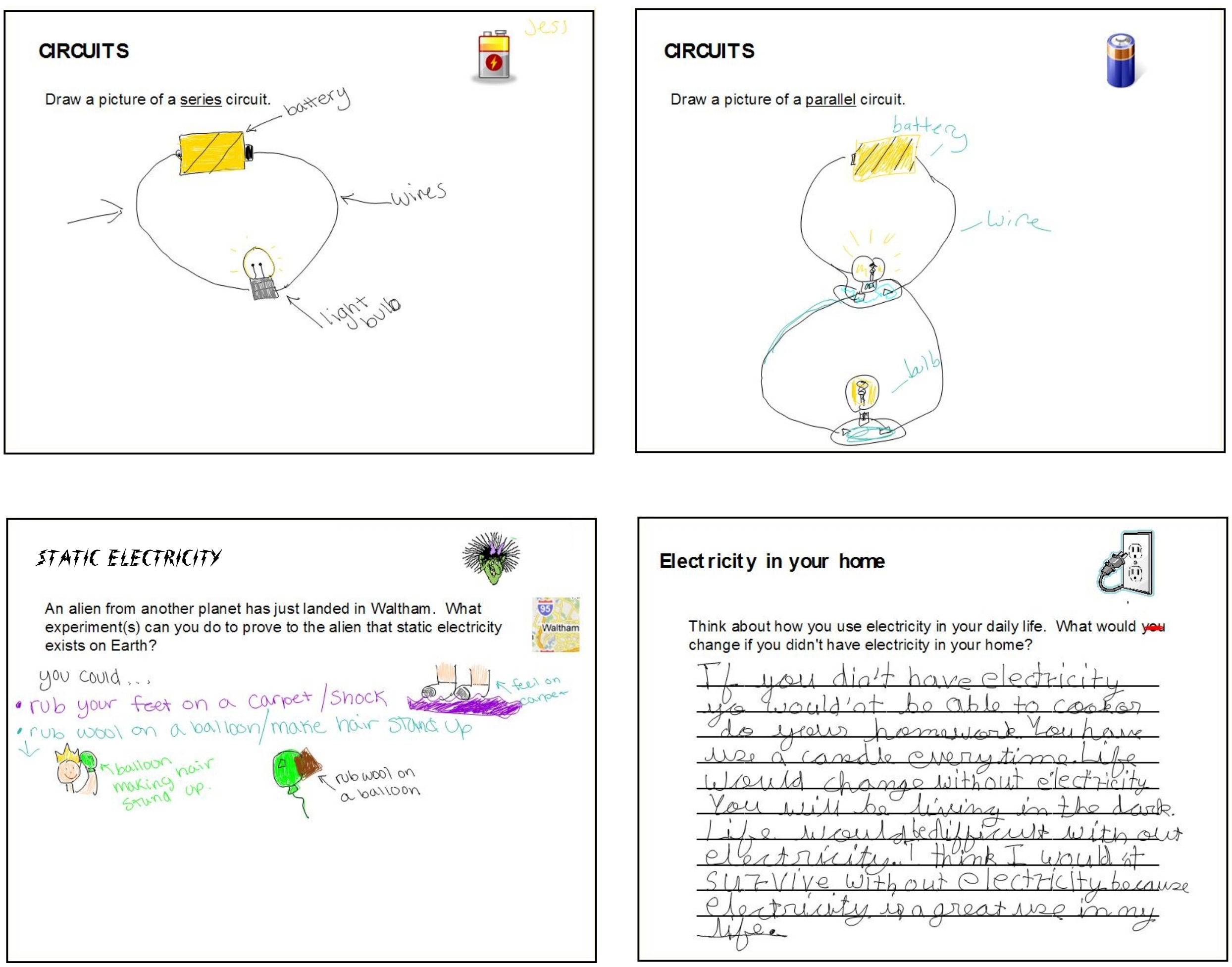


Figure 16. 4th grade science work on electricity

In one classroom session, the fourth grade students took charge of teaching the class. Below are examples of their classmates' work. (This trial is discussed in more detail below in Section 5.1.)

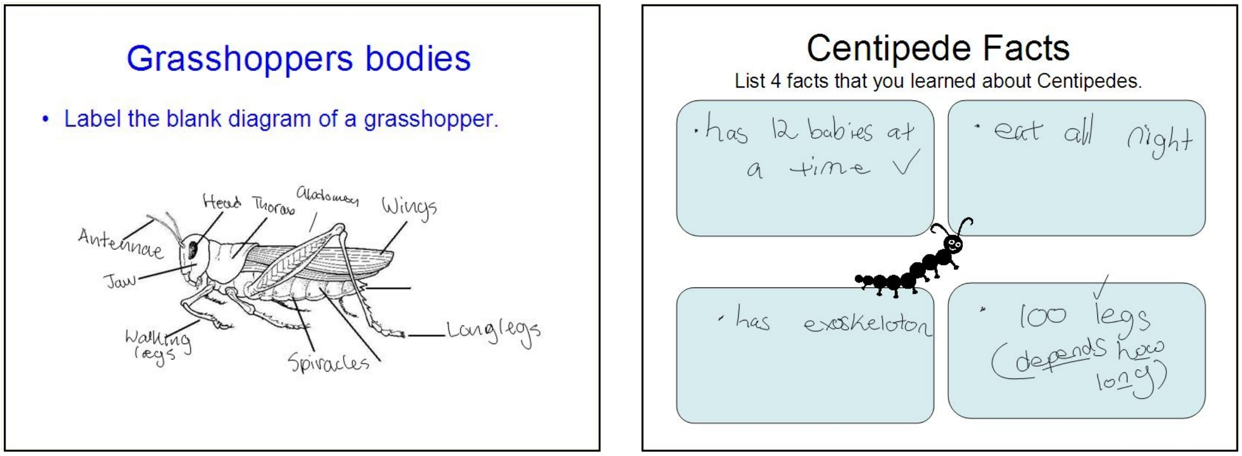


Figure 17. 4th grade student-created lesson on insects

Fourth grade math. In a fourth grade class in Newton, the teacher used the tablets to help her students visualize volume. Below are examples of her students' work.

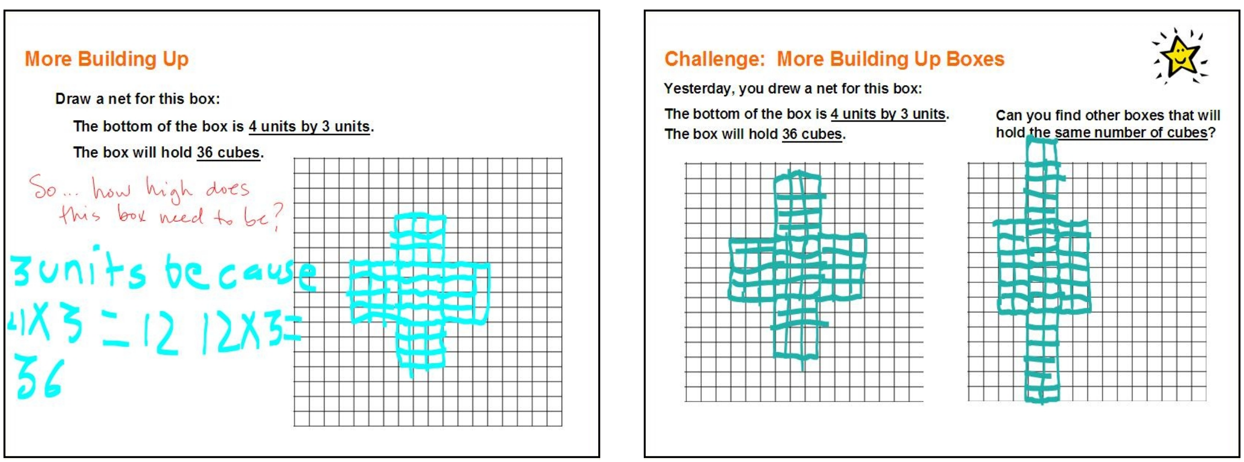
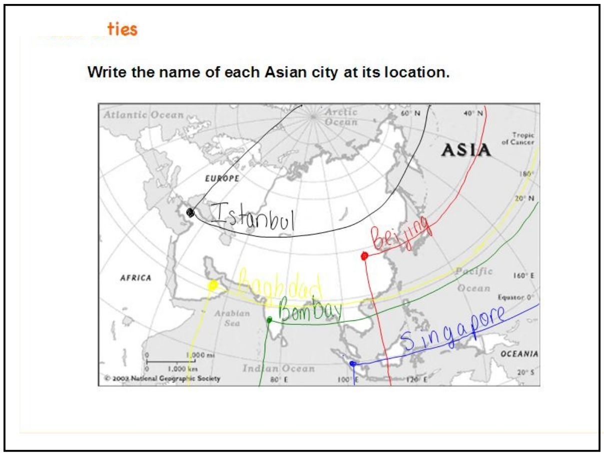


Figure 18. 4th grade work on creating nets to visualize volume

Sixth grade science. We worked with a sixth grade teacher in Waltham who used the tablets to teach her students about latitude and longitude and the Ring of Fire.



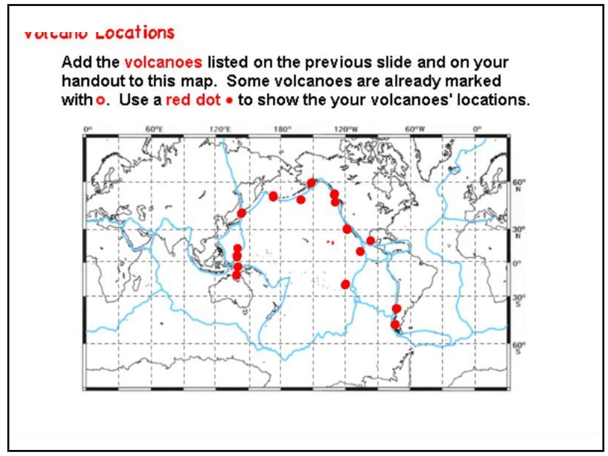


Figure 19. 6th grade work using maps for lessons on latitude and longitude and the Ring of Fire

4. Curriculum Adaptation

In each classroom, we worked with teachers to adapt their existing curriculum for use with the tablet computers. This adaptation was often nontrivial. The task involved:

- Creating open-ended items, based on the teachers' curriculum as much as possible, that would take advantage of tablet characteristics and provide the opportunity for rich classroom conversations

- Deciding how to break up the material into sequences of slides. This task was often challenging due to the restrictions of the slide metaphor and the lack of screen real estate with 12" tablets

- Designing graphics

- Creating PowerPoint slides to be exported into the format needed by our technology; some teachers were more comfortable than others in creating their own slides

As we go forward, we intend to focus our work on a particular math curriculum so that we can avoid the time-consuming task of adapting curriculum separately for each classroom. Working within a single curriculum also has the advantage that we can use the assessments created by that curriculum's authors as a tool for evaluating the technology. In the long run we intend to create a system that could be used with any curriculum, but we feel that in the short run removing the curriculum variable will provide us with more controlled research opportunities and a smoother classroom implementation process.

5. Summary of Findings

5.1 Use of the technology

Both teachers and students found the technology easy and intuitive to use. Students enjoyed using the pen, especially being able to use multiple colors and to modify their inscriptions by erasing and redrawing. Sometimes students were distracted by the colors—in particular by the highlighter —but this issue was largely a function of classroom management. To minimize the distraction, we removed the highlighter from the available tools. Some students wanted to use a keyboard. Several of the more technologically adventurous students figured out how to open the tablet and swivel the screen so that they had access to the keyboard. In future implementations, we intend to give older students the ability to type.

Teachers liked being able to annotate student work using the pen, since it extended what they do with paper-based student work. They also liked having a digital record of student work, especially when a student submitted a series of answers that revealed the evolution of his or her understanding.

Most students enjoyed submitting their work, especially if they thought they had correctly solved the problem. While some students preferred to have their work displayed anonymously, many of the students didn't care if their work was identifiable. One reason for this lack of concern was that in smaller classes anonymity was difficult to achieve, as students knew one another's handwriting. Students also were less concerned about having their incorrect answers shown if a classroom culture had been established in which considering one another's work was an accepted process, and the students had learned how to be respectful of others' work, whether or not it was completely correct.

Although teachers used the ability to show and discuss student work during class to different degrees, they all felt that this capability was one of the most pedagogically useful aspects of the tablets. It takes skill and practice, however, to choose appropriate student work for classroom discussion "on the fly." Some teachers found this task easier than others, primarily based on their pedagogical style.

In terms of student learning, most of the teachers felt that the tablets resulted in increased engagement, focus, questioning, and work completion for most students. One fourth grade teacher observed that her students had grasped the concept of divisibility better using the tablets than they had previously. Most of the teachers thought that continued use of the tablets could lead to increased student learning, but we did not have the opportunity to test these claims; that is the work of the new research project.

Sometimes the software seemed to exacerbate common classroom issues. One example is the problem of students finishing their work at different times. This issue is a common one, and the teachers we worked with were accustomed to providing "sponge problems" for students who finished early and relying on students to take out a book to read if they finished this additional work. No student wanted to read a book, however, if he or she had a tablet in front of them, so they tended to get distracted playing with the tablet. We anticipate that this issue will become less of a concern when the tablet isn't a novelty and when teachers work with a curriculum rich in extra "sponge" problems; we will be investigating these issues in our second grant.

In the classroom in which we were able to conduct three trials, one of the trials involved groups of students playing the role of teacher, creating a lesson that involved having their classmates wirelessly submit answers to questions about the lesson. (The students created their own PowerPoint presentations, which we exported into the file format needed for our technology.) The students were able to use the technology in the role of teacher very easily—a testament to the intuitive user interface. Their classmates enjoyed writing answers to questions, wirelessly submitting the answers, and seeing their answers displayed publicly, just as they had with the teacher presenting and guiding a lesson. Two of the submitted answers are shown in Figure 17.

5.2 Classroom data collection

As detailed in the Final Evaluation Report, submitted separately, data collection included:

- formal observation of trials attended using an observation protocol
- post-trial interview with participating teachers (five teachers)

- student focus-group
- student evaluations collected at end of trials

Observations were coded and analyzed to discern patterns of change among identified learning dimensions present during the trials. Teacher interviews were coded and emergent themes noted and analyzed. Student evaluations were reviewed and repeated themes noted and analyzed.

Excerpts from Evaluation Reports are below. (See the Final Evaluation Report, submitted separately, for more details.)

Year 1

p. 3. What [our] findings suggest is that INK-12 tablet sessions provide ample classroom opportunities for interactive instructional methods (lecture with discussion), increased communication and feedback (Send/receiving data), and engaged students in active learning situations. Conversely, interruptions are few, as is general technology instruction (this might suggest that participating students are comfortable with computer technology, and adapted quickly to the interface since very little non tablet-specific technology training or support occurred). There were also very few instances of cooperative learning (explained by students focusing on their own tablets, not working in groups), and passive reading seat work.

p. 4. [Our] findings suggest that overall, students were highly engaged (85% of the time)….

p. 6. Regarding subject matter, grade eight studied slightly more of each content area mathematics and science than the younger students, while fourth grade spent more time on technology than eighth graders. All these findings logically follow developmental learning expectations for the grade levels, though we would hope to see an increase in the higher cognitive intake levels for all age students as the programs mature in classrooms.

p. 8. The greatest number of student comments included the asset of receiving fast feedback from the teacher, the ease of erasing a submitted response, the varied visual representations possible with the colors and pen shapes, how they thought the technology helped cover more material than they normally did, and the importance of seeing other students' answers publicly.

p. 11. What we have learned from teachers and students is that the INK-12 tablet computing environment has much to offer classrooms, at both the 4th and 8th grade level, and in both mathematics and science education. Classroom learning characteristics represent many of those associated with project-based learning, interactive instruction, active learning, and inquiry-based learning. Students respond very well, in particular to those elements social in nature, for example, publicly sharing work and communicating with the teacher via wireless messaging. The laptops themselves, while somewhat awkward to deploy, keep charged, test, and distribute, proved very easy to use for both teachers and students; the interface seemed intuitive to all users.

p. 15. Overall, students seemed very engaged, not just the first "novelty" moments, and that excitement resulted in increased participation. The drawing component provided an alternative input to handwriting or keyboarding, which proved popular and successful with all kinds of students, especially those in the lower academic sector. Student sharing of work was very successful, whether anonymous or not, and provided a classroom context that invited discussion and student-led explanations. Teachers were unanimously enthusiastic about using and developing lessons specifically for the tablets. They suggested features, improvements, and thought of many potential uses beyond those specified by the project. All felt to some extent that wider and longer-term use was possible within their classrooms, and would be eager to continue trialing the technology should the opportunity arise.

Year 2

p. 4. Note the greatest change in Year 2 is the increase of classroom discussion (12.5%), the increase in small group discussion (10.7%), and the increase of teachers interacting with students 1X1 (9.1%). These suggest that in fact, the modifications to the tablets, the changes in curriculum design, most likely resulting in increased ease of use, have led toward an increase in collaboration (classroom discussion and small group discussion).

p. 5. These findings again support those from the first year in that INK-12 tablet sessions provide ample classroom opportunities for interactive instructional methods (lecture with discussion), increased communication and feedback (Send/receiving data), and engage students in active learning situations.

p. 5. These findings suggest that again, as with last year, students were highly engaged (91% of the time, up 4.2% from Year 1), that although the majority of cognitive activity was at the first level, Receipt of knowledge (91%, down 2.3% from Year 1), there was significant evidence of Level 2, Application of Procedural Knowledge (44%, up 3.3% from Year 1), and Level 3 (31%, up 0.8% from Year 1), Knowledge Representation. Even for Level 4, Knowledge Construction, while the total activity was relatively rare (4%), it too showed a gain (2.7%). These readings help validate the scale used, as the years show quite similar evidence; however, the slight gains toward increasingly complex cognitive activity suggest an improved teaching and learning platform from the first year.

References

1. Koile, K., Reider, D., and Ruben, A. INK-12: A Pen-based Wireless Interaction System for K-12. In *The Impact of Tablet PCs and Pen-based Technology on Education: Evidence and Outcomes*. Reed, R. and Berque, D. (editors). Purdue University Press, 2010.

2. Koile, K. and Singer, D. Assessing the Impact of a Tablet-PC-based Classroom Interaction System .In *The Impact of Tablet PCs and Pen-based Technology on Education: Evidence and Outcomes*. Reed, R., Berque, D., and Prey, J. (editors). Purdue University Press, 2008.

3. Koile, K., Chevalier, K., Rbeiz., M., Rogal, A., Singer, D., Sorensen, J., Smith, A., Tay, K.S., and Wu, K. Supporting Feedback and Assessment of Digital Ink Answers to In-Class Exercises. In *Proceedings of IAAI 2007*, July, 2007.

4. Koile, K., Chevalier, K., Low, C., Pal, S., Rogal, A., Singer, D., Sorensen, J., Tay, K.S., and Wu, K. Supporting Pen-Based Classroom Interaction: New Findings and Functionality for Classroom Learning Partner. In *Proceedings of First International Workshop on Pen-Based Learning Technologies 2007*, May, 2007.

5. Koile, K. and Singer, D. Development of a Tablet-PC-based System to Increase Instructor-Student Classroom Interactions and Student Learning.In *The Impact of Tablet PCs and Pen-based Technology on Education: Vignettes, Evaluations, and Future Directions*. Berque, D., Prey, J., and Reed, R. (editors). Purdue University Press, 2006.