INK-12: Teaching and Learning Using Interactive Ink Inscriptions in K-12
Annual Report, Year 2, August 2012

PIs: Kimberle Koile (MIT), Andee Rubin (TERC)
Evaluator: David Reider (Education Design, Inc.)

1. Introduction

The INK-12 project is investigating how the combination of two technological innovations—*pen-based input* and *wireless communication*—can support classroom practices that teach two skills critical to mastering STEM disciplines: 1) *creation and manipulation of representations for mathematical and scientific objects,* and 2) *communication of those representations and associated feedback.* We are investigating how technology that facilitates these capabilities, via a set of networked tablet computers, can support teaching and learning key mathematical and scientific concepts in upper elementary school. *Pen-based interaction* enables creation of inscriptions—handwritten sketches, graphs, notes, etc.—which are critical in STEM fields, where content is often most easily expressed as a mixture of text and drawings. *Wireless networking* enables facile communication of inscriptions, and other representations, among teachers and students, and supports formative assessment and classroom discussions directly based on student work.

During our second year, we continued to develop our software and conducted six multi-day trials in fourth and fifth grade classrooms using the NSF-supported curriculum *Investigations in Number, Data, and Space*. Pedagogical strategies from this curriculum that are particularly relevant to the INK-12 project include: students creating mathematical representations, sharing representations and other work, talking about different approaches to problems, and revising their work in response to feedback.

In the sections that follow, we describe the INK-12 interaction model and our research questions, detail our technology development, and describe our classroom trials and findings. Excerpts from the evaluator's report, submitted separately, are included in the last section.

2. INK-12 Interaction Model

The basic classroom setup is as described in our Year 1 Annual Report: 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 with which student and teacher machines communicate. Using the tablet computer's pen, each student writes on his or her tablet screen, e.g., answers to problems, then wirelessly submits his or her "digital ink" inscription to the teacher. The teacher can view all student submissions and lead a class discussion by choosing several submissions to annotate and display anonymously via the projector. The INK-12 project extends this *create* and *share* model of interaction to include an intermediate *interpret* step, designed to aid teachers with what we observed to be a very difficult task—sorting and choosing pedagogically interesting student work for discussion. Our current *create*, *interpret*, and *share* model of interaction is shown in Figure 2.1 and described below.

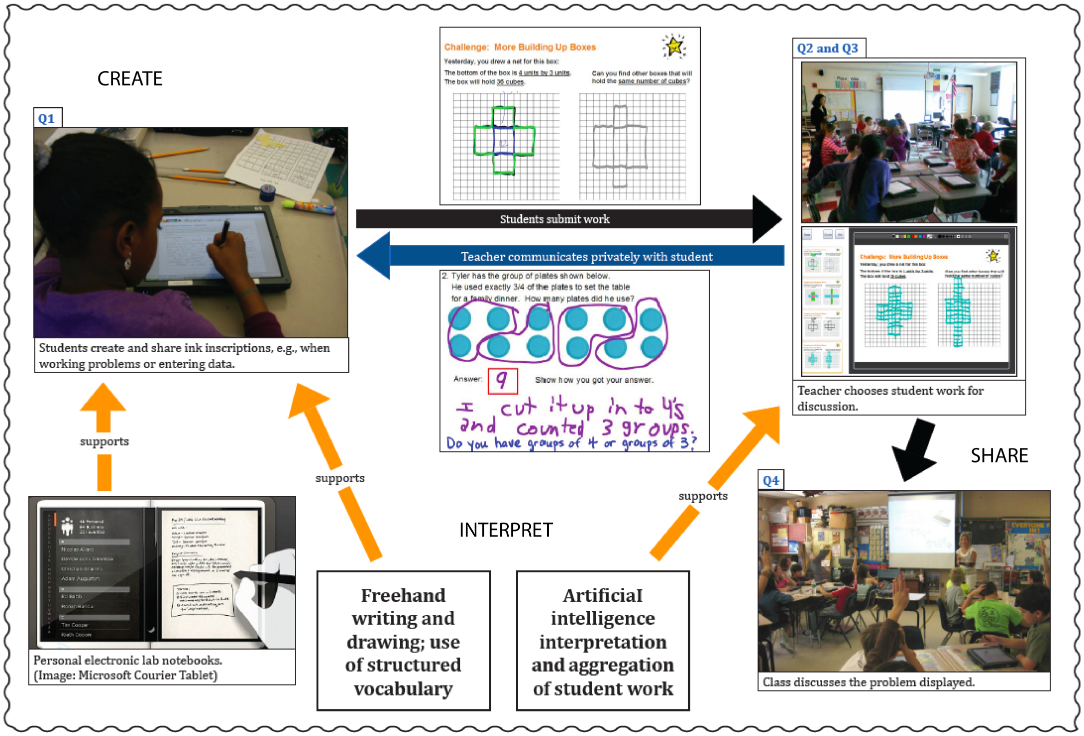


Figure 2.1 INK-12 model of classroom interaction

Create. Students create inscriptions freehand, as in the example in Figure 2.2a, and also with the aid of what we broadly call *palettes*—sets of graphical icons that can be used as parts of inscriptions. One kind of palette will contain pre-programmed icons such as geometric shapes, grids, or chemical elements. Another kind of palette will contain icons that teachers and/or students design and define in class so that they are using common representational tools. Such icons are used as "stamps" to create a drawing containing multiple identical images. An example is shown in Figure 2.2b. The graphical icons create a *structured vocabulary* that can aid interpretation, both by human and by machine.

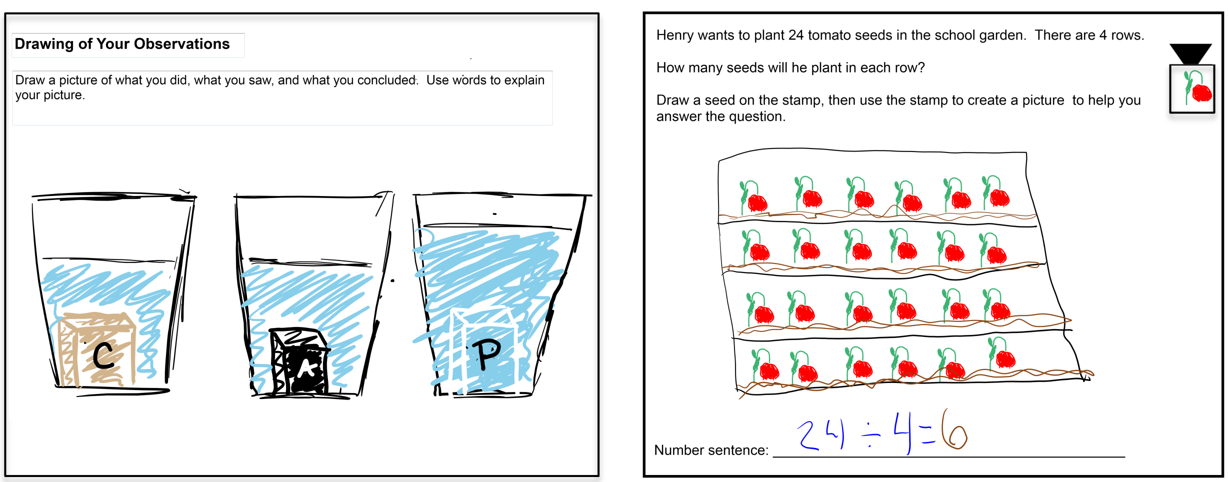


Figure 2.2 a. Freehand drawing describing a displacement experiment

b. Drawing made using a stamp to solve and explain a multiplication problem

Interpret. To support teachers in viewing, sorting, and choosing student work, we are developing software that uses artificial intelligence (AI) techniques to interpret, aggregate into similarity classes, and assess student work when possible. In some cases it is possible to use handwriting recognizers to interpret student work. Structured vocabularies, e.g., such as the stamp of a tomato plant shown in Figure 2.2b, facilitate the interpretation process, as the computer will "know" where particular icon images are located. A computer, for example, will be able to identify the identical stamped images in Figure 2.2b more easily than the freehand cups and materials in Figure 2.2a. The challenge, discussed in a later section, is to enable the computer to know what the image represents, e.g., a single tomato seed in this example.

Share. Teachers want to be able to publicly display multiple examples of student work and annotate the examples as a way to encourage conversations in which students defend their reasoning and listen critically to others' reasoning. We are developing a variety of formats in which to display multiple examples of student work and tools for writing on the display either before or during class discussion.

With this create, interpret, and share model of interaction, our INK-12 research questions are the following:

1. How do inscriptions created using digital pen-based technology differ from those created using pen and paper?
2. How can structured vocabularies enhance students' inscriptions and the software's ability to interpret student work?
3. What tools can effectively help support teachers in selecting student work for classroom discussion?
4. How does the use of technology for submitting and sharing student work change classroom participation structures?

This year we investigated these questions by continuing to design and implement features for our software system, which we call Classroom Learning Partner (CLP), in the fall and deploying it in classroom trials in the spring.

3. Technology Development

We focused technology development this year in the following areas: *AI methods* for interpreting and grouping student work, *structured vocabularies*, *ink replay* for viewing a student's process of creating inscriptions, *audio explanations*, new viewing and display features for the *teacher user interface*, and a *persistent store* for student work.

AI Methods

Sorting and choosing student work for class discussion can be overwhelming for teachers. To help with this task, we are investigating the use of artificial intelligence (AI) techniques to interpret and group student work into similarity classes to help teachers review student work more quickly and easily. In particular, we are investigating interpretation of five types of handwritten digital ink student answers: *handwritten text*, e.g., for numbers, equations, words; *shading* of a given region, e.g., for fraction problems; *data tables* containing handwritten text; *graphs*; and geometric *shape recognition*, e.g., for circles, squares, etc.

For *handwritten text*, we use the built-in Microsoft handwriting recognition software that is a component of the Windows operating system. Preliminary analysis of the software's recognition of students' handwritten answers reveals three characteristics of the software:

1. It performs well on long words and series of words due to matching against an English dictionary. In the examples shown in Figure 3.1, it correctly identifies the word "multiplication," in spite of the misspelling.

Figure 3.1 Student handwritten response correctly interpreted

2. Handwriting in the absence of stray ink strokes achieves high accuracy rates. In the examples shown below in Figure 3.2, the software correctly interprets one student response, but not the other, in which a stray vertical line causes addition of an extra digit after the "72".

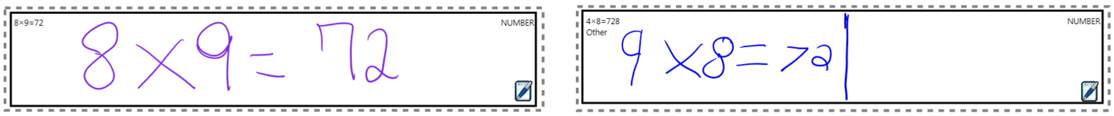


Figure 3.2 One response correctly interpreted, one incorrectly interpreted due to stray ink stroke

3. Specifying a type for the expected response generally improves the interpretation result.
In the example shown on the left in Figure 3.3, the second character is correctly identified as a "4" instead of a "Y" because the handwriting recognition software is expecting a number rather than a letter. In Figure 3.3 on the right, the denominator is correctly interpreted as an "8" rather than a cursive "E".

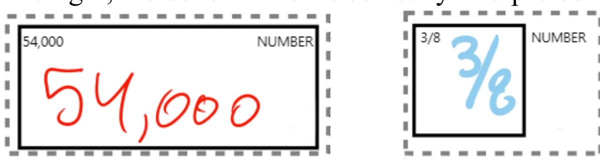


Figure 3.3 Student handwritten responses correctly interpreted as numbers

Specifying the type, however, is not always sufficient, as illustrated in the examples in Figure 3.4. The response on the left is mixed text and number; the text is correct, but the comma in the number is incorrectly interpreted as a "1". On the right, the fraction is incorrectly interpreted as a two-digit number due to the handwriting recognition software's difficulty in interpreting vertical columns of text.

Figure 3.4 Student handwritten responses incorrectly interpreted

Analysis of 43 student responses for the three multiplication problems shown in Figure 3.5 revealed a correct interpretation rate of at least 80% for each problem, with a rate of 88% for the middle problem (50 x 3). We are continuing our analysis of student handwritten responses in order to determine whether the achievable interpretation rates are sufficient to enable meaningful clustering of student responses into groups based on similarity of response.

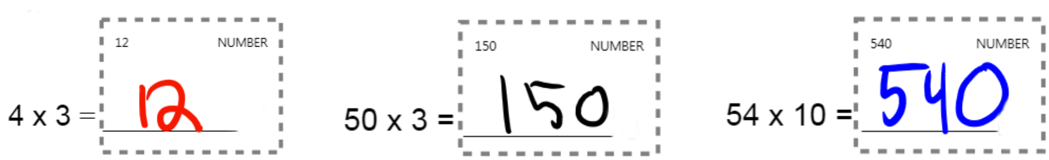


Figure 3.5 Student handwritten responses correctly interpreted as numbers

For *shading* problems, we have developed an interpretation technique that computes the percentage of a region that is shaded. The technique discretizes a region into grid cells and divides ink strokes among the cells, identifying the group of cells that contain strokes. It also identifies horizontal and vertical lines that should be considered guidelines rather than part of the shaded area. Below is a student response to a fraction shading problem (Figure 3.6a) and the same response with the underlying grid and machine-interpreted shaded area shown (Figure 3.6b).

Figure 3.6 a. Student response to being asked to shade in ½ of a rectangle

b. Student response with underlying grid and machine-interpreted shaded area shown

Note that providing the student with a boundary for the region to be shaded greatly increases the ease and accuracy of machine interpretation. Below in Figure 3.7 are examples of student responses to being asked to create a visual representation of 2/3. Because the students drew their own boundaries, an ink interpreter would have difficulty locating both the region and the shaded area of interest, and therefore would not be able to interpret the student response. Since the point of the lesson was to create a representation for the fraction, rather than to draw a rectangle, providing the rectangle does not compromise the lesson.

Figure 3.7 Student fraction representations that would be very difficult for a machine to interpret

The results of one of our tests for the fraction shading method are shown in Figure 3.8. In the math problem analyzed, the students were asked to shade 3/8 of a region. The histogram in the figure depicts the number of student responses for a range of values returned by the interpretation method. The majority of student answers were interpreted accurately enough for grouping the answers into similarity classes, with the peak of the range between .35 and .45, which is close to the target value of .375. The answers that proved difficult to interpret were the result of diversity in the way students supplied answers: While some students meticulously filled every pixel in a portion of the region, others supplied a cursory set of scribbles that barely covered the area they intended to shade. We are continuing our analysis of student responses and investigating improvements to our interpretation method for shading problems.

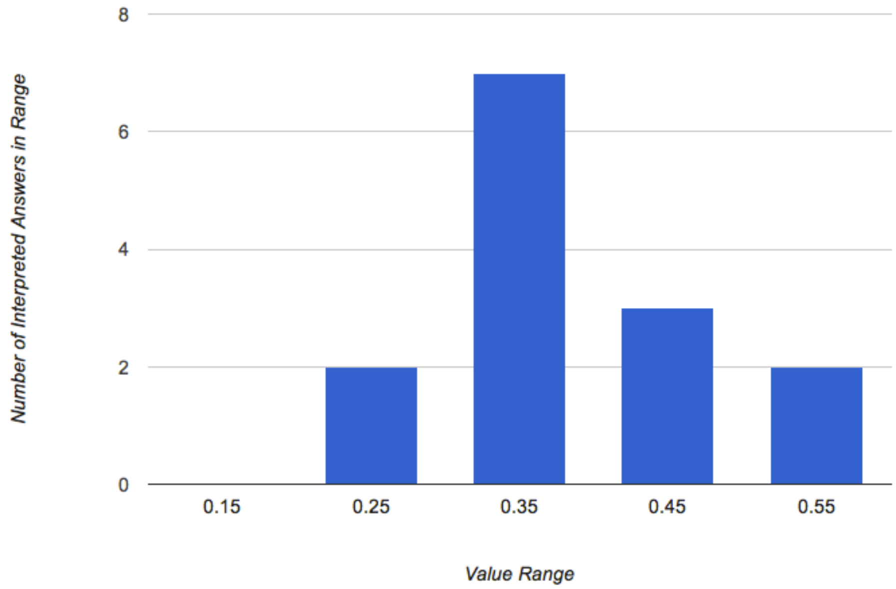


Figure 3.8 Analysis results for fraction shading problem; correct interpretation of shading is .375

For interpreting *data tables*, we developed a technique that combines handwriting interpretation and the grid discretization employed for shading problems. For data tables, the cells in the interpretation grid correspond to the cells in the data table. Ink strokes are assigned to a single cell, then passed to the handwriting interpreter. Shown below in Figure 3.9 is an example of a data table with a student's answers. The interpretation method correctly identified the numbers in this example as "40" and "8".

Input	**8**	**24**	**32**	40	**48**
Output	**2**	**6**	8	**10**	**12**

Figure 2.9 Data table with student handwritten responses

Testing the interpretation method for the problem shown in Figure 3.9 revealed a 93% accuracy rate for the number "40" and a 57% accuracy rate for the number 8 in the sample of 14 responses. Analysis of other data table problems continues.

For *graphs* we developed an ink stroke segmentation technique that extracts shape information and develops a numerical description of a set of ink strokes that represent points and segments between points. The information describes the geometry of the strokes in terms of curvature between key points, which are points with high curvature. Below in Figure 3.10 is an example of interpretation of a graph using this technique. The key points that the interpreter identified are shown as red dots.

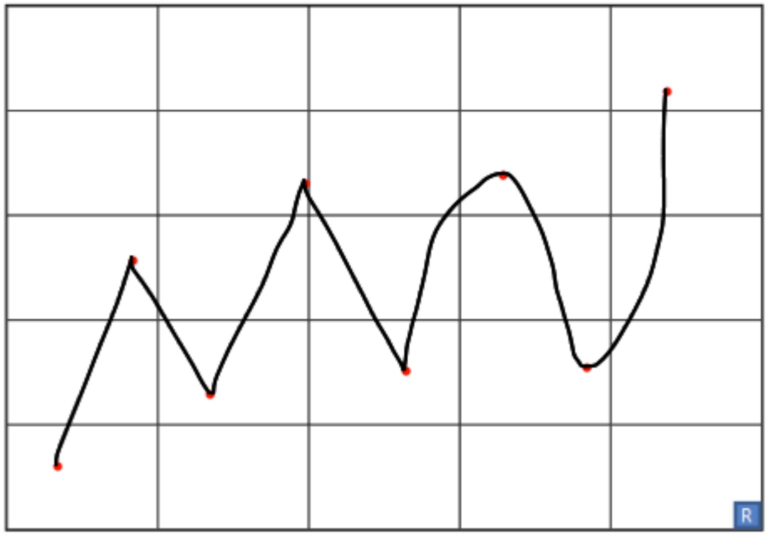


Figure 3.10 Interpreted graph; the identified key points are shown as red dots

The math curriculum in our classroom trials did not include graphing problems this year, so we did not evaluate the graph interpretation method on student work. The method performed well on graphs created outside the classroom, and we will test it with student work this next year.

For *shape recognition*, we use Microsoft's built-in shape recognizer, which detects squares, rectangles, triangles, circles, and ellipses. Shape recognition is especially useful for determining where particular shapes have been drawn on a number line or graph, and where items have been circled. Shown below in Figure 3.11 is a test of the shape recognizer. We did not test the shape recognizer on student work this year. We intend to do so this next year.

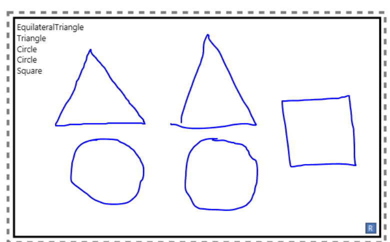


Figure 3.11 Interpreted shapes

Structured Vocabularies

Creating representations with multiple copies of identical groups can support students' understanding of mathematical relationships. In CLP, students can create their own replicable images using what we call *stamps*, and a new tool that we implemented this year, which we call *tiles*. Each of these tools adds structure to student work, aiding interpretation by both human and machine. Both tools are accessible to the students via a top command bar, shown below in Figure 3.12.

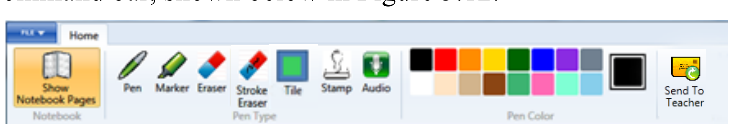


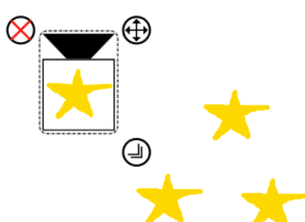
Figure 3.12 Command bar; students tap on Tile or Stamp to add one of the objects to a notebook page

Details of the stamp and tile tools are presented below; use of the tools in classrooms is described in the Classroom Trials section (Section 4).

Stamps. Shown in Figure 3.13 is a fourth grade student using a stamp to help her solve a multiplication problem. She tapped on the stamp tool icon on the top command bar, drew an image on the blank stamp that appeared on her notebook page, then dragged the stamp object to create multiple identical images.

Figure 3.13 Student using a stamp, whose image she drew, to explain that four rows of six tomato seeds result in 24 tomato plants (6 x 4 = 24)

We added functionality this year that enables students to move, delete, or resize any stamp object or image object created using the stamp: By hovering over the object, e.g., the stamp object shown in Figure 3.14a, command icons pop up for the operations. A stamped image is created by touching the tablet pen to the stamp "handle," dragging the image to a new screen location, then raising the pen. Three such images are shown in Figure 3.14a. Shown in Figure 3.14b is an example of student work created using a stamp to illustrate 15 ÷ 3 = 5.



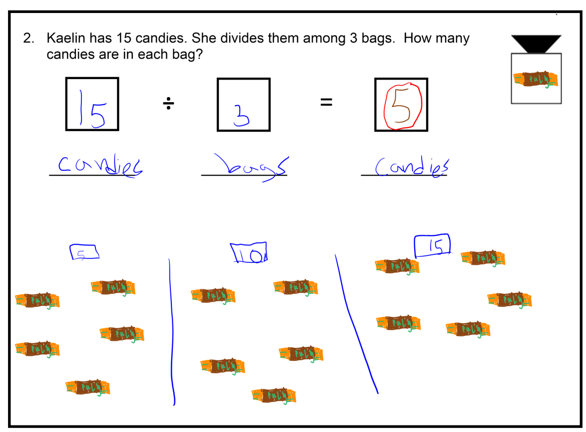


Figure 3.14 a. Stamp with popped up command icons for deleting, moving, and resizing; and three stamped images

b. Student work using stamps to explain a division problem

We are investigating methods for machine interpretation of student work created using stamps. In the example shown in Figure 3.14b, the machine can identify the location of each of the 15 stamped images. With the aid of ink interpretation methods, it also can identify the vertical lines and group the images into three groups of five objects. What it cannot do, however, is "know" that each image represents a single object, in this example a piece of candy. Without such information, the machine cannot match the student response against answers supplied by the teacher. We are working on methods for enabling students to explicitly state what their stamp represents so that such matching, and the resulting grouping of student work based on the matching, will be possible.

Tiles. Shown in Figure 3.15 is a fourth grade student using tiles to help him solve a multiplication problem. He tapped the tile icon on the command bar, then tapped the screen where he wanted a tile to appear.

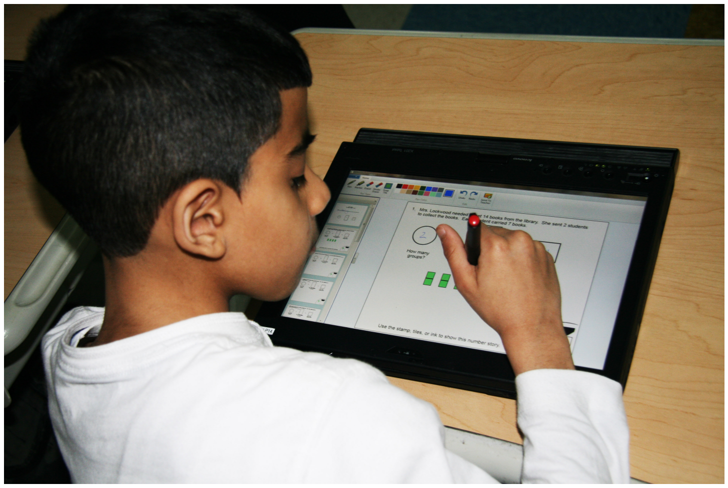
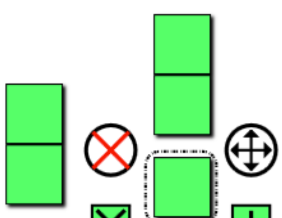


Figure 3.15 A fourth grade student using the tile tool

Students can create towers by "snapping" the tiles together: When the tiles are dragged so that they are touching, they are joined together vertically. The towers then become objects that can be deleted, moved, duplicated, or modified. As with stamps, the command icons pop up when the student hovers the pen over a tile or tower. Shown below in Figure 3.16 are examples of tiles, towers, and student work employing tiles and towers.



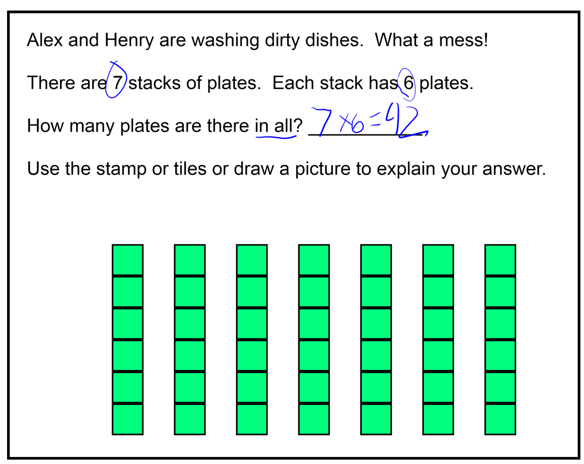


Figure 3.16 a. Tiles "snapped" together into a tower *b.* Student work using tiles to show 7 x 6 = 42

We are investigating methods for machine interpretation of student work created using tiles. The machine can identify the location and number of tiles and towers, and there is no ambiguity as there is with the use of stamps, so machine interpretation will be more straightforward.

Ink Replay

Teachers routinely use formative assessment to garner insights into students' thinking strategies. Typically the instruments available to teachers consist of periodic assessments that provide data about students' performance, but little information about students' thought processes. We implemented a feature this year that does give teachers insight into students' thinking: When students work with their CLP notebook—write a text explanation, draw a picture, etc.—their interactions are recorded in what we call an *interaction history*, which can be replayed by the teacher. As described in more detail in the Classroom Trials section (Section 4), this feature enables a teacher to understand much more about student thinking than is possible by viewing completed work. Consider the following examples of student work shown in Figure 3.17. Both examples show well-articulated explanations. The student on the left struggled with the problem, however, as evidenced by multiple erasures and different strategies attempted before arriving at his final answer. This struggle was evident when the teacher played back the student's interaction history. Classroom observations confirmed that the student had struggled with the problem, then received help from a teacher's aide.

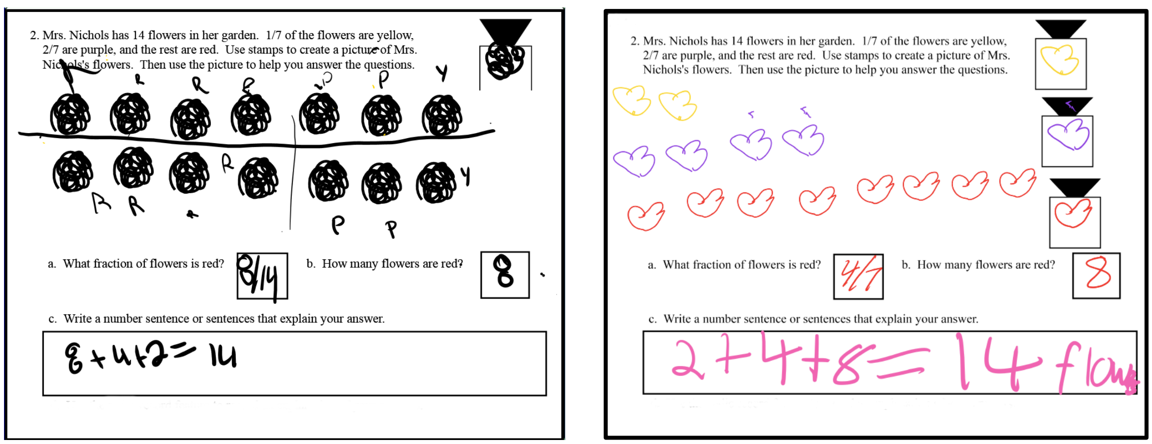


Figure 3.17 Student work examples; only by viewing interaction history did the teacher know that the student whose work is shown on the left struggled with the problem

In implementing the interaction history functionality, we had to design not only an appropriate representation for the history, but also determine how many student interactions could be stored as part of the history without slowing down CLP or the wireless network traffic between student and teacher machines. We investigated the following questions: Since the interaction history is stored as part of a student notebook page, what size of notebook page would result in acceptable network transmission time for use in the classroom? To achieve this page size, what kinds of interactions should be sampled, and how often should interactions be sampled and added to the history? What sort of format would enable efficient and fast transmission of interaction histories over the network?

Figure 3.18 shows the results of our analysis of network transmission delay as a function of page size. The data suggest that page sizes under 2 MB are 47% more likely to take less than 10 seconds to be transmitted across the network than pages consisting of between 2 MB and 7 MB. We therefore chose a target page size of less than 2 MB—large enough to hold sufficient information, but small enough to be transmitted in a reasonable amount of time.

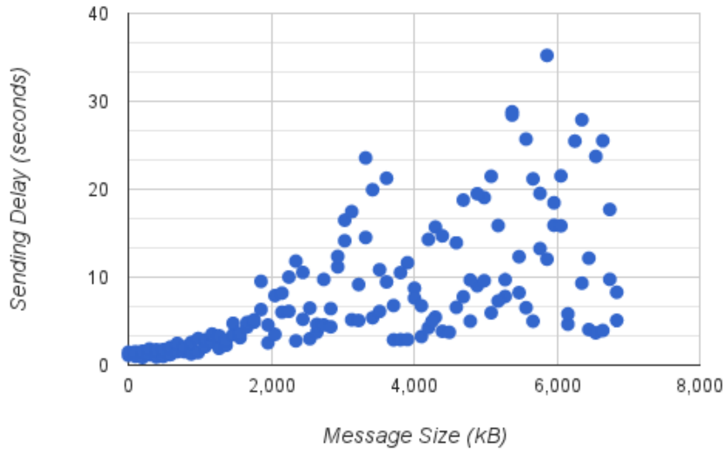


Figure 3.18 Timing data for network transmission delay vs notebook page size

In investigating which student interactions to store, we arrived at the following list: adding, removing, or moving any sort of object on a page, e.g., stamp or tile; adding or erasing ink; submitting work to the teacher. We investigated different methods for encoding this information in two different binary formats[1] for storage and transmission; and explored different sampling rates, i.e., how often to sample student interactions. Our optimal sampling technique, which sampled interaction every 100ms then segmented pen strokes into lines and arcs (rather than leaving them as a large set of points), resulted in a 70% decrease in the size of the interaction history. Our optimal encoding method resulted in a further 85% reduction in average page size. Figure 3.19 depicts the effects of two different encoding (aka serialization) methods on notebook page size.

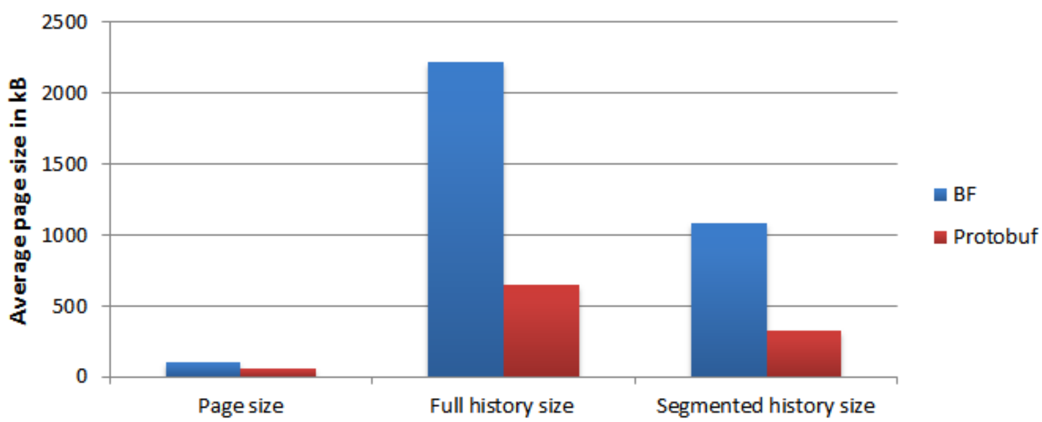


Figure 3.19 Effects of serialization methods on page size: Segmenting pen strokes in interaction histories results in acceptable page sizes for encoding via Google's Protocol Buffers (Protobuf)

We evaluated the storage and transmission of interaction histories in half of our classroom trials and determined that the histories did not slow down student or teacher machines. The histories also did not slow down network traffic in our trials with classes of size 7. The histories did slow down network traffic, however, in our trials with classes of size 16 and 21, so we will investigate further reductions in the size of the histories so that the histories can be submitted to the teacher for viewing during class. Teacher use of the histories is discussed in the Classroom Trials section (Section 4).

[1] Microsoft's BinaryFormatter and Google's Protocol Buffers

Audio Explanations

Elaborating on mathematical statements or scientific observations is key to students' developing advanced reasoning skills, but writing sometimes can be a barrier. This year we implemented an audio recording feature so that students can create oral explanations of their written work. We wanted to keep the user interface for recording simple and consistent with our existing interface. We also realized after testing in one classroom that students needed to be able to record more than one explanation. Our final design, which we tested in one of our classroom trials (see Section 4), is shown in Figure 3.20. Students add an "audio object" to their notebook pages, just as they add stamp or tile objects. Tapping on the green microphone in the top command bar adds the audio object to the page; the figure below shows two such objects, designated by the gray bar with the REC record or the play symbols. The object with the symbol already contains an audio recording, which is played by tapping the symbol. A recording is added to the object with the REC symbol by tapping on that symbol and speaking. The tablets have a directional microphone that captures the speech quite well. To delete an audio explanation, the student hovers over the object, as with stamps or tiles, and taps on the delete symbol that pops up. When students submit their work, their audio explanations are sent to the teacher along with the other work on the page. The teacher is able to play the recordings on her machine, either privately or for the class.

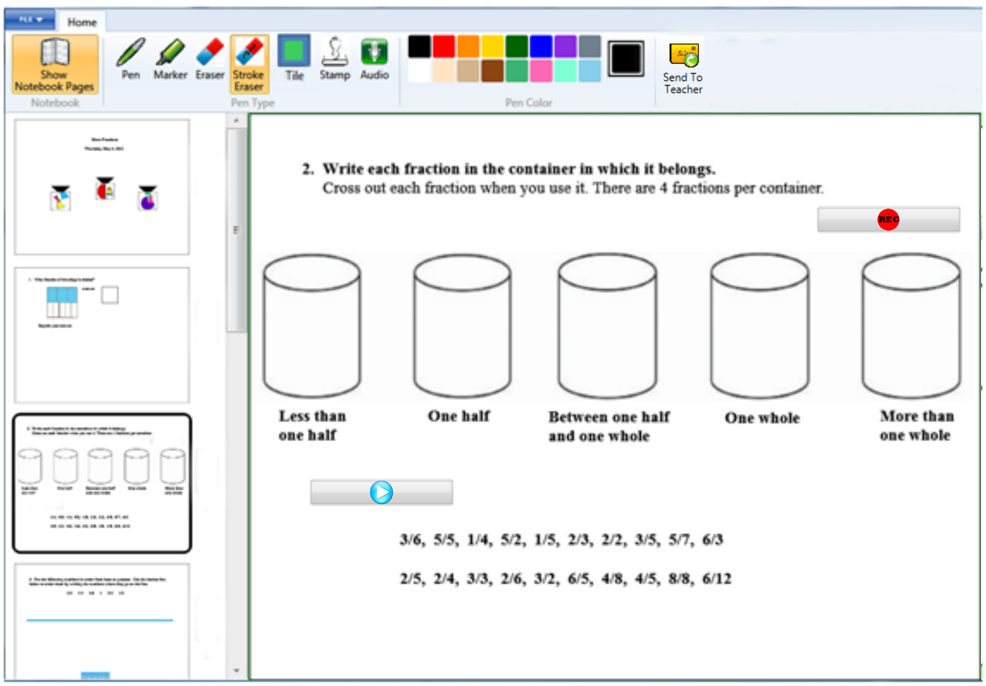


Figure 3.20 A student notebook page containing two audio objects, one with a recording (on lower left)

Implementation of the audio feature employed the Media Control Interface (MCI) developed by Microsoft to allow access to multimedia programs such as CD-ROM players and audio controllers. The interface enabled us to store and play the student explanations as either .wav or .mp3 recordings. As with the interaction histories, we had to consider the size of the audio recordings and the potential slow down of the CLP software running on student and teacher machines and of the network traffic. The .wav recordings are higher fidelity, and as such result in larger audio files. The higher quality recordings were not needed in the classroom, so we opted for the smaller .mp3 format, which reduced the file size by 85%. The .mp3 audio files caused no problems in storage on student notebook pages or in transmission to the teacher machine.

Teacher User Interface

We implemented features that enable the teacher to view student work and choose examples for public display. Shown below in Figure 3.21 is a screen shot of the teacher user interface. The far left panel displays the pages in the teacher notebook; the next panel to the right displays the pages of student work submitted for the notebook page with the highlighted icon. The central main display window shows student work examples that the teacher has chosen by tapping on pages in the student work panel. The examples are laid out in what we call a *grid display*, which can be projected when the teacher taps on the "Send to Projector" button on the top command bar. The student work is labeled with the student names on the teacher machine, but can be projected anonymously. The teacher can write on the grid display, and her ink will be displayed automatically on the projector. The far right panel shows other grid displays that the teacher has created and can select for projection at any time. The ability to create displays ahead of time is one of the teachers' favorite features: It enables them to prepare for class discussion ahead of time, either before or during class.

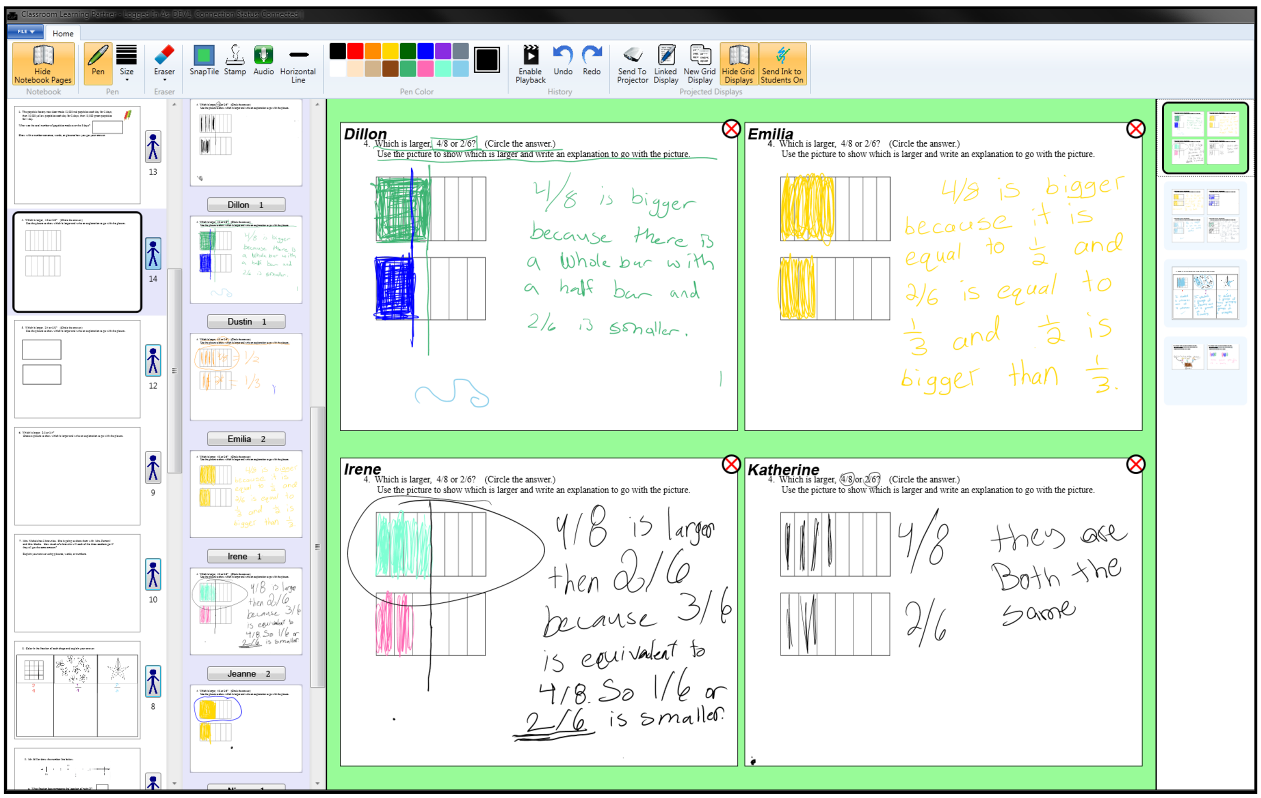


Figure 3.21 Screen shot of CLP's user interface for teachers

Persistent Store

When student work is created using digital technology, the work needs to be stored in such a way that it can be accessed after it has been created. We implemented a database for storing student notebooks and submissions, and also for enabling the teacher to easily view work from different lessons and different students. We needed a database that was flexible enough to accommodate different implementations of CLP notebooks and full-featured enough to enable a variety of query methods for viewing the student work. We settled on MongoDB, an open-sourced database with an active development community. MongoDB databases are easily scalable; can store data of arbitrary length, such as ink strokes, as well as images; and have built-in functions for quickly creating queries. Our implementation efforts involved multiple iterations of testing different representations for CLP notebooks and page objects, encoding (serialization) techniques, and networking protocols in order to enable student work to be transmitted from student machines to the database during class without disrupting the student machines or the network traffic. The database stores CLP notebook, page, and page object information; the relationship between these three types of objects is illustrated below in Figure 3.22.

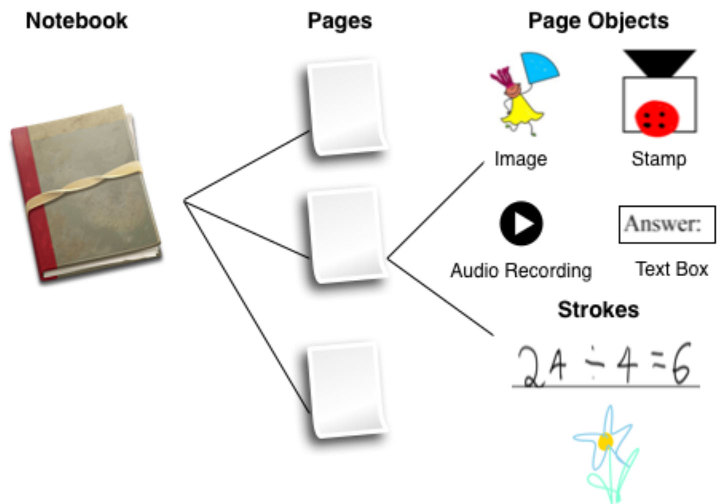


Figure 3.22 CLP hierarchy of data objects

Networking is at the core of the CLP system architecture, and we needed to ensure that the task of storing student work in a database did not disrupt the network traffic in the classroom. We chose to use a mesh network for its simple implementation and its ability to easily send the same message to multiple machines, e.g., a note that the teacher writes on a publicly displayed page going out to all student machines. A mesh network consists of a set of machines connected, in our case wirelessly, to form a connected graph. In our implementation, messages “flood” the network, i.e., are broadcast to multiple machines, which then pass them on to neighboring machines. Only the machines for which a message is intended pay attention to the message. This architecture was sufficient when only sending student written work over the network to the teacher machine and database, but became strained with the inclusion of more data in the form of multimedia elements on pages, e.g., audio explanations, and the storing of student interaction histories. To reduce the use of network bandwidth, the database saving system needed to send as little redundant data as possible and as efficiently as possible so as not to disrupt classroom usage. Our solution was to send student work on a page granularity: When students submit their work to the teacher, the single page on which the work appears is sent to both the teacher’s machine and to the database. This design groups together objects that appear on a page and helps to minimize network traffic: The entire notebook is not sent, which would involve sending many pages that had not changed, nor are individual objects sent, which would complicate the encoding of the object and page information in the database and the subsequent decoding upon retrieval from the database.

In addition to implementing and testing the database, we implemented a prototype interface for retrieving student work from the database. Below in Figure 3.23 is a screen shot of that interface, which enables users—principally teachers and researchers at this point—to query the database without having to learn the MongoDB query language. The interface borrows from the CLP teacher interface, displaying retrieved pages in a panel on the left of the screen. Tapping on a page shows that page in the main display window. In this example, work is retrieved by student name and date. The option also exists to retrieve pages matching tags we call Page Topics, which can be added to notebook pages at the time the pages are authored. A teacher might, for example, tag a particular page as being about “2-digit multiplication” and use that tag to subsequently examine her students’ 2-digit multiplication work.

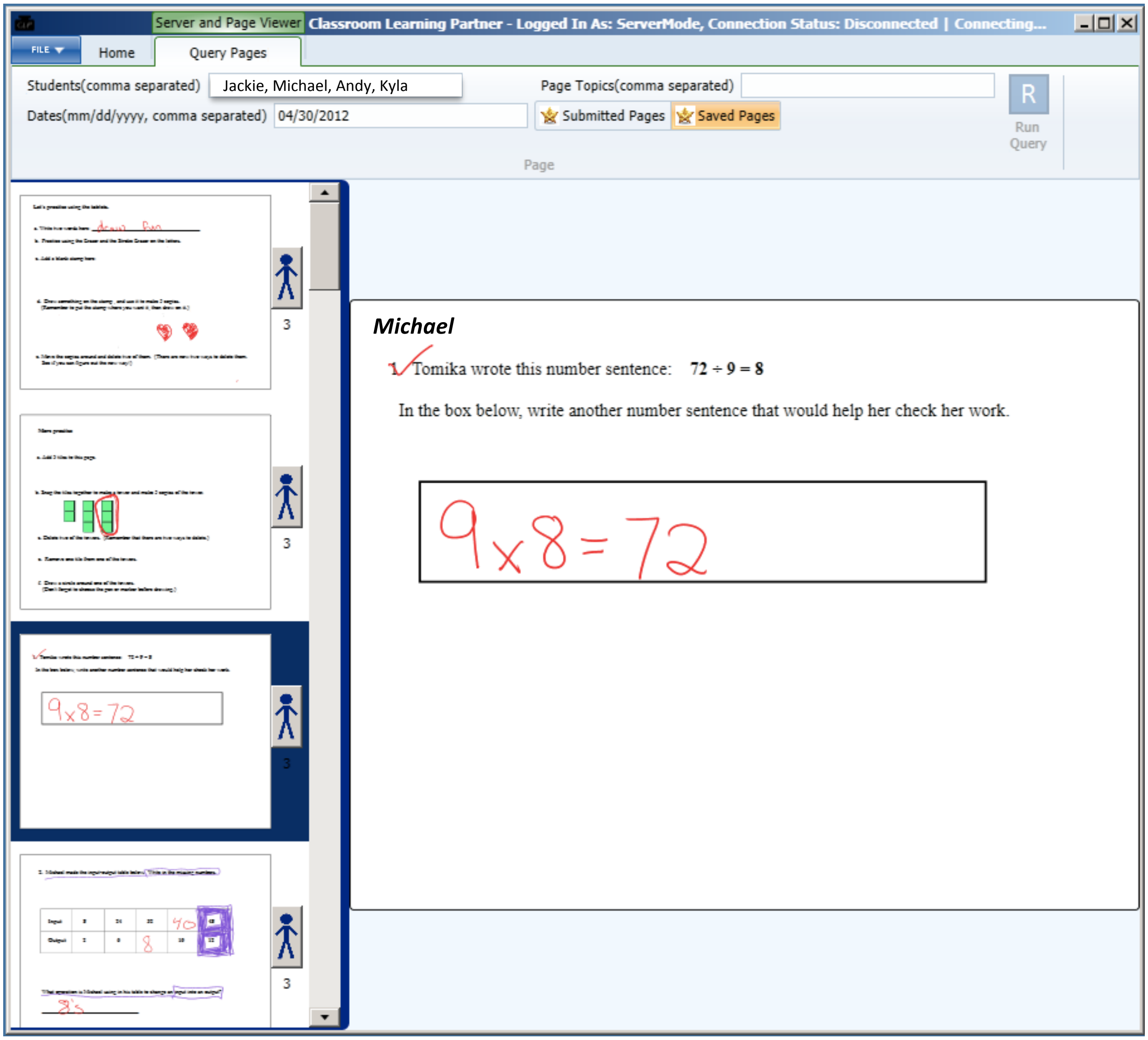


Figure 3.23 Screen shot of the database query interface

4. Classroom Trials

We conducted six multiple-day trials in four classrooms in two schools in Spring 2012. Each daily session lasted between 50 minutes and several hours. After each classroom trial, we continued to refine the software based on our observations and interviews with students and teachers. The trials are detailed in the table below.

City	School	Special Needs?	Grade(s)	# of Classrooms	# of Days	Emphasis	# of Students
Cambridge	Baldwin Elementary School	N	4	1	5	Math (multiplication)	21
Cambridge	Baldwin Elementary School	N	5	1	6	Math (data and graphs)	21
Waltham	Northeast Elementary School	N	4	1	3, 5	Math (MCAS practice: multiplication, division, fractions)	16
Waltham	Northeast Elementary School	Y	4 & 5	1	3, 7	Math (multiplication and division)	8, 7

A typical classroom session would begin with a member of the INK-12 team and/or the classroom teacher introducing the activity, the content expected, and what students were to do and what they might expect. Next students would work on their tablets while the teacher or other assistants roamed the classroom, helping students individually. When students felt they had responded or completed the set of questions or tasks, they would submit their work to the teacher, whose own tablet would notify her and save the submission. When the specific activity was completed, or when the teacher decided enough time had been spent, the students would look up from their computers and collectively view the presentation screen, upon which selected student work was shown to prompt a discussion. After discussion, students returned to their tablets; sometimes to revise their work, sometimes to work on the next problem in the sequence. Often, the tablet session ended with the teacher commenting and reviewing what the class had done that day, and what the gains or problems were.

In each trial, we collected classroom data from the following sources:

- Classroom video, logged and used to track student's use of and reactions to the tablets
- Transcripts of teacher interviews, carried out by the project evaluator
- Written observations of classroom lessons, both with and without tablets being used
- Written field notes on student focus groups
- Student work created on the tablets
- Still photos of the classroom and projected images

Below are findings from the classroom trials in each of our four classrooms.

1. Cambridge, Baldwin School, Grade 4
Instructional materials: *Investigations In Number, Data and Space, Grade 4*, Unit 8, How Many Packages? How Many Groups? Sessions 1.1 – 1.4

Math instruction in this teacher's class dealt with 2-digit by 2-digit multiplication problems, focusing in particular on ways of decomposing the problem into several simpler ones. An array model for multiplication is a centerpiece of the strategy toward which students work. Students also practice estimating products by using *landmark numbers* (e.g., multiples of 5, multiples of 10) and, throughout the unit, they make up story problems to correspond to the calculations they are doing, to reinforce their understanding of the meaning of multiplication.

Figure 4.1 shows a student's work including a story problem to go with the numerical problem, an estimate of the answer to the problem and an exact answer calculated by decomposing the problem into two easier sub-problems.

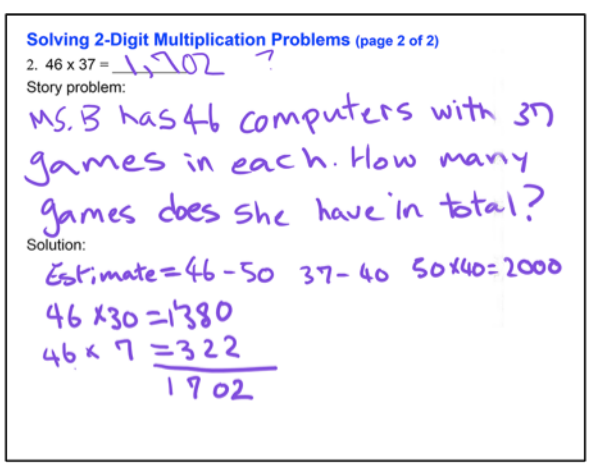


Figure 4.1 Student response to 2-digit multiplication problem, including story problem

As students were submitting their answers to these problems, however, the teacher noticed several answers such as that in Figure 4.2, in which students had incorrectly decomposed the problem This error is a common one, which the array visualization is specifically meant to address; the teacher was able to realize quickly that a substantial portion of her class was struggling with the decomposition because she had immediate access to the student work on her tablet.

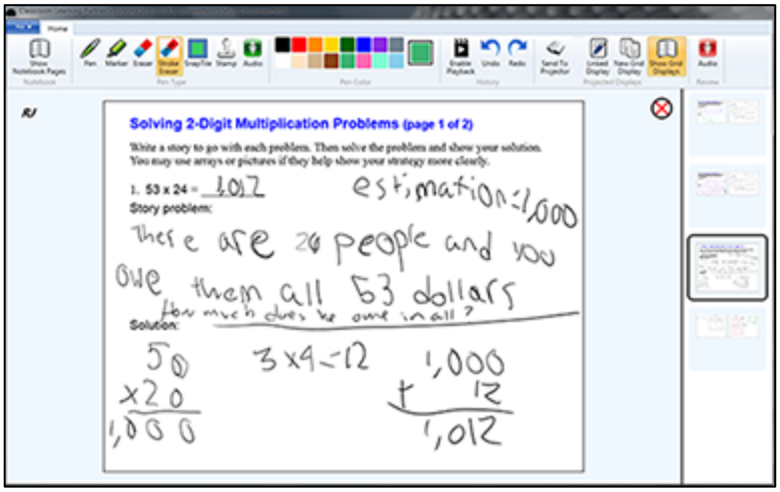


Figure 4.2 Teacher view of student work showing common error in 2-digit multiplication problem

The teacher stopped the class and led a discussion in which she explicitly addressed students' errors, drawing on her tablet the picture in Figure 4.3. The drawing was projected so that the entire class could see it and also appeared simultaneously in each student's individual notebook. The teacher pointed out that many students, such as the one whose work is shown in Figure 4.2, were including only the shaded areas in their calculations and were thus leaving out the products in the unshaded portions, represented by the equations in the upper right corner of the page.

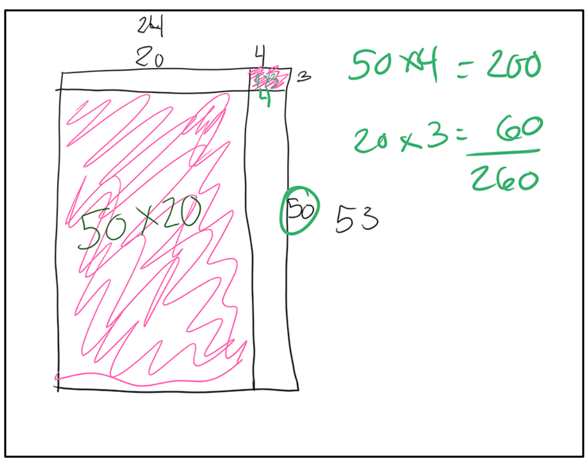


Figure 4.3 Teacher's illustration of array model for 2-digit multiplication

This explanation and picture helped many of the students, and the next day, a significant portion of the student work reflected the array structure, as shown in Figure 4.4.

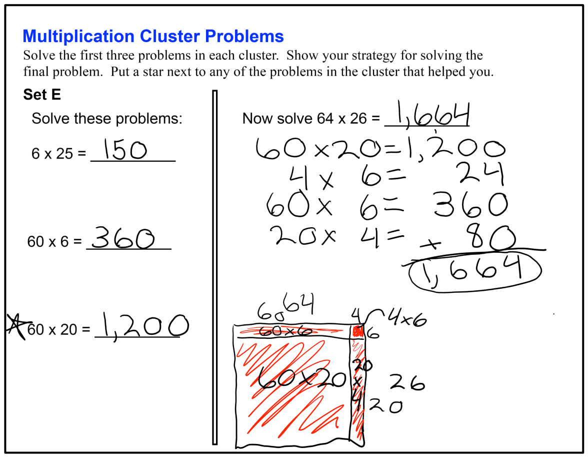


Figure 4.4 Student work using array model for 2-digit multiplication

For some students, however, the array structure still seemed too abstract, as it does not distinguish between the size of the group and the number of groups. The Investigations curriculum provides a Teaching Note that offers another option that reflects the structure of a multiplicative situation more clearly, using sketches rather than arrays. The teacher discovered this Note and decided to share the approach with the class, using her tablet to draw and project the picture in Figure 4.5. The picture represents the situation: 42 bags of 38 apples. The bags of 38 apples are represented as bags of 30 with 8 more added.

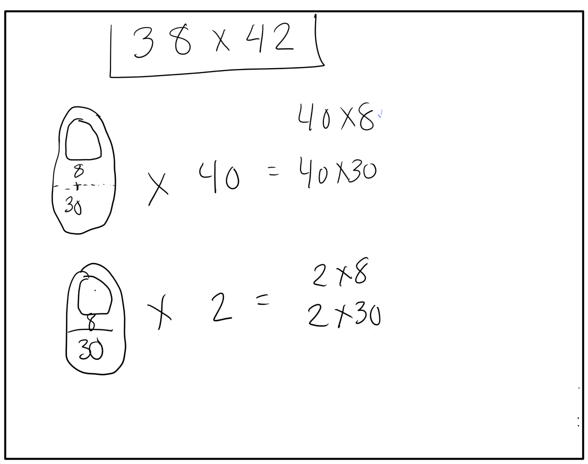


Figure 4.5 Sketch representation of 38 x 42, drawn by the teacher

Our work in this teacher's class provided evidence of the usefulness of several aspects of the INK-12 technology. Because she was able to review student work easily during class on her tablet, the teacher was able to detect a problem common to several students and intervene promptly. She did so using her tablet as an "overhead projector," so that what she drew was immediately projected for the entire class to see. Because of the wireless network linking the tablets, however, her drawing also appeared—and was saved—on each student's notebook. Thus, when she went around to help individual students who were still having trouble later, she was able to refer to her explanatory drawing in the students' notebooks.

2. Cambridge, Baldwin School, Grade 5

Instructional Materials: *Investigations in Number, Data and Space, Grade 5*, Unit 9. <u>How Long Can You Stand on One Foot?</u> Sessions 1.1 – 1.4

The focus of the curriculum in this class was data collection, representation, and analysis. The first several lessons revolve around a data collection activity to investigate the length of time people can stand on one foot with their eyes closed. Students compare their own balancing time on right and left feet, then compare their balancing data with that of students in another fifth grade class (provided with the curriculum) and adults from whom they collect data at home.

The curriculum design calls for the entire class to collaboratively create two large line plots to display their data, one each for left and right foot. Students call out their results and the teacher marks the values on the line plots; when the line plots are complete, students discuss the data. We decided to have students create their own line plots on their tablets and have the teacher choose several to display as a basis for discussion. In order to make the data visible to everyone, we had students write their balancing times (in seconds) on the teacher's tablet so that all of the data were projected, as shown in Figure 4.6. (Students' names have been blocked out to protect anonymity.)

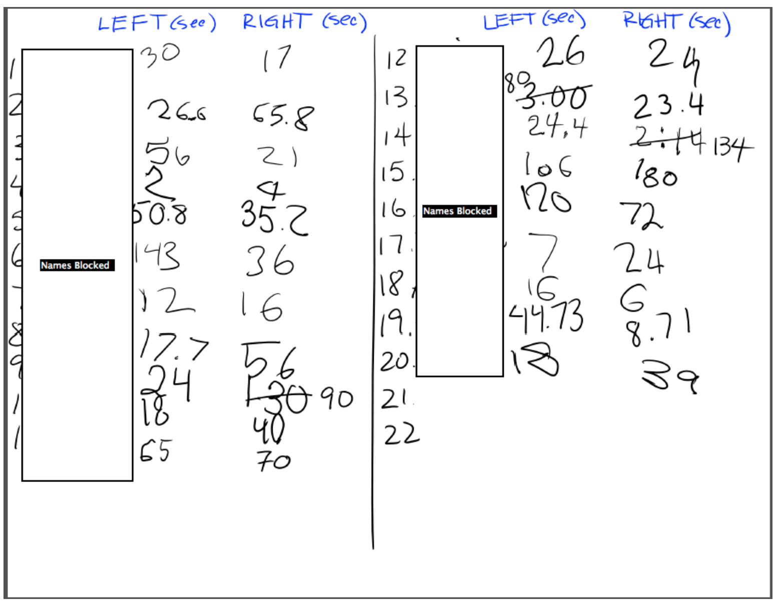


Figure 4.6 Student data from balancing on one foot, as collected on the teacher's tablet

Several students, however, had trouble copying the data from the projected display onto the line plot on their tablets, so the next day we provided each student with a paper copy of the data. This solved the "I can't see the data" problem, but we discovered another issue: The tablets were too small for some students to comfortably make a line plot, especially if they had large handwriting and/or wanted to label many values along the axis. Some students had creative solutions to the lack of space, such as Figure 4.7. This student divided each line plot into three large (non-equal) segments and created a histogram-like graph.

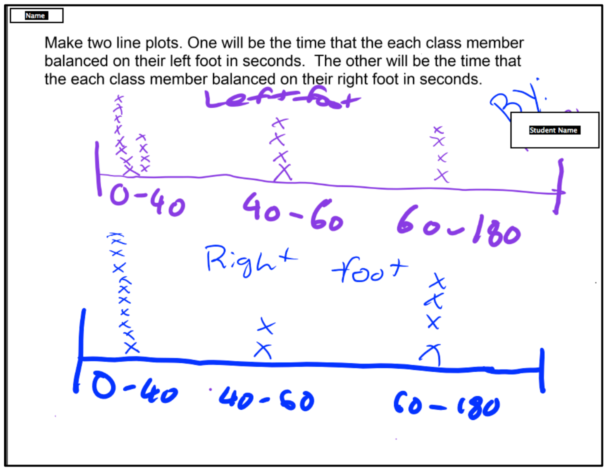


Figure 4.7 Student representation of balancing data

Some students broke their line plots into two parts, drawn on two separate lines, as in Figure 4.8.

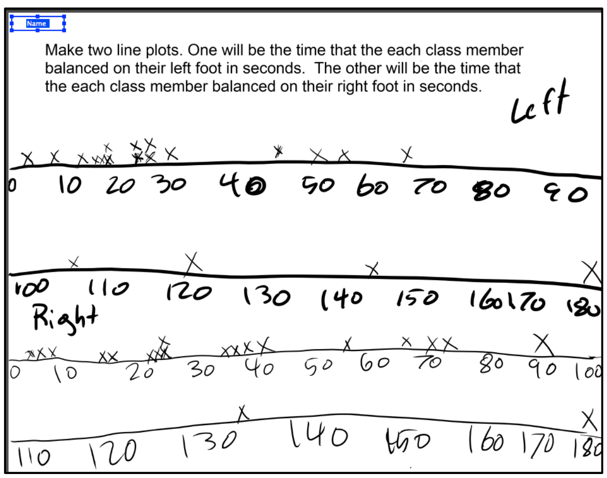
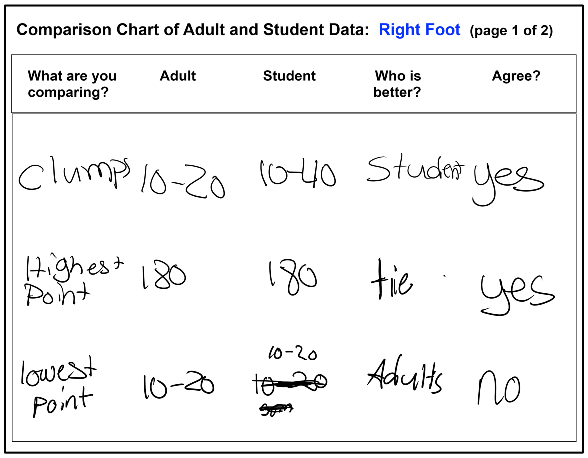


Figure 4.8 Student representation of balancing data

Other students chose to make their line plots on a blank tablet page to gain more room, and one boy refused to use the tablet, instead drawing his graphs on regular paper, which was slightly larger than the tablet screen.

In contrast to the problems students had drawing data representations on the limited size of the tablet screen, the next activity, which involved their comparing students and adults on their balancing ability, fit the tablet well. One student's answers to these questions, shown below in Figure 4.9, illustrate the structure of this part of the lesson. Note the final column, in which the student is supposed to check his or her answer with a partner; it would be interesting to know the story behind the set of answers in the last row.



Comparison Chart of Adult and Student Data: Right Foot (page 1 of 2)

What are you comparing?	Adult	Student	Who is better?	Agree?
Clumps	10-20	10-40	Student	yes
Highest Point	180	180	tie	yes
lowest point	10-20	10-20 ~~10-20~~	Adults	no

Figure 4.9 Student work comparing balancing data from adults and students

The teacher was able to display several students' answers to these comparison questions at the same time and lead a discussion about the criteria students used to decide which group was better at balancing.

Our residency in this class highlighted issues about the process of using tablets to implement a paper-based curriculum. A recurring issue has been that of screen real estate—the tablet screen is smaller than an 8 ½ x 11 sheet of paper, and students tend to write somewhat larger on the tablet than they do on paper. As a result, it is not always possible to simply "copy" what is on a paper-based student sheet to the tablet screen. The next version of CLP will have scrolling pages, which will help in some cases, but there is no substitute for physical space. It seems that both hardware manufacturers and the consumer public are moving toward smaller hand-held devices for education (although, simultaneously, we are moving toward larger TV screens) with little thought about how that form factor will impact students' experiences.

3. Waltham, Northeast School, Grade 4

Instructional Materials: MCAS (Massachusetts standardized state test, which students take in May) Prep problems, drawn from previous years' MCAS items in one trial; and other curriculum materials, focusing on multiplication, division, and proportional reasoning, in a second trial

Working in this class inadvertently allowed us to investigate just how far the technology "novelty" factor would stretch. Not only were we in her class for eight days, but most of the math work students did was relatively unexciting, as it was test preparation. The results were mixed. We definitely saw students' interest decrease to the point that they did not seem excited to see us arrive with the tablets. When we interviewed them about their experiences using the tablets, however, they were still very enthusiastic and insisted that it was more fun to do math using the computers.

An interesting design decision arose in the context of students' work on basic fraction concepts. A simple problem uncovered some serious gaps in students' understanding of fractions, as shown in Figure 4.10, students' answers to the question: Which is larger, 1/3 or 1/4?

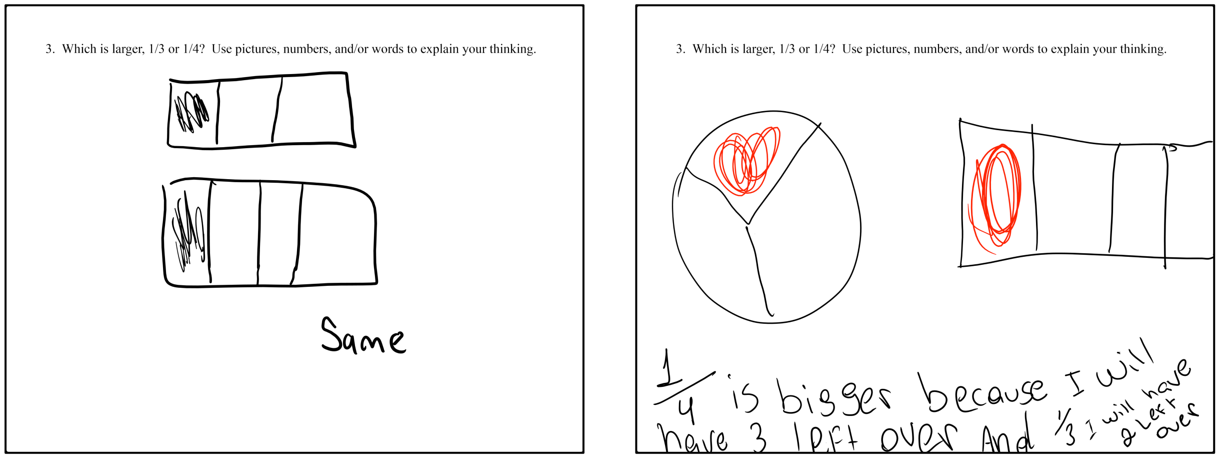


Figure 4.10 Student representations of fractions showing a lack of understanding of the idea of a "consistent whole"

It became clear that some students didn't have a firm grasp on the idea of a "consistent whole," i.e., that in comparing two fractions, it is important that the whole be the same size. They seemed to have less of a problem doing fraction problems where the whole was a set of discrete objects (e.g., Ms. Tyler has 14 flowers. 2/7 of them are red. How many flowers are red?), since the size of the whole was explicitly given. But when it came to fractional problems involving area where students had to 1) draw the whole, and 2) divide it up into equal-area pieces, some students struggled. The student whose work is shown on the left in Figure 4.10 exhibits both problems: His wholes aren't equal and he hasn't partitioned the wholes into equal parts. The student whose work is on the right in Figure 4.10 has also drawn unequal wholes that are even different shapes, and it's unclear both how she decided to divide up the shapes and what relationship her picture has to her answer.

In light of these experiences, we discussed the possibility of implementing drawing tools for creating and partitioning representations of area models for fractions. We considered a tool that would draw equal-sized "wholes" for students and tools that would automatically divide a whole into some number of equal parts, as specified by the student. These kinds of tools would keep students from creating the kinds of representations shown above—and drawing incorrect conclusions based on them. On the other hand, students need to actively recognize the importance of having equal-sized wholes, and it's possible that having tools that do this work for them would circumvent their understanding. The jury is still out on this question; we plan to look at the kinds of tools other math educators have developed to support fractional reasoning (e.g., Dynamic Number from Key Curriculum Press) and consider integrating them into the our software.

We also introduced two new features in this class, which are described in the Technology section (Section 3): teachers' ability to replay the way that students solved problems, and students' ability to make audio recordings of explanations.

Ink replay. The students were asked to complete the following math problem: "Henry wants to plant 24 tomato seeds in the school garden. There are 4 rows. How many seeds does he plant in each row? Write a number sentence, and circle the number that answers the question. Use the stamp to create a picture that explains your answer." One student's response is shown in Figure 4.11.

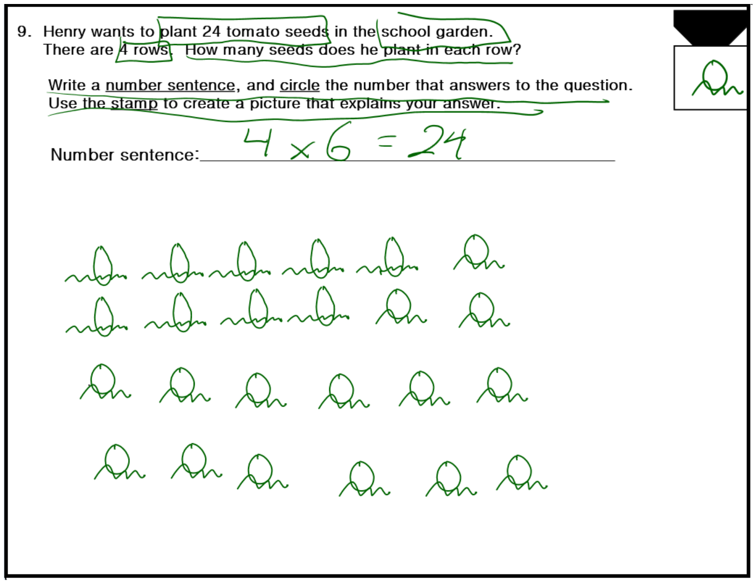


Figure 4.11 A student's response for a division problem

The solution shown above suggests that the student had mastered the material because she reached a correct answer for both a number sentence and a pictorial representation of the problem. The teacher had no way to know from this response, however, whether the student knew the mathematical relationship being described and drew the picture as an explanation, or used the picture to help figure out the math. The interaction history gave the teacher insight into the student's thinking process: The playback of the interaction history shows the student creating the seed stamp, then placing seeds in 4 rows of 5. She then placed one more seed at the end of each row to create 4 rows of 6, and filled in the number sentence "4 x 6 = 24". This interaction indicated to the teacher that the student did not know how to approach the problem, but that the student instead used information given in the problem to create 4 rows and experiment until she had the required number of seeds. Replaying the interaction histories for other students enabled the teacher to identify those students who completed the number sentence before creating their pictures, which suggested mastery of the material.

We will continue our investigations of the ink replay feature this next year.

Audio explanations. Students were given the opportunity to add audio explanations to their work for several days during the trial. Preliminary observations about use of the audio recording feature are the following. When presented with a choice of explaining their reasoning, the class was generally evenly split between students who provided only a picture, those who provided a picture and an audio explanation, and those who provided a picture and a written explanation. One student out of 16 provided only an oral explanation for one of the problems. For the most part, the oral explanations that accompanied written explanations simply repeated the same words as were written. Both the written and the oral explanations also often restated a number sentence rather than actually explaining the reasoning behind the sentence. Thus it became clear that the students needed a lesson in what makes for a good explanation, regardless of whether that explanation was written or oral. The use of the oral explanations in the classroom, however, was quite interesting. After the students worked through their problems and submitted their responses to the teacher, the teacher chose student work to display for class discussion. She asked students prior to playing their recordings if they were comfortable with her doing so. Interestingly, while some students wanted the teacher to play their recordings, other students who were typically comfortable speaking to the class preferred that their recordings not be played. The teacher speculated about the students' reluctance, saying, "Recording voice may feel less safe to them because they can't take it back. You can scribble out writing." In addition, we suggest that one can modulate an oral response based on feedback, both oral and visual, from listeners. The teacher also speculated that in

a classroom culture that supports students in being comfortable about making mistakes and in respectfully disagreeing with their classmates, students might be amenable to sharing recorded explanations.
A couple of logistical observations that we noted: The directional microphones on the tablet computers worked well for recording; background noise was negligible. The tablets' speakers were adequate for students playing back their explanations at their desks, but not for playback to the entire class. The teacher's machine needed external speakers in order for the explanations submitted to her to be heard by the entire class.

We will continue our investigations of the audio recording feature this next year.

4. Waltham, Northeast School, Grade 4 and 5
Instructional Materials: two trials, each with curriculum materials focusing on multiplication and division

The INK-12 project conducted two classroom trials for a total of 10 sessions of between 45 minutes and an hour in a substantially separate class of students with disabilities at the Northeast School in Waltham, MA. Students are assigned to this class based on having IQs below 70 as determined by district/state tests, but no behavioral issues such as autism. The class included two students who had limited knowledge of English and others who had difficulties with focusing and attention. For the first three sessions the class consisted of eight students. After that, one student moved to another town, so that for the second set of seven sessions, the class had only seven students. The focus of the mathematics was multiplication and division. The teacher had been working with the students on their multiplication facts, but did not have the resources to work on building conceptual understanding of the operations. She welcomed the INK-12 project as a way to help her students develop mathematical understanding beyond memorizing the facts.

The lessons in the first four sessions were built around using stamps to solve multiplication story problems. At first, a pre-made stamp was introduced, with the object in the story already drawn. Mickey's[2] work in Figure 4.12a has a clear organization for the cookie stamps and uses a reliable strategy of counting by 2's to solve the problem. Other students, such as Eliza, used the stamps and repeated addition to solve the problem, as shown in Figure 4.12b

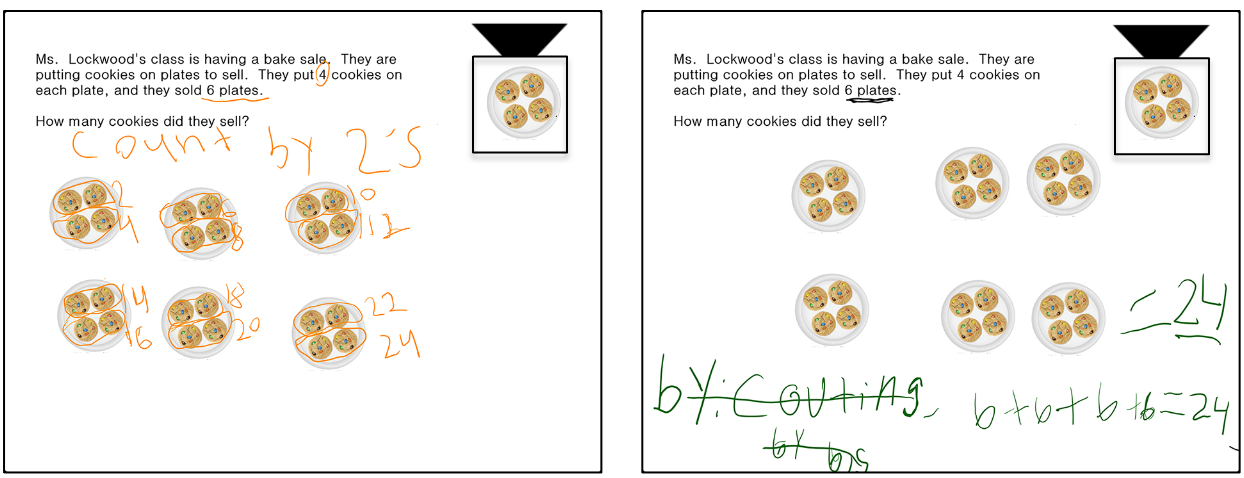
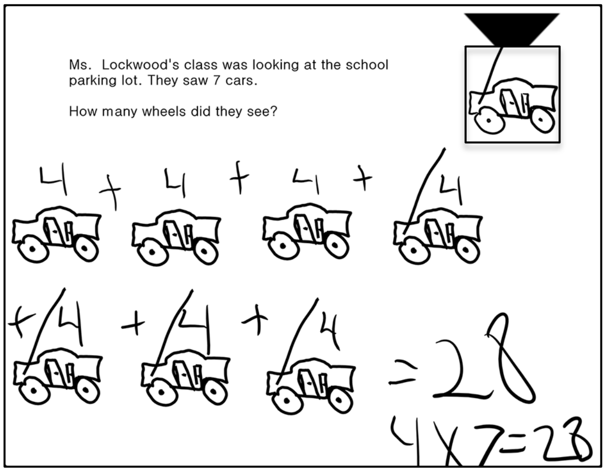


Figure 4.12a. Mickey's work using stamps for 4 x 6 *b.* Eliza's work using stamps for 4 x 6

Subsequently, problems were introduced in which students drew their own object on the stamp. The students were engaged by being able to make their own representations. The teacher reported that in addition to engaging the students, the stamps helped students organize their thinking, and kept them from perseverating over details of the drawing. The students with a limited knowledge of English did particularly well when they were able to draw their own stamps. Hector created a stamp of a car with four wheels, created several copies of it and used repeated addition to solve a multiplication problem

[2] All student names are pseudonyms to protect the students' identities.

about wheels, as shown in Figure 4.13a. When he had been asked a similar wheel problem orally, he had not been able to solve it. Hector also developed a reliable way to do division problems using a dealing out strategy with his own stamps, as shown in Figure 4.13b. Although he did not write the number sentence correctly, he represented the problem correctly and knew what all of the parts were.



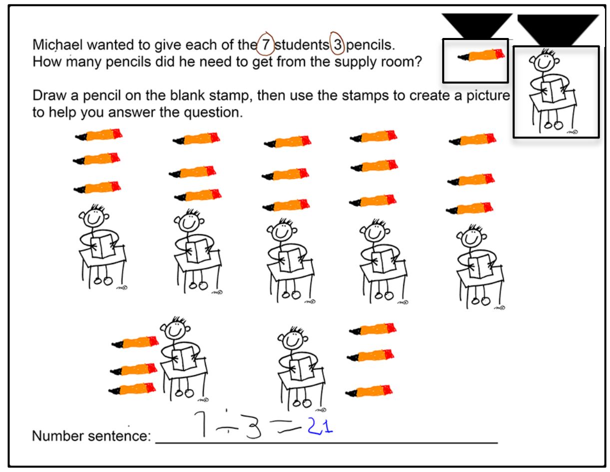
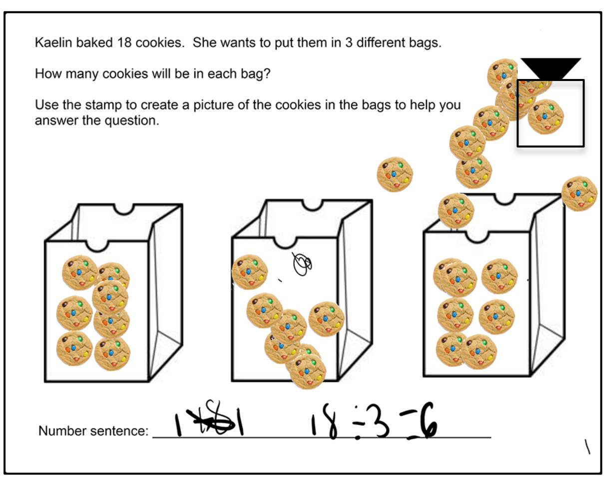


Figure 4.13 *a*. Hector's work using a car stamp *b.* Hector's work using a pencil stamp

Alfonso, another student with limited English proficiency, had more success drawing his own stamps, as opposed to using the pre-made stamps. He had some fine motor control difficulties with the pre-made stamps, which frustrated him. Figure 4.14a shows Alfonso's work using pre-made stamps. Although he solved this division problem correctly, the representation did not show 18 cookies, and he had a hard time moving the stamps. When he created his own stamp with 3 stickers on it for the problem: "if each student gets 3 stickers and there are 8 students, how many stickers are there in all?" he was able to represent and solve the problem correctly, as shown in Figure 4.14b. Alfonso was also able to use his drawings to correctly solve some division problems, as shown in Figure 4.14c, even though when we started working with the class, Alfonso did not understand what division was and was unable to answer any division questions on the pre-assessment.



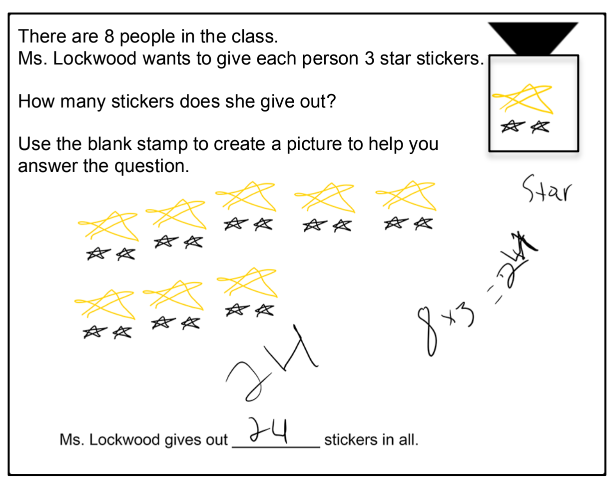


Figure 4.14 *a.* Alfonso's work with a premade stamp *b.* Alfonso's work with his own drawn stamp

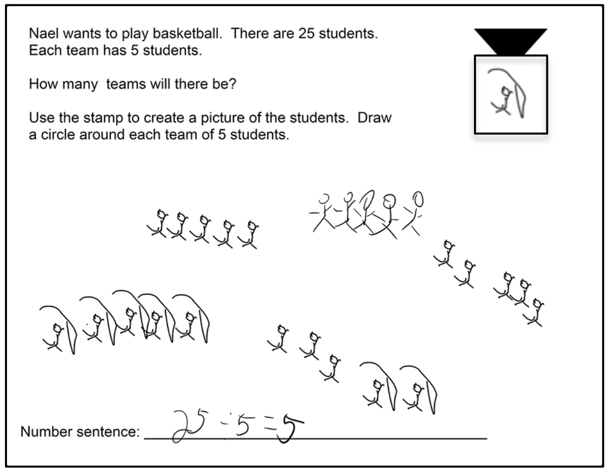
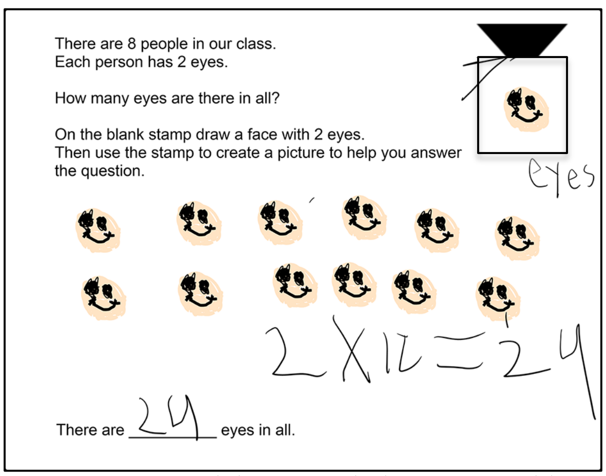


Figure 4.14 c. Alfonso's division work with his own stamps

For some students, extended practice using stamps appeared to facilitate significant growth in their thinking. During one lesson using stamps, Mickey went from not representing the correct problem, to being able to represent and solve a problem correctly, to being able to write, represent, and solve his own number problem, as shown in Figure 4.15 a through d. While this student, as well as the others, still needs a lot of practice to solidify his understanding, this success can be a foundation for future work with multiplication and division.



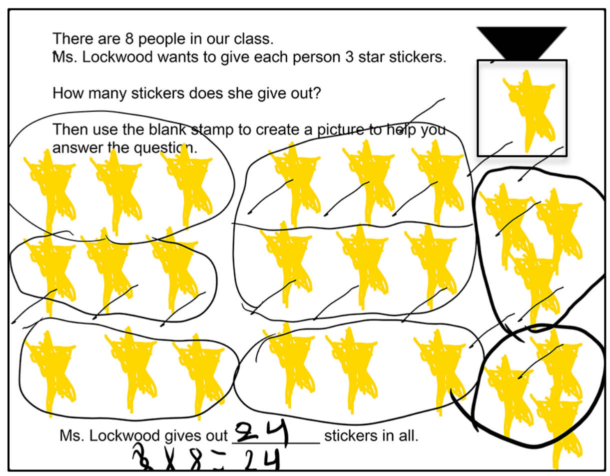


Figure 4.15 a. Mickey's work: incorrect problem *b.* Mickey's work: correct problem

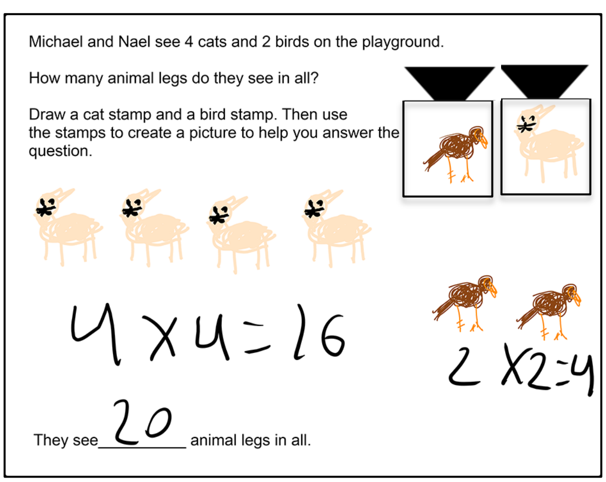


Figure 4.15 c. Mickey's work: correct problem *d.* Mickey's own problem

The next four lessons used tiles, virtual manipulatives that could be used individually or combined into stacks, which we called "towers." These lessons involved "The Tower Game," based on a paper by Tzur, R., et al: *Students with Learning Disability in Math are Left Behind in Multiplicative Reasoning? Number as Abstract Composite Unit is a Likely 'Culprit.'* In The Tower Game, students draw cards that specify how many towers they should build and how many cubes are in each tower, then they use these to compute a total number of cubes. (For an example of the Tower Game, see Figure 4.16a). In the first lesson, the students played the game using physical snap cubes and building actual towers. They were able to do this, although they had some trouble keeping track of what each number in the number sentence represented and how the number sentence related to the snap cubes. During the next session, they played the game using tiles on the computer rather than physical cubes, as in Figure 4.16b . They then moved on to story problems with a similar multiplicative structure, writing a number sentence to match the story, and using shapes to indicate "objects" (analogous to "tiles") and "groups" (analogous to "towers"). Words such as "groups" and "objects" provided very difficult for these students, so the constraints of the lesson were changed so that they could use labels that were specific to each problem, as shown in Figure 4.17.

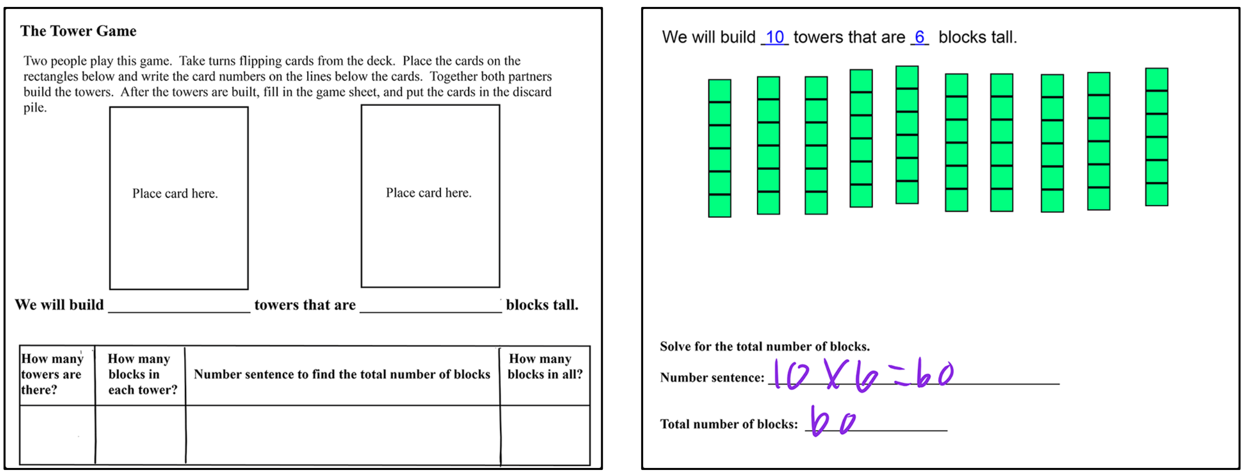


Figure 4.16 a. The structure of the Tower Game *b.* Using tiles to play the Tower Game

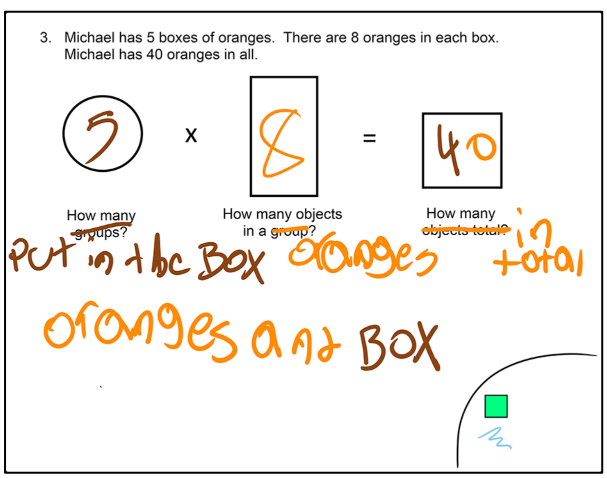


Figure 4.17 Substituting specific labels for "group" and "object"

Since the tiles were cumbersome for some students, they were also given their choice of using stamps or freehand drawing to represent a number sentence. Most students chose stamps or drawings, but some students had success with the tiles. The tiles and the structure of the problems appeared to be particularly helpful for Nelson, a student who had issues with focusing. Without the tiles and the problem structure, Nelson would race through a problem by either just writing a number sentence that might have the right answer but didn't match the problem, as in Figure 4.18a, or by drawing a representation that didn't match the problem at all, as in Figure 4.18b. With the tiles, he was able to represent and solve the two similar problems in Figures 4.19a and 4.19b correctly.

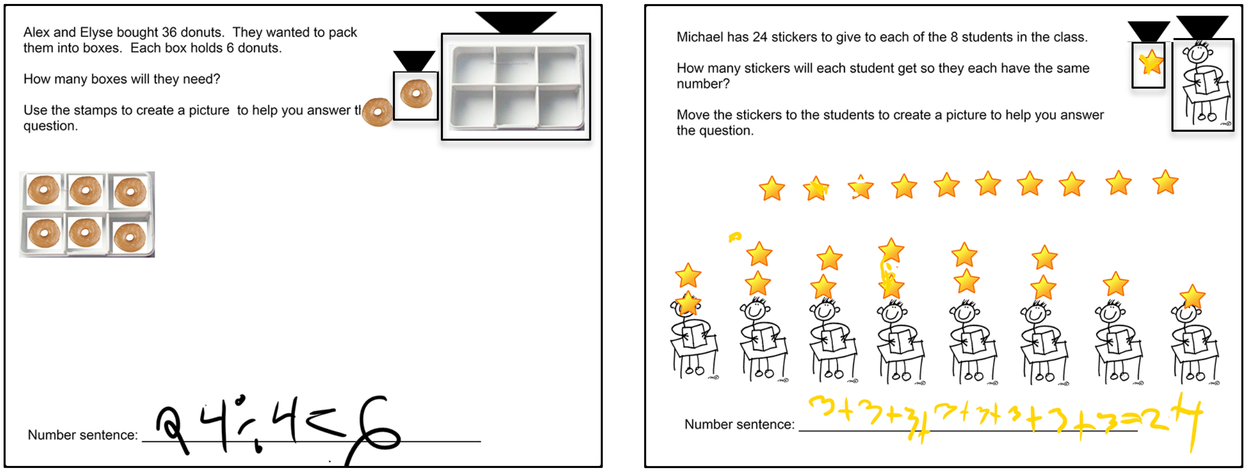


Figure 4.18 *a.* Nelson's work: incorrect problem *b.* Nelson's work: incorrect problem

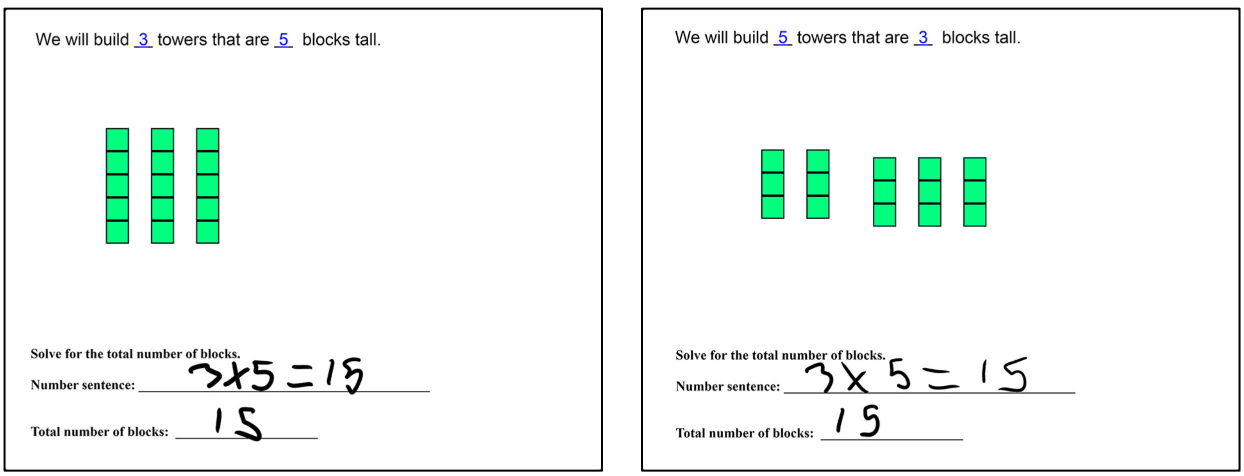


Figure 4.19 *a.* Nelson's work with tiles *b.* Nelson's work with tiles

All students had some success solving multiplication and division with the tiles, however, deciding between multiplication and division was difficult for the students. Division was especially challenging, as the students had relatively limited experience with this operation. Some students solved division problems correctly but their number sentences did not match their representations. Some students had the correct representation, but an incorrect number sentence. Some students could write a multiplication sentence that represented the division situation, but were unsure which number in the sentence was the required answer. Again, these students need repeated practice with predictable structures, such as the stamps or tiles, to solidify their knowledge of these operations.

Pre- and post-assessments with multiplication and division items were administered, both orally and in written form, to all the students in this class. Items included multiplication and division computation, solving story problems, and problems involving visualization, e.g., If there are 3 tennis balls in one can, how many are there in 4 cans?

The assessments suggest that the students from this substantially separate class made some progress in solving multiplication and division problems through their experience using the tablets. On the post-assessment, they were more confident in their ability to solve problems. They all had a strategy for each problem, even if it was counting by 1s and were more likely to explain how they got an answer than they had been on the pre-assessment. For example:

1. For 20÷5 one student said that she put cubes in her head, indicating that she put 20 in 5 groups of 4.
2. For 4x3, one student said , "I know 3x3 is 9 and then he said 10,11,12."
3. One student solved 10÷2 by going remembering that 5+5 = 10 and reasoning that there were 2 groups of 5 in 10.
4. One student said "36÷6 is 6 because 6x6=36."

As there had been during the class sessions, there was considerable variability in students' ability to connect representations with number sentences on the post-assessment. Although a few students were able to connect representations with number sentences on the post-assessment, others were not. For example, for 7x3, some students drew 7 things and 3 things (as opposed to 7 groups of 3), but had the correct number sentence. It was also difficult for them to connect real-life contexts with what they know. For example, they might know 8x2=16, but be unable to answer the question: "If there are 8 stickers on one page, how many are there on 2 pages?"

In summary, data from the field test, the assessments, and the post-field test teacher interview, conducted by the evaluator, indicate that the students in the class gained confidence through their use of the tablet computers. The use of the stamp feature for most of the students, and the tiles for a few of them, helped them organize their thinking and limited their tendency to perseverate and erase, thus facilitating their understanding of multiplication and division. Although the sharing of student work was not as powerful in this class as others, probably because the class does not often engage in discussion and because of the attention difficulties of some, the students were empowered by seeing their name on the large monitor, and their work referred to as an example of a particular strategy or representation.

5. Evaluation

As detailed in the Evaluation Report, submitted separately, the evaluator's data collection included:

- formal observation of trials using an observation protocol
- post-trial interview with participating teachers
- inventory analysis of student work samples
- student comments collected during and 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.

Excerpts from the Evaluation Report are included here. See the full report for more details.

5.1 Teacher Reflections (pp. 8-11)

In post-session interviews, teachers commented on the impact the tablets had on their classrooms and their own teaching. Responses were grouped into categories reflecting the areas of interest to teachers.

INK-12 Interface

Teachers were pleased again with the stamps, especially in how they focused the classroom work on analyzing mathematical groupings and not the drawing activity, which students can easily find both fun and distracting.

> "Last year there was drawing; they got into that and when it came to math there were too many steps to shift the brain. They couldn't keep up with drawing so much and then they began thinking the whole program was a drawing pad and forgot the math. This year with the stamps; the less preliminary steps, the better."

Another teacher praised the ability to view the class completion rates quickly,

> "Really looking at everyone['s work] quickly was so helpful, figuring out who's ahead, who's behind, you could even tell who was goofing off, I mean I know these kids by now, but the information on my tablet really let me see the whole class while I was teaching up front."

Inscription

Teachers again this year really liked the idea of students inputting data via inscriptions instead of keyboards, and felt it added to the lesson design.

> "The reality is they just can't type, or are very slow and full of mistakes. I mean getting them to write and submit would take a whole class period. I think they think it's also closer to their notebooks so they feel freer…."

> "You saw my [special needs] kids, they would have a really hard time typing out what they wanted to say,…, using the pen made it fun for them, it's something familiar, and when they submitted their work, I'm sure it gave them confidence that their work was just as good as the next [person's]."

Teachers appreciated how the drawing helped give insight into students' intentions.

> "Seeing them draw lets me understand what they know much better than a simple answer in a box. Sure they could do this on a worksheet, but it's so much faster, more convenient, I can save it all and everyone else can see the examples if I put them on the screen later. It's really easy for them."

> "I really like how they can circle their drawings or numbers to emphasize what they want me to see, or better yet, to show me how they're working through a problem, not just giving an answer."

Adapting to Classroom Technology

Classrooms are now technology-enabled, with computers and SMART boards.

> "We have SMART boards, the kids all use computers, so it's not a stretch for them, in fact I think it's easier because of the pen. They can learn anything about technology really quick. Using it in math was a surprise for them at first since they haven't really done that before, but then it seemed normal to them after a few days."

Teachers also pointed out how the tablets were new to some students, and they enjoyed the portability and inscription aspects,

> "They really liked how the computers were just a notebook. I think that helped blend them into the classroom for a lot of kids. They love drawing and enjoyed seeing the colors and lines. They loved the stamps, you saw how crazy they got in the beginning. But also, they're small [tablets] and today's students, even this young, are thinking portable; they see it at home, they will expect it at school. Watching me walk around the class with my computer, it's natural for them."

Motivation and Engagement

Very similar to last year, the tablets provided a motivation for students, especially when first introduced. The teacher in the special needs class commented,

> "They really were engaged, both with the tablets and the guest teacher, but I know they really loved working on the computers. It's different for them, but it provided a very particular focus, which is what these kids respond to… they have such a narrow field that looking at the tablet, I saw them look at it like a window and all their work is on it, and I really think they were less distracted."

Another teacher commented on how students seeing their work on the screen motivates them to contribute.

> "They loved that they might be chosen to be the example, to have their work up there in front of the class and to talk about it. That was a big part of their motivation. It's just different than with other paper and pencil, ELMO [overhead projector]… it's fast and there are other students' work up there, kind of like part of the class is on the screen."

Classroom Management

Whereas last year some teachers commented on the difficulty of multi-tasking with the tablet while trying to teach the class, this year comments suggested they were growing more familiar with how the technology can be used.

> "I have to do a lot when I teach the class, keep everything under control, look at my tablet, explain the subject, select student work, and find out who needs my help. But it was a lot easier this year, I don't know why, maybe because I'd done it before. I like being able to see what everyone's doing from my tablet with the little diagrams."

Another teacher resonated similarly,

> "I always walk around, so this is really good for me, the students are used to me doing that, looking over their shoulders, but here it's more efficient; I can see who's submitted what in time and who has not. I can take it [tablet] with me to check on the kids. That really helps me keep everyone on task. I don't think they could just follow instructions and sit by themselves at the computer for an entire period."

Sharing

Teachers commented on how sharing student work was valuable for their classrooms and students.

> "I like the whole class sharing because it gets everyone discussing the lesson. I still like picking out the samples and have a whole-class discussion and putting up several 3-4 slides; that's nice. It's a nice way for kids to share their work. They're more interested in talking about it if it's their own."

> "I like how you can make it anonymous because it's safer for some kids, especially the shy ones. I think it's a good thing. I've seen more kids participate than when we use the overhead. If they want to be known, they just yell out 'that's mine!' "

In discussing sharing the audio recordings, teachers felt that sharing within small groups would be better than with the whole class.

> "Kids sharing their audio in small groups [lets them] feel much safer than with everybody I think because they know all the others in the group will share theirs, so it's a matter of fairness. I think one way to use the audio is to have a small group listen to everyone's then discuss who's right or wrong and come to a group consensus, then share out to the class."

Teacher Workload

As with any new classroom technology or innovation, there is the consideration of additional workload on teachers to effectively learn and use them.

> "I think after a few classes, I know what to expect. I looked at the student work after school from home and it wasn't too bad. I'm in the middle of this with you guys, so I'm prepared to put in that work, but I really think it could become a normal part of my workday. I mean, everything they submit is online and I don't need to carry folders home."

> "It's a lot of files to sift through, but I'm getting better at it, especially clicking on the students' name and getting their work is really easy. This would take the place of grading other kinds of work. During the class, it doesn't take more time, I don't think."

5.2 Evaluation Summary (pp. 16-17)

INK-12 is progressing very well according to its plan and has met or exceeded expectations for its second year. The implementation plan, designed in two 2-year phases is on target; Year 2 continued software improvement and interface modifications as well as additional classroom trials in mathematics; all anticipated tasks were accomplished. Response to the tablets from both teachers and students is very positive, with teachers having become increasingly confident as a result of both 1) the technology becoming more robust and "working better" and 2) familiarity with the tablets, the curriculum, and the teaching styles that support INK-12 instruction. As a design experiment, data from Year 2 classroom sessions (usage characteristics, technical, curricular, pedagogical, and classroom management) will inform the next iterations of development during Year 3, when the team will offer science sessions in addition to math sessions, and the research team will begin assessing content knowledge gains in comparison with students from non-INK-12 classrooms using the same curriculum. The project to date has made a lasting impression on teachers in how they use real-time student data to inform and support classroom discussion, a practice they had not done previously to the extent they are able to do so with the INK-12 technology:

> "When you hear them explaining each others' work in front of the class, you know they've learned the concept, and then you see all the other kids go back and do their problems over and send to me. They never would do that otherwise."