COVER FEATURE

Ink, Improvisation, and Interactive Engagement: Learning with Tablets

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Instructional models that reflective educators develop and share with their peers will primarily drive advances in the use of tablets in education. Communities that form around platforms such as Classroom Presenter and Group Scribbles should provide an excellent forum for such advances.

> *Mark now the farther development. I shall only ask him, and not teach him, and he shall share the enquiry with me: and do you watch and see if you find me telling or explaining anything to him, instead of eliciting his opinion. Tell me, boy, is not this a square of four feet which I have drawn?*
>
> Socrates[1]

In one of the earliest recorded reflections on pedagogy, Socrates drew a figure in the sand to demonstrate to Meno that the slave already knew how to construct a square with double the area of a given square. Socrates aimed to show that he didn't need to teach, only to engage his student's memory of knowledge from a past life.

Today, we no longer think of learning as merely "recollection." Instead, we see learning as an active, constructive process that builds on prior knowledge. More generally, the learning sciences have led to important advances in our understanding of the process of learning as involving

- learners' active engagement,
- a focus on knowledge construction,
- feedback and formative assessment leading to adaptive instruction, and
- participation in a community of learners.[2]

Despite our changed view of learning, necessitated by recent scientific research, Socrates' pedagogical use of learning technology remains relevant. The Greek philosopher improvised an informal sketch in the sand to structure an interactive, engaging learning experience. Why didn't Socrates prepare his points before class, using the PowerPoint of his day: a chisel and block of stone? A few possible reasons come to mind.

First, his hand-drawn sketch was likely more expressive of the key concepts Socrates wished to communicate than a neat, chiseled presentation would have been. Second, an informal sketch might have invited the participation of his student in active reasoning more effectively than a more formal, fixed diagram would have. Third, the act of drawing, gesturing, and speaking in close synchrony let Socrates focus his student's attention on the meaning of the diagram he was preparing. Fourth, by asking probing questions, Socrates learned much about his student's existing state of knowledge, letting him adapt his instruction to his student's needs.

This example highlights why today's classroom teachers might prefer Tablet PCs with their constellation of affordances, and the right software, over desktop or laptop computers. Compared to typing, ink can express important ideas more vividly.[3] For example, handwrit-

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ing expresses mathematical notation more naturally than typing.[4] With ink, teachers can also highlight and annotate over words and diagrams, thus focusing student attention on the key features of those visual representations while gaining the efficiency of preparing complex visual aids in advance.[5]

Tablet PCs can also help with adapting instruction and inviting participation. Today's classrooms are becoming fully wireless, which lets teachers harvest and aggregate students' contributions.

Transforming classroom practices around collected and aggregated student work could have profound learning implications.[6,7] In particular, many educators have experimented with student response systems, often called *clickers*. In a model application of such systems,[8] a lecturer asks students a probing multiple-choice question. At first, students anonymously respond with their answers and results aggregated into a histogram that lets the students and teacher see the pattern of responses in the classroom. In the most common case, there are some right and some wrong answers. Students are then encouraged to discuss the question with their neighbors and to convince each other of the answer. The teacher then takes a follow-up poll. Depending on the results of this poll, the teacher then adapts instruction. If only a few students got the right answer, the teacher knows to reteach the material via a complementary approach. If most students got the right answer, the teacher can move on. Hence, the heart of the method is the combination of probing questions and engaging students in peer instruction.

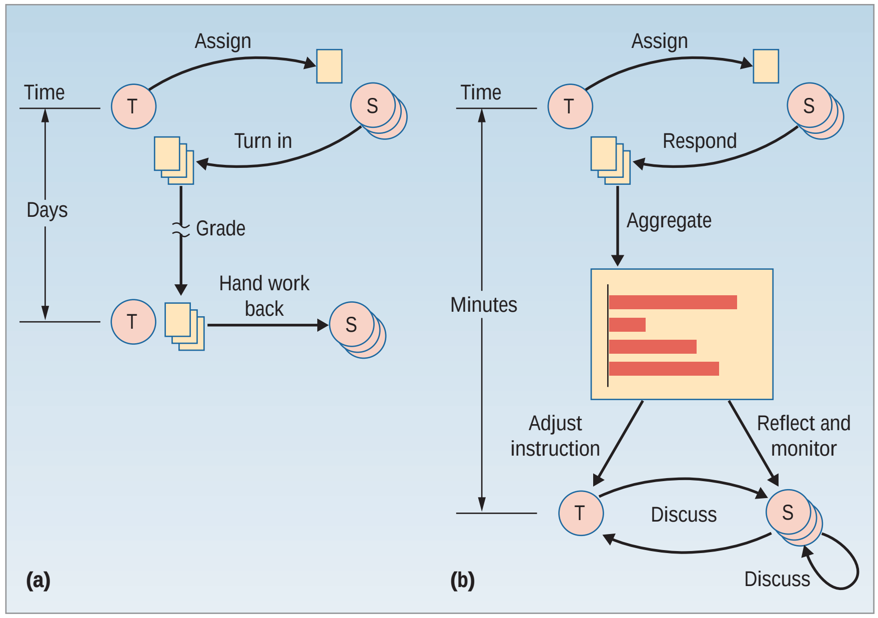


Figure 1. Interacting around student work. (a) Traditional methods require extensive paperwork and can take days to complete; (b) networked classrooms allow a much higher level of interaction and can accomplish an equivalent workload in minutes.

As Figure 1 shows, this method can improve teaching and learning by

- decreasing from days to minutes the time it takes teachers and students to get feedback,
- enabling the teacher to adapt instruction,
- encouraging students to reflect and monitor their own progress, and
- engaging students in arguing for their point of view.

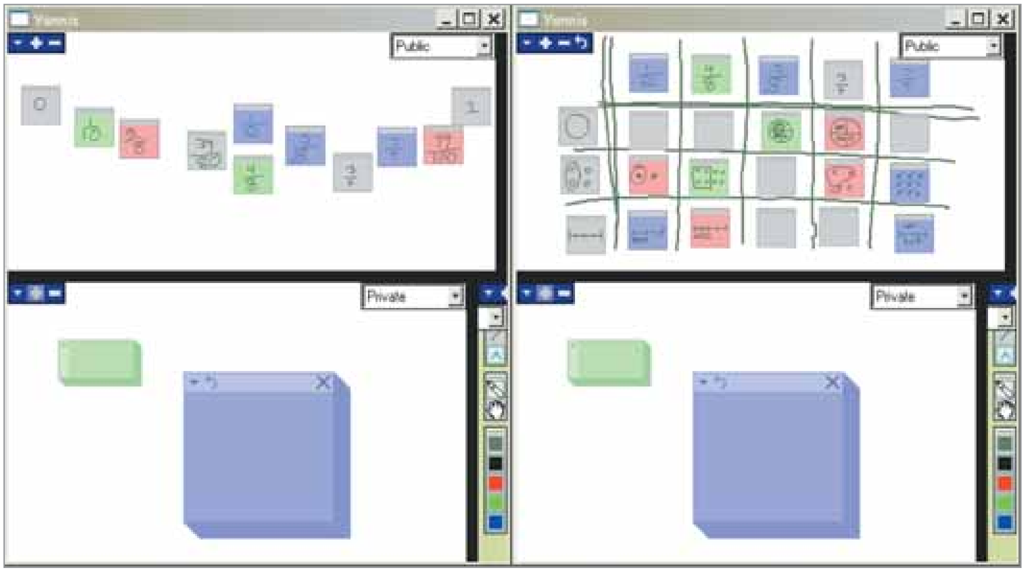
Tablet PCs allow richer interactions than those possible with a clicker. One application that illustrates this, Classroom Presenter, takes as its starting point a prototypical classroom situation in which an instructor presents prepared PowerPoint slides. The instructor can gather students' annotations or sketches on a particular slide and use this collected information to drive further classroom discussion. For example, the instructor can ask students to sketch the next step in the visualization of an algorithm and then discuss the varied possibilities.

Both clickers and Classroom Presenter are powerful classroom innovations, but both presume that the teacher coordinates all classroom interactions explicitly; they do not support coordinated use of the technology among students. Thus, we set out to design a software platform that supports generalized coordination among students and a teacher.

INTRODUCING GROUP SCRIBBLES

Group Scribbles starts from the desire to maximize the power of ink, improvisation, and interactive engagement in a wireless, tablet-based learning environment. improvisation is the central design goal: We intend Group Scribbles to be a platform that supports teachers in inventing and enacting new forms of collaboration and coordination in their classroom without resorting to additional programming. To support improvisation, Group Scribbles offers a powerful metaphor based on familiar physical artifacts from the classroom or office: adhesive notes, bulletin boards, whiteboards, stickers, pens, and markers.[9]

The fundamental unit of expression in Group Scribbles, the Scribble Sheet, is a small square of virtual paper just large enough to express a single thought or concept, whether via a quick sketch or a few words. Scribble Sheets can be posted to public boards, visible to all participants. Multiple sheets can be arranged to express ensemble ideas, such as groupings, chronologies, or hierarchies. A smaller sheet, termed a *label*, can be attached to the larger Scribble Sheets as an annota-



(a) (b)

Figure 2. Group Scribbles. This application (a) helps students place their fractions in order, from the public board's left to right side, and (b) helps the teacher organize examples of the different representations into a table's row header and move some interesting fractions to the table's column header.

tion. In addition, each participant has a private board on which to create and arrange Scribble Sheets. A given classroom instance of Group Scribbles will have one or more named public boards accessible to all users. The screen is divided to show the user's private board in one region and a public board in another.

On the private board, a user finds a Scribble Pad, an endless source of fresh Scribble Sheets. Users can pull sheets off the pad and write or type on them to generate new content. Users can zoom out several levels to help arrange and maintain their Scribbles. When users are ready to publish a Scribble Sheet, they simply drag it onto the public board, where all participants can view it immediately.

On a public board, any user can reposition any Scribble Sheet so that, while individual sheets express individual thoughts, the entire board expresses collective ideas. In this way, users can sort, group, or otherwise arrange Scribbles to express interdependent meaning. A user can take a Scribble Sheet from the public board, bring it onto a private board—for example, for activities calling for exchange or to take a token representing a turn in a sequence—and optionally return it to the public board.

Underlying the Group Scribbles visual metaphor is a "tuple spaces" architecture that supports the three classic operations required by a coordinated, distributed computing system:

- *Write*—dragging a Scribble Sheet from a private to a public board.
- *Read*—viewing the Scribble Sheets on a public board.
- *Take*—dragging a Scribble Sheet from a public to a private board.

The Take operation is especially important because it allows coordinated, synchronous activity among students without requiring the teacher to provide detailed centralized instructions.

Group Scribbles, used by researchers across the globe, can be downloaded for free (http://groupscribbles.sri.com). Our close colleagues in Spain, Singapore, and Taiwan continue to tell us about new educational applications for Group Scribbles. Along with our own Group-Scribbles-based activities,[10] these applications offer compelling examples of the ways in which using the Tablet PC with the right software can transform teaching and learning. Two examples show the expressive power of this constellation of affordances in highly interactive teaching.

INK AND IMPROVISATION

The following lesson, designed for teaching fractions in elementary school mathematics, has structural features that could be reused for many different levels of instruction. In presenting the lesson, we emphasize the role of ink and improvisation as they relate to learning science principles. Imagine this lesson enacted in a wireless classroom where the teacher uses an electronic whiteboard and the students have tablet devices.

To begin, the teacher asks the students to scribble fractions between 0 and 1 and post the Scribble Sheets to the public board. Thus, at the lesson's onset, the students—actively engaged—populate the whiteboard with their handwritten fractions.

Already, the lesson has accumulated many possible branch points. For example, if the teacher finds that some students have used a decimal or percentage, she could invite students to replace those Scribble Sheets with the equivalent fraction expressed as a ratio. The students themselves coordinate this operation through Group Scribbles. Whereas at a physical whiteboard, to avoid chaos the teacher must regulate which students come to the board, in Group Scribbles the Take operation executes atomically. This prevents more than one student from taking the same sheet and thus enables self-coordination.

Let's assume instead that all students understood the teachers' intent and produced fractions like 1/4 or 2/6. The teacher can then continue the lesson by asking students to attach a label to the biggest fraction, or the smallest, or the closest to 3/4, and so on. This is like a clicker activity, and the teacher could follow in the style of peer instruction by asking students to convince their neighbor of which fraction is biggest. In the case where fractions like 5/7 and 5/6 are present, knowledge-rich conversations can result: Which is bigger and why?

Figure 2 shows how Group Scribbles also facilitates flexible use of space to organize student work. For example, the teacher can take advantage of this to ask students to place their fractions in order, from the public board's left to right side, as Figure 2a shows. Group Scribbles supports multiple simultaneous drag operations, enabling all students to actively order their fractions at the same time. Students can self-organize the visual space in meaningful ways, a feature not possible with clickers or other tablet applications. Again, there might be opportunities for the teacher to ask students to label fractions placed in the wrong order, rather than pointing these out to the students herself. There might also be opportunities to discuss equivalent fractions, like 1/3 and 2/6.

Let's assume the teacher next wishes to discuss the topic of equivalent fractions. She could observe that 1/3 and 2/6 are equivalent and ask, "Are there any additional equivalent fractions you can think of? Please try to write down at least three and keep them on your private board." The teacher asks students to keep these Scribble Sheets private because if 20 students each submitted three additional fractions, the public board would become cluttered quickly.

The teacher can manage the space in the public board using the following rhetorical style: "Asher, would you share one of your equivalent fractions by dragging it to the public board now? Thanks; 3/9 is also equivalent. How many of you had 3/9? Did anyone have a different equivalent fraction?"

In this way, the teacher can gather a rich diversity of equivalent fractions from many different students, one at a time, without overwhelming the space. Ideally, the teacher would use this as a basis for engaging the students in explaining how they know that fractions are equivalent, which could lead to a discussion of how to prove fractions are equivalent—showing they can be reduced to a common fraction, for example.

Alternatively, the teacher might choose to move into an activity about different representations of fractions. This might start as did the equivalent fraction exercise. The teacher could ask students to generate two or three ways of depicting 2/6, then collect the variety of emergent depictions, such as pie charts, divided bars, or a number line. This leads smoothly to an activity that uses Group Scribbles' Take feature to coordinate a distributed activity.

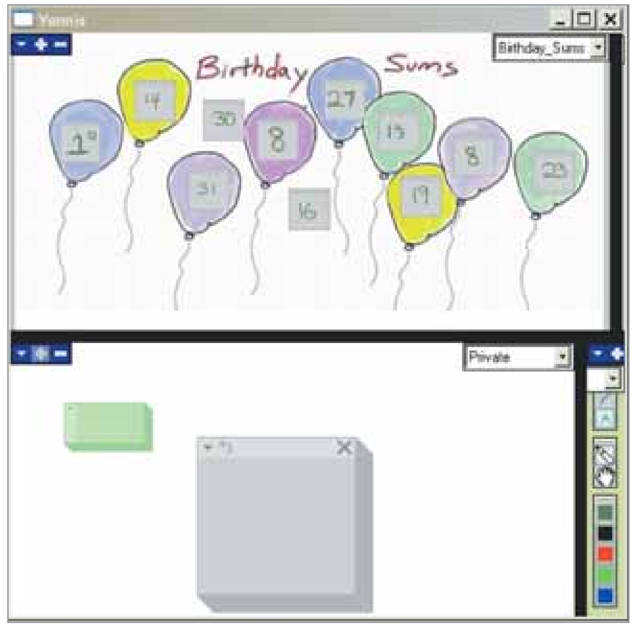


Figure 3. Birthday Sums. This Group-Scribbles-enabled participatory game explores the design of distributed algorithms.

Figure 2b shows how the teacher can organize examples of the different representations into a table's row header and move some interesting fractions to the table's column header. Blank sheets can be posted to the table's cells.

Assume this results in 20 cells and that the class has approximately 20 students. The teacher could now ask students to replace a cell with a Scribble Sheet that depicts the given fraction in the given representation. The teacher does not need to tell individual students which cell they should take; students can self-select and the Take operation will coordinate student activity such that each cell is only taken once. The resulting matrix of fraction representations, shown in Figure 2b, is both a powerful formative assessment of what the class knows and a prop for further discussions.

This lesson exemplifies key learning-science principles. For example, students are actively engaged in creating, organizing, and representing the lesson's mathematical content. Space is used in ways that reflect mathematical knowledge—ordering the fractions from left to right, for example. The lesson is centered on mathematical relationships like ordering, equivalence, and representation. Formative assessment and adaptive instruction are possible throughout the lesson, as both the teachers and students receive rich and continuous feedback on what students know. Finally, at several points in the lesson students act more like a community than they would in a conventional classroom—for example, when they convert their peers' decimal and percentage numbers to conventional fractions or when they jointly complete the table in the last part of the lesson.

Although this lesson focuses on elementary school fraction content, we have found that similar lesson structures are appropriate for university courses. For example, a chemistry professor can ask students to produce Scribble Sheets with different molecules and forms of representation, such as formulas, electron-dot diagrams, or ball-and-stick diagrams. A physics professor can have students sketch a ball at different places in its trajectory and place these in order, from most to least kinetic energy. A Chinese-language professor could use Scribble Sheets to organize a lesson on how "radicals" (components of a character) are put together to form different Chinese characters. Indeed, Scribble Sheets fit Chinese characters very neatly.

COORDINATING INTERACTIVE ENGAGEMENT

Our experiences with Group Scribbles have led us to conceptualize their key benefit for education as making group learning more playful.[11,12] Ink and improvisation support play by allowing the more informal representations of sketches and gestures and by enabling a smoother flow of activity among participants. However, ink and support for improvisation are not enough: A key feature of play is coordination.

The role of coordination in play can be observed by watching children involved in schoolyard games. Starting from the simple game of catch, the elemental skill students learn is to synchronize their attention and actions with those of a partner to accomplish a shared outcome.

Regrettably, in a classroom setting, the cost of coordination is traditionally a major barrier to engaging in more playful learning experiences. A teacher who must guide and arbitrate all transactions in a game can easily become overburdened.[13] This leads many teachers to quickly revert from playful experiences to standard lecture and discussion formats. Even though collaborative and coordinated activities have high learning value, they have been too hard to implement.

We found that Group Scribbles can radically simplify the coordination of classroom games. It's no longer necessary for the teacher to centrally manage all transactions. The right configuration of boards and sheets, combined with a few verbal instructions to the class, can naturally enable students to self-organize their activities. The use of Group Scribbles in this context builds on prior success with a genre of activity called *participatory simulations*, which employs group play to actively engage students in serious content issues.[14,15] In a participatory simulation, technology brokers the exchange of information among classroom participants, letting the teacher focus on the pedagogical role. Group Scribbles makes it possible for teachers to construct these participatory simulations by themselves and even to invent a participatory simulation on the fly in the classroom.

Group Scribbles can implement a variety of participatory games, including hangman, *Password*, and *Apples-to-Apples*.

The learning activity we call *Birthday Sums* offers an example of a Group-Scribbles-enabled participatory game. As Figure 3 shows, although not initially apparent, Birthday Sums is an exploration of the design of distributed algorithms. The instructor begins by asking group members to write their birth date on a Scribble Sheet, which is then posted to a public board. The instructor then challenges the class to come up with methods by which they could add up all the birthday numbers.

After a while, someone in the classroom suggests the distributed algorithm: "Everyone take two numbers, add them, and put the result back. Repeat until only one number is left." Enacting this algorithm as a class is fun, but it also reveals important conceptual issues at the heart of algorithm design. For example, the participants must determine how to

- prevent a deadlock where everyone has taken exactly one number and thus no one can add and no one can get another number;
- know they added all the numbers, or determine that one processor stalled before returning its partial result; and
- make sure they detect and correct errors if one processor adds incorrectly.

Enacting such algorithms as a class generates a palpable excitement, maximizing cognitive engagement in a situation where the class as a whole acts as a distributed machine that tries out variant algorithms.

In the Group Scribbles project, we found the system can implement a variety of participatory games, including hangman, *Password*, and *Apples-to-Apples*. In addition, we have used Group Scribbles to transform single-player games such as crossword puzzles and Sudoku into collaborative games. With Group Scribbles, these games leverage the synthesis of the computer screen's representational power and the wireless network's collaborative capacity.[16] While these games lack the kinesthetic qualities of playground games, they share their highly interactive, negotiable, and appropriable properties.

REFLECTIVE TEACHING WITH TABLETS

Wireless tablet computers can offer new affordances for informal sketches, improvisation, and interactive engagement that take this form factor beyond that possible with prior technologies. Realizing this potential requires navigating design tensions.[13] For example, in the Group Scribbles project, we struggled with the ten-

sion between planned and improvised activities and the tension between informal ink and the notations a computer might more easily recognize, such as typed text or mathematical notation.

Another salient tension arises between supporting classrooms as they are today and nurturing classrooms that feature more student-initiated activity and collaboration among students without a teacher at the hub. Learning science research consistently shows that technology can improve student understanding only when students and teachers use it to do meaningful work with course content. Thus, we find it prudent to conceptualize technologies such as Group Scribbles as a potent infrastructure component that must be activated by new teaching practices. These practices can build on lessons from the learning sciences: active engagement, a focus on knowledge construction, feedback leading to adaptive instruction, and group play in a community of learners.

Today's approaches to teaching and learning have moved beyond Socrates' notion of learning as recollection to new metaphors and approaches. Nonetheless, Socrates provides a fine example of a reflective practitioner who engages in scholarship about his teaching practice.

Given the central role of teaching practice in learning outcomes, advances in the use of tablets in education will be driven not primarily by technology features but rather by instructional models that reflective educators develop and share with their peers. Communities that form around platforms such as Classroom Presenter, Group Scribbles, and related applications should provide an excellent forum for such advances. ■

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