Teaching Mathematics with Tablets

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Mathematical pedagogy

Mathematicians have been using blackboards for centuries. The first large slate for writing with chalk was apparently hung at a high-school in Edinburgh in 1801. In modern times, many lecturers use, almost universally, PowerPoint slides for research talks, but also for teaching., The projection of static slides, with the occasional embedded video, has become the new orthodoxy in biology and medicine.

Not so in mathematics or physics. Developing a complex calculation on the blackboard has the advantage that the pace of writing and speaking matches the cognitive pace of the students trying to understand the lecture. The lecturer can advance at different speeds, can stop and stimulate questions, and can address those queries during the class. PowerPoint slides are too perfect, finished and polished, so that they do not stimulate discussion and the lecturer can become unwieldy fast for the average student.

Fig. 1: The "historical classroom" at the Martin-Luther University in Halle, Germany. Every new professor at the university has to teach its inaugural class using the blackboard visible behind the lectern.

Of course, blackboards have disadvantages. Sometimes they are too small (see Fig. 1) and sometimes the lecturer can make mistakes that could be avoided by projecting finished and refined slides. It is said of David Hilbert in Göttingen, that he made so many mistakes during his lectures, that his assistant would afterwards correct them on a manuscript made available to students later during the day. But that is the charm of teaching mathematics: it consists in developing the whole subject starting from a few axioms and like a performer, in full view of the audience. Who would go to the opera just to see Pavarotti slide a CD into a player?

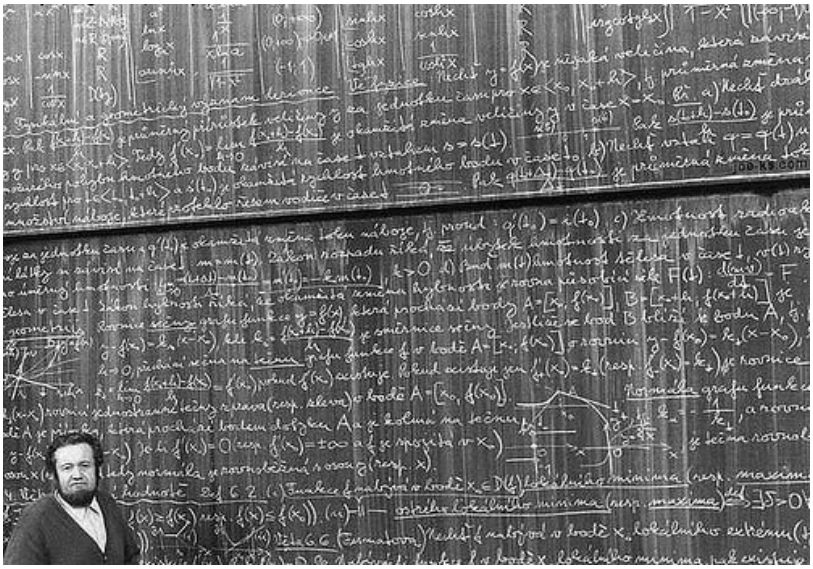

Fig. 2: Experts on the use of the blackboard can produce mathematical art

Data Walls

I have been teaching mathematics for years using large data walls consisting of several LED screens mounted in the classroom. Fig. 2 shows four screens arranged in a row. The screens are bright enough so that lights in the classroom do not have to be dimmed. The contrast of LED screens provides a superior visual experience than a chalkboard. Students sitting in the last row can still see the diagrams and formulas clearly. The lecturer writes on a contact sensitive tablet laying on a stand. This allows the lecturer to talk directly to the class, keeping eye contact.

Fig. 3: The “intelligent classroom” at Freie Universität Berlin

The four screens and the tablet are connected to a desktop computer retrofitted with a special extension board for controlling the five screens (the tablet is the fifth screen). As is visible in Fig. 3, the lecturer can use different colors and line widths. Images can be pasted on the screens. The images come from a pre-assigned folder in the hard disk or just from the clipboard (allowing cut-and-paste from a browser, for example). The screens do not have to be “erased”; when the lecturer runs out of space the image just scrolls up. The lecturer can scroll up or down during the lecture to show previous material again. The complete lecture is

stored and is available right after the class in two formats: a) As a PDF file of the complete lecture, b) In a special format which allows "replaying" the lecture at home. The user just starts the player in the browser and the class is shown like a video on the user's screen, including the audio signal captured with an ambient microphone.

The program running on the five screens has been called IntelliChalk (for intelligent chalk). It is, first, a painting program which provides the lecturer the tools to draw and write with high quality. But it is also a program which manages images for pasting, as well as scans of handwritten notes. Usually mathematics lecturers prepare notes for their class on paper. These notes can be digitized using a digital camera mounted on a desk. The software digitizes the ink on the notes and separates the notes in different files, which we call "macros". The macros are available for the lecturer in the classroom computer. The lecturer can then just paste definitions, or the statement of a theorem, and just write the proof or development he or she is interested to explain, saving time during class.

Teaching with a tablet

Not all classrooms at UNR have been provided with LED screens. The majority of them have a projector mounted on the ceiling which can project to a single screen. Where two screens are available, the system projects the same image on both.

I have conducted some provisional experiments with contact-sensitive tablets whose screen can be mirrored to the classroom projector. New tablets, such as the iPad Pro with electronic stylus can be used for drawing using several colors and line widths. The notes are written on "paper" that can be extended indefinitely just by scrolling on the tablet. The final notes can be easily exported as PDF files and can be put automatically in a cloud repository, right after class. Fig. 4 is an example of one screen of notes for an actual class at UNR.

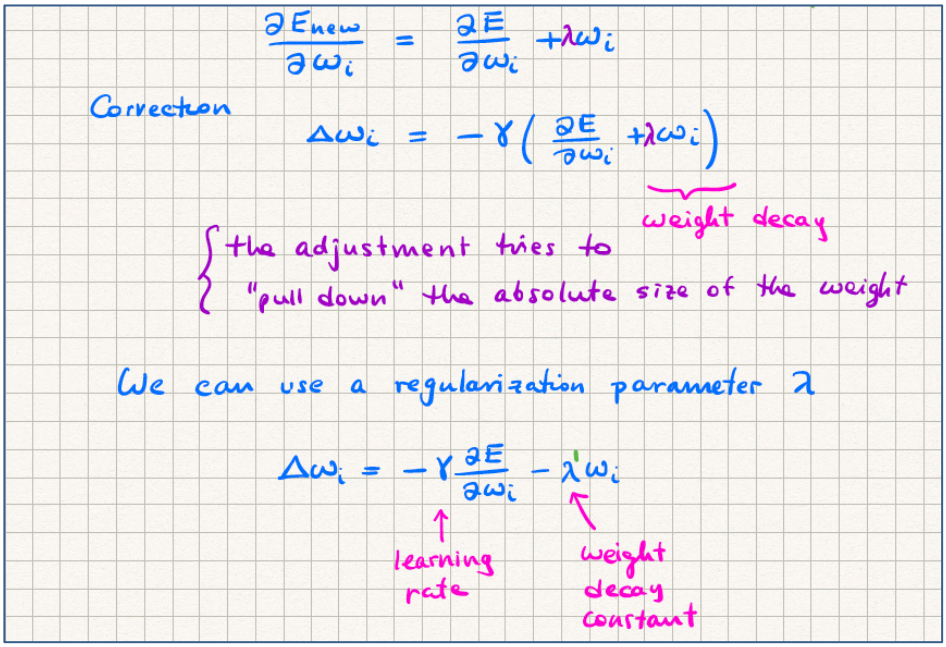

Fig. 4: A class at UNR done with an iPad whose screen was mirrored to the classroom projector

The color of the paper and its structure (lined or not) can be chosen from the tablet. The students see the development on the class on this virtual blackboard.

The advantages of such an approach compared with a blackboard are:

- Material which has been written down in advance can be freely mixed with the real-time development of formulas or diagrams. Colors can be used, erasing is easy. The page can be extended by scrolling down.
- Images taken from the Internet or produced by programs can be integrated in the board image.
- PowerPoint slides can also be used and can be marked (as annotated PDF files)
- The lecturer can talk directly to the students if the tablet is positioned on top of a lectern.

In my experience, using a tablet is the closest you can come to the experience of using an actual blackboard.

The disadvantages of the tablet at the present are:

- The reduced writing space provided by a single screen in the classroom. This can be mitigated by scrolling down the page, but it is no real substitute for the writing "real state" provided by several blackboards.
- The connection can be done using the screen mirroring function of the tablets, but on the side of the projector an Apple TV, a Google Chromecast or a Microsoft stick needs to be connected via HDMI or VGA to the projector. The Apple TV and Chromecast need to connect to the university WiFi network.
- Writing happens separate from the projection, so sometimes the lecturer needs to move from the lectern to point at the screen, in order to call the attention to an important point.

Fig. 5 shows the configuration used for the experiments at UNR.

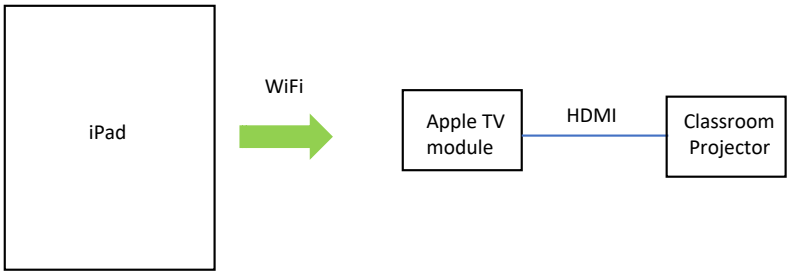

Fig. 5: Mirroring of the iPad screen using WiFi and an Apple TV module

Classroom experiments at UNR

Fig. 6 and 7 show an actual lecture using the tablet for writing and for annotating PDF documents. The tablet was connected to the projector using the configuration described above. There is no lectern in this classroom, so I had to carry the iPad while teaching, which represents a minor inconvenience.

Switching between documents is very easy and the lecturer can write on a blank page, or annotate PDF files of PowerPoint slides, or documents in general. In the lecture shown in Figs. 6 and 7, I could discuss a journal paper and proceed to explain the architecture of a neural network drawing it on the virtual whiteboard.

I have also recorded videos of a lecture in my office, using the recording capability of the Apple operating system. The screen is captured while drawing and is saved, together with the

microphone signal, as an MP4 video. The videos were stored in a repository that the students could access. It is then easy to produce a lecture for the students for viewing at home.

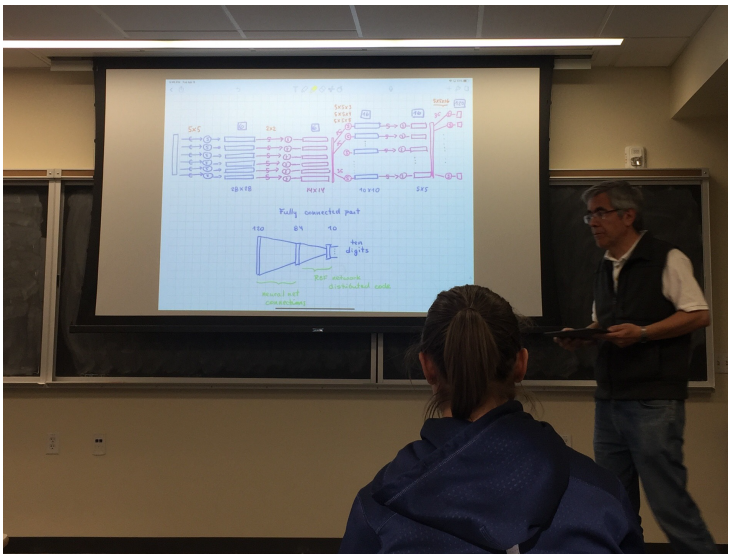

Fig. 6: Writing with the electronic pen on the tablet

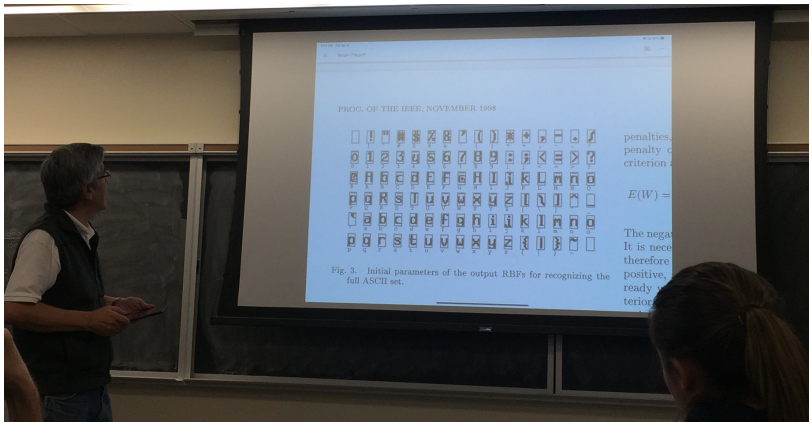

Fig. 7: Pulling up a journal paper in PDF and zooming in

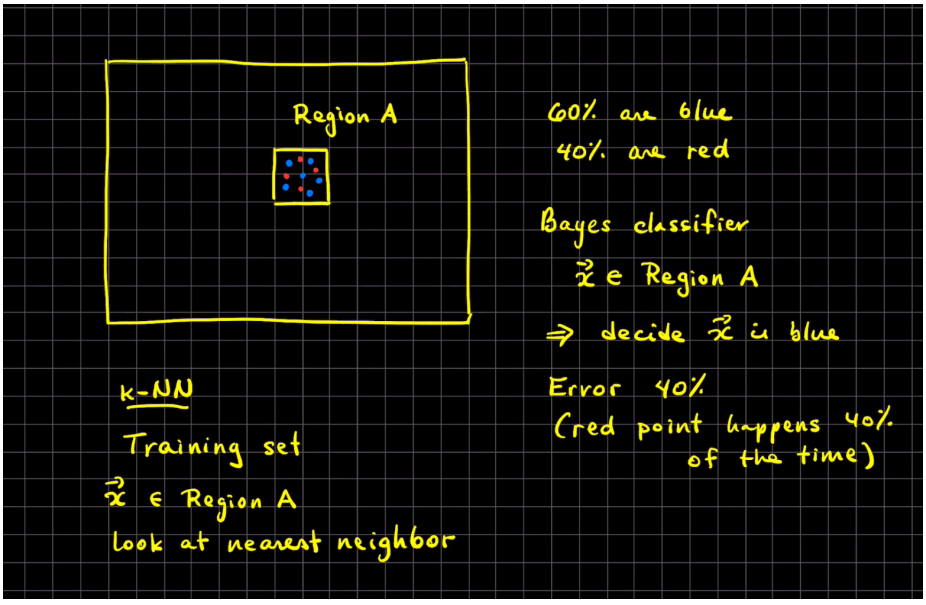

Fig. 8: A lecture captured as video (with sound) for the students

Future work

The drawing Apps which have been developed for tablets produce good images for projection in the classroom. However, they have not been developed for teaching, but for taking notes.

It would be possible to develop an App suited for teaching mathematics and the sciences in the classroom, which could offer some of the following features:

- Integration of handwriting and images, or slides, in a simple manner (by pasting the images from a folder prepared before the lecture).
- Automatic scrolling of tablet notes across several LED screens.
- Handwriting recognition, or buttons, for starting secondary applications such as simulators, algebraic servers, or an image search over the Internet.
- Videos can be pasted to the board.
- The students in the classroom can follow and annotate their own local copy of the class material using their own tablets. The student's annotations constitute an additional information layer on top of the blackboard image.
- The lecture is available over the Internet as a file for printing, or as a file for replaying the lecture as a movie (screen contents and audio). This is possible using the iOS screen capturing capability, but this feature should be callable from the App.
- Video of the lecturer him/herself is available as an additional synchronized stream.
- Such an App could be used also in conference mode for delivering classes through the Internet, live or differed.
- Voting using the student's tablets.
- The App locks the tablets of the students during class, so that students cannot use it for other applications, making sure that they stay focused on the lecture.

Thinking about the future of books, the App could recall specific chapters or sections of the book to which handwritten notes could be attached (additional explanations or extensions).

Having developed such an App, it would be feasible to do pedagogical experiments with students taking notes in their tablets, connected to the tablets of the lecturer. The students could scroll back to previous material, independently of other students. The lecturer could transfer control to any student, so she or he could continue writing on the virtual blackboard for the whole class to see.

An intelligent classroom prototype

Ideally, it could be possible to equip one classroom at UNR with a large LED data wall capable of showing several screens of lecture notes. The price of data walls has continuously gone down during the last years.

The students would be provided, each of them, with a tablet. If a company in this field (Apple, Samsung, LG, Microsoft) is willing to donate the equipment, an experiment could be done at UNR in an upper-level class with a limited number of students.