Programming Research Group

OUT OF THE OFFICE INTO THE SCHOOL: ELECTRONIC WHITEBOARDS FOR EDUCATION

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Abstract. In this paper the use of boards as a tool for communication in offices and schools is reviewed. The importance of boards for mathematics teaching is discussed. The advantages and disadvantages of 'traditional' blackboards and 'electronic' whiteboards are outlined by giving a comprehensive literature review of reports on electronic boards.

It is argued that due to a lack of research it has not been possible to convert the benefits that electronic whiteboards ('e-boards') offer in office settings, namely to print, save, and share the written information on the board, into the classroom. 'Stand-alone' electronic whiteboards without additional devices, such as electronic tablets or hand-held scanners, are seen to reinforce a 'talk and chalk' style of teaching. Consequently, it has yet to be demonstrated that electronic whiteboards could provide a benefit for teaching and learning. Some suggestions are given as to how additional input devices might offer new opportunities for communication in the classroom.

Keywords. board; whiteboard; electronic whiteboard; interactive whiteboard; digital board; ubiquitous computing; mathematical communication

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Contents

1 Introduction

Electronic (interactive) whiteboards have recently been introduced in many educational settings with the promise of providing a benefit for teaching and learning. However, until now, little research on the educational value of these electronic boards has been conducted. Moreover, it is important to remember that these boards were developed as a result of identified requirements in *office* settings rather than schools. Consequently, their educational potential has yet to be demonstrated.

As a first step, this paper reviews the development of electronic whiteboards in offices and provides an overview of several projects in offices and schools employing these boards. The vast majority of these projects were driven by the technology, that is to say there is a lack of empirical research on the role of the board for teaching and learning. It is hoped that this paper could provide the background for such research in the future.

In the next section, the general features of boards and the development of electronic whiteboards in offices will be discussed. A number of projects in offices that provided supplements are reviewed. In Section 3, the role of the board for teaching and learning mathematics is examined, before projects in educational settings involving electronic boards are summarised. Finally, in Section 4, the question of whether and how these boards might have an educational value will be addressed.

For our purpose, it useful to introduce some terminology to distinguish between 'traditional' and 'electronic' boards. The term *blackboard* will be used to refer to any 'traditional', erasable writing surface whether it is white, black, or some other colour, and whether the marks are made with chalk, crayon, or ink. 'Blackboard' is preferred to the term 'whiteboard' because the latter is often used in computer science to refer to a collaborative drawing tool, e.g., the Whiteboard application in Microsoft NetMeeting. The term *electronic*[1] *whiteboard*, or simply *e-board*, will be used for interactive, electronic, or digital boards.

[1] *Electronic* is preferred to *interactive* as there seems to be a lack of 'interactive' uses in the projects described in this paper.

2 Boards in offices

Boards are an easy-to-use tool for the dynamic production of diagrams and pictures (Hörsken, 1998). They form "a natural focus for presentation or group discussion" (Stafford-Fraser and Robinson, 1996, p.135) and mobilise lines of attention and activity to a single field (Macbeth, 2000, p. 30). Items on the board are *ephemeral*, i.e., they are easily changed or corrected.

Two purposes of boards in offices can be distinguished: for use in meeting rooms; and for use in individual offices. In meetings rooms, boards are used as a shared drawing surface (Aytes, 1995, p. 57) to serve as an external, public memory of the items discussed (Streitz et al., 1994, p. 347). They "provide a shared and focused memory for a meeting, allowing flexible placement of text and figures, which complements our human capabilities for manipulating spatial memories" (Stefik et al., 1987, p. 32). In informal office work boards provide a ubiquitous tool to be used for several heterogeneous tasks in parallel, often displaying various segments that may correspond to different tasks, different people, or writing at different points in time (Mynatt, 1999; Mynatt et al., 1999). O'Hare (1993) summarised the advantages of boards as follows:

> Since there is one of it, that everyone can see, it focuses attention on the task. Since everyone contributes to it, it is collaborative. Since it is constructed in real time, it has a history and sequence. Since it is extensive in two dimensions, it allows a more complicated structure than linear logical evolution or chronological or causal sequence. Since it is a random-access device, it does not have to be merely a temporally congruent record of remarks; it can speak to different people in different voices privately, and can 'listen' on its own schedule, as later contributions can be inserted easily at the left, and pregnant early insights can be placed in empty space far to the right, as though the discussion hadn't 'gotten there' yet. Since it is easily erasable, it strikes as a nice balance between commitment and experimentation. It's safe and robust; there's no electric cord to trip over; it doesn't need spare bulbs; and so far, there's no evidence that chalk dust or markers cause cancer! (p. 246)

Research on the role of boards is scarce. The most notable exception are ethnomethodological studies of work (Garfinkel, 1986) which have tried to topicalize practices with 'paper', 'pages', and 'blackboards' as of fundamental importance to an understanding of the situated, lived character of work. Three studies have been explicitly concerned with the role of the board: Roth (1996) studied the use of a board in a science class of a Grade 6/7 unit; Suchman and Trigg (1993) observed two artificial intelligence researchers working together at a whiteboard (and studied their use of representational devices); Stefik et al. (1987) examined the use of boards in a research laboratory (Xerox Parc, Palo Alto).

It was the latter study at Xerox Parc which led to the development of electronic boards in the early nineties. Stefik et al. (1987) observed the following problems of blackboards (chalkboards):

> space is limited and items disappear when the space is needed for something else, and rearranging items is inconvenient when they must be manually redrawn and then erased. Handwriting on a chalkboard can be illegible. Chalkboards are also unreliable for information storage (p. 32).

As these problems were easily overcome by using a computer, e-boards were developed at Xerox Parc to combine the advantages of blackboards and computer technology.

2.1 Electronic whiteboards in offices

Electronic boards were developed as a consequence of the identified disadvantages of traditional boards and made it possible

- to *print* the displayed material on the board;
- to *save* the information for later retrieval; and
- to *share* the written content of the session (either synchronously via video-conference, or asynchronously via email).

Most e-boards work very much like a gigantic touch-screen, using an LCD projector connected to a multimedia PC. All operations that can be performed with a conventional whiteboard (marking, erasing, drawing) are retained[2].

[2]There have been attempts to achieve these goals with other means. For example, the *BrightBoard* (Stafford-Fraser and Robinson, 1996) system used a video camera and audio feedback to enhance the facilities of an ordinary whiteboard, allowing a user to control a computer through simple marks made on the board. As the board was an ‘ordinary’ blackboard (rather than an ‘electronic whiteboard’) it avoided the common disadvantages of the latter, e.g., poor resolution, problems with erasing, and the high price, but did not provide full ‘interactivity’.

The first electronic whiteboard was developed at Xerox Parc in Palo Alto in the early nineties (Elrod et al., 1992; Pedersen et al., 1993; Welch et al., 1994) and used for small, informal group meetings as well as a distance meeting tool. They were part of Mark Weiser's vision of *ubiquitous computing* (Weiser, 1991, 1998), which aims to enhance computer use by making the interface effectively invisible for the user. The basic idea of ubiquitous computing is that technologies should "weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 1991, p. 66). Recently, Norman (1998) introduced the concept of an 'invisible computer', as a computer "should be quiet, invisible, unobtrusive, but it is [at the moment] too visible, too demanding" (p. viii)

Today, ten years later, there are numerous companies that produce these boards, for example, SMART Technologies or Promethean (see Appendix A). To get an idea of the potential of electronic whiteboards for teaching and learning, several projects that have explored additional aspects of e-boards will be reviewed below. These additional facilities included turning the information on the board into *meaningful segments* (Section 2.1.1); providing hardware for *remote collaboration* for workers in different locations (Section 2.1.2); facilitating the *interplay between different devices*, such as an electronic board and electronic tablets (Section 2.1.3); offering resources for the *remote control* of the board and *private and public spaces* for each participant (Section 2.1.4); and, finally, creating a *seamless integration* between the physical and the digital world (Section 2.1.5).

As mentioned in the introduction, these projects were mainly driven by the technology and there is a lack of empirical research.

2.1.1 Meaningful segments

In order to turn the items on the boards, simple pixels on a screen, into *meaningful* segments, a software application called **Tivoli** was developed for the original Xerox electronic whiteboard (Pedersen et al., 1993; Kurtenbach et al., 1994; Moran et al., 1995, 1997, 1998a,b). It was geared towards small, real-time 'working meetings', and introduced certain *domain objects*, which represented the semantic context of a meeting, for example, whether items were related to a calendar, a 'to do' list, or a budget meeting. This presupposed what kinds of 'objects' were required (here, a 'to do' list or a calendar), which was relatively straightforward, as the 'users' were the 'developers' as well.

This concept of meaningful segments was further developed in the **Flatland** system (Mynatt et al., 1999; Mynatt, 1999; Igarashi et al., 1999), which was geared to support long-term, informal use in an individual office setting rather than group meetings. Here, segments on the board were created, which were active or inactive, could be automatically shrunk and allocated different behaviours.

2.1.2 Remote collaboration

Electronic whiteboards offer a new resource for remote collaboration. To investigate this in the context of architects working in two different locations, Ishii et al. (1992, 1993, 1994) developed the **ClearBoard** system. This new hardware provided a shared drawing surface that permitted co-workers in two different locations to draw on a shared drawing surface, while maintaining direct eye contact. The metaphor of a 'glass whiteboard' was advocated, where the parties in a two-way video conference were projected on opposite sides of the glass, allowing both face-to-face discussion and shared use of a drawing space (Figure 1). In contrast to Tivoli, ClearBoard did not add 'meaning' to any items on the board, but rather aimed for 'seamlessness' (continuity) with existing work practices. The goal was to allow two architects in different locations to work in (almost) the same way as if they were co-present.

2.1.3 Interplay between different devices

Yet another aspect of electronic whiteboards, the sharing of information between different devices, was pursued by Rekimoto (1998). The **Pick-and-Drop** software allowed objects to be 'picked' from one device, an electronic tablet, and 'dropped' onto another, say the electronic whiteboard (Figure 2).

This was an important step as electronic boards were no longer treated as a stand-alone tool, but seen in connection with other devices. The **Pebbles Project** (Myers et al.,

Figure 1: ClearBoard for seamless collaboration (Ishii et al., 1994, p. 83)

1998) aspired to a similar goal and allowed the connection of multiple Personal Digital Assistants (PDAs) to a main computer. This allowed collaborative *simultaneous* drawing on an e-board from the various PDAs. With a comparable aim in mind, Hourcade and Bederson (1999) developed a Java package for multiple input devices, including multiple mice. In this context **Single Display Groupware** (Stewart, 1997, 1998; Stewart et al., 1999) should also be mentioned, that enable co-present users to collaborate via a single shared display and the simultaneous use of multiple input devices.

2.1.4 Remote control. Private and public spaces

With additional input devices, electronic tablets or even normal computers, it is possible to allow every participant in a meeting to have access to her or his own work as well as to the public display at the front. These two requirements, *remote control* and the distinction between *private and public spaces* were explored in the **CONCERT Lab** at the GMD in Germany (Streitz et al., 1994; Mark et al., 1995, 1996, 1997; Holmer and A.Streitz, 1999). A whole room with interconnected technology, was built to support group meetings in office settings. Each participant had access to a workstation for individual work, as well as access to a large public display which was used for presentations and the coordination of group activities (Figure 3).

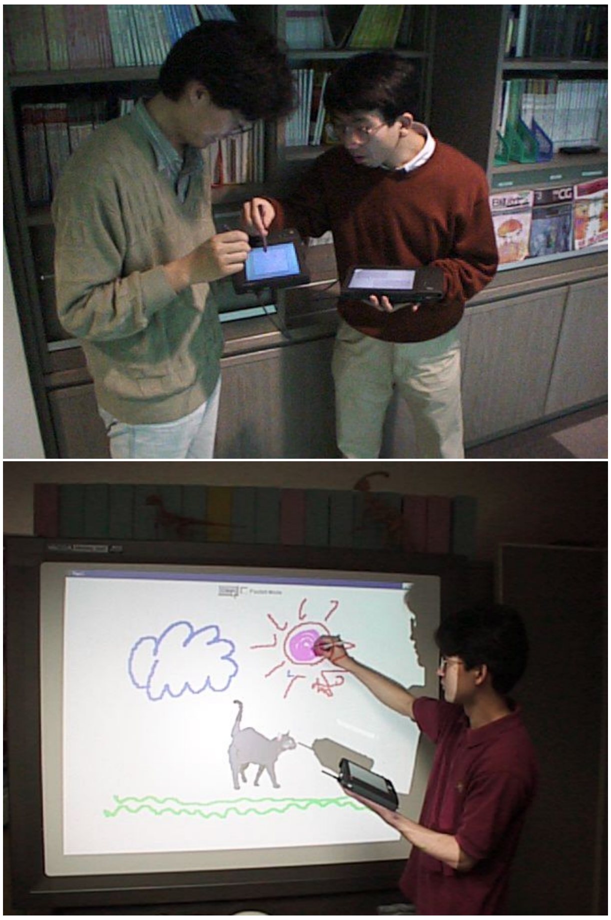


Figure 2: Data exchange between PDAs and the electronic whiteboard

Figure 3: Private and public displays within the CONCERT Lab project

Remote access and the difference between private and public spaces were also tackled at the University of Arizona in the form of **Electronic Meeting Systems** (Nunamaker et al., 1991, 1995). These were rooms, where a series of networked computers were arranged in a U-shape around a large-screen video display at the front. As participants typed their comments to a question ("How can we double our sales over the next four years?"), the results were integrated and displayed at the front. Everyone was able to see the comments of others, but without knowing who contributed what. This anonymity seemed to create equal opportunity for participants as "their input can be anonymous, people can float unconventional or unpopular ideas without political risk" (Nunamaker et al., 1995, p. 158).

2.1.5 Seamless integration

The most recent development is the aim to provide *seamless integration* between the physical and the digital world. The researchers at the GMD in Germany developed further the CONCERT Lab room into the **i-LAND project** (Streitz et al., 1998, 1999; Geißler, 1998). The goal was to provide a computer-augmented room, which included an electronic wall, an interactive table (a horizontal electronic whiteboard), two computer-enhanced chairs (for remote control) and a scanning device. The scanning device made traditional paper documents immediately available in the network, providing seamless integration of hand-written and digital resources. Furthermore, it was possible to share information between different devices, for example, the electronic board and a laptop.

To allow participants to seamlessly change between looking at their private space, another participant, or the public display at the front, the **Design Conference Room** (Ferraro et al., 1995; Geisler et al., 1999) was built at the Rensselaer Polytechnic Institute. Through a specific hardware construction (Figure 4) each participant had three different lines of view: to the private system, to the public system, and to other participants.

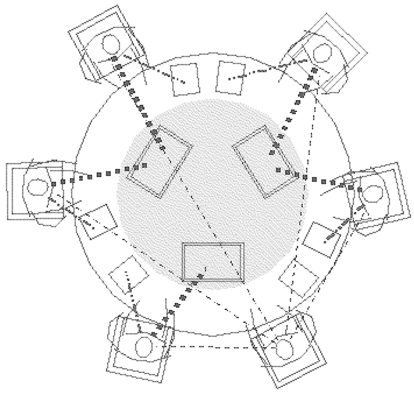


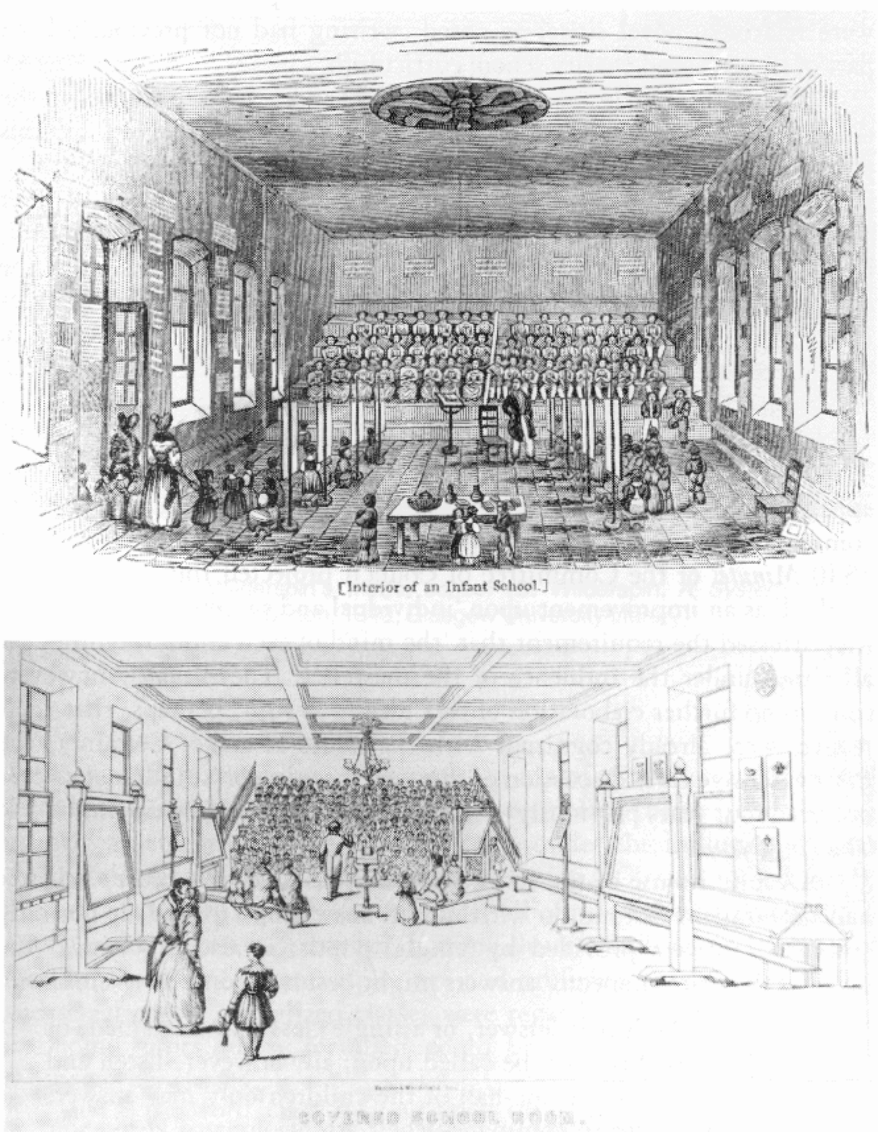
Figure 4: Design Conference Room with three lines of view (Geisler et al., 1999)

3 Boards in schools

Having reviewed the various projects involving boards in offices, let us now turn to the role of boards in schools. Although blackboards and chalk are recorded in Comenius' *Orbis Pictus* (1656), they did not become common in schools until the nineteenth century (Hamilton, 1978). Hamilton (1990) links the emergence of boards in schools to a shift to front-of whole-class teaching, linked to the introduction of question and answer teaching and batch production methods of schooling (p. 75). This is demonstrated by two classroom drawings in Stow's *The Training System* displayed in Figure 5. The first drawing, taken from the 1836 edition, does not show a blackboard, whereas blackboards are displayed in the 1850 edition.

Until recently, the only publications dealing with boards in schools focused on 'neat and legible' writing on the board (Ewart, 1922; Crichton, 1954; Ramshaw, 1955), i.e., they were concerned with boards as a tool for the *teacher* and as a resource for whole-class teaching (Kent, 1969; Hörsken, 1998). Jaworski (1994) illustrates the typical use of the board by secondary school teachers:

> Typically, the teacher introduced the mathematical content of a lesson using exposition and explanation (teacher talk), usually from the front of the classroom (using blackboard and chalk). Pupils were then given exercises through



Figures 8 and 9
Different representations of schoolrooms in the 1836 and 1850 editions of David Stow's *The Training System* (Glasgow and London). Note the blackboards in the later edition. (A copy of the 1836 edition is held in Glasgow University Library)

Figure 5: Blackboards in schools (Hamilton, 1989, p. 104)

which they practised the topics introduced by the teacher. (p. 8)

It is therefore typically the *teacher's* writing that is displayed on the board in classrooms. The marks on the board transform the transient resource of speech, into the persistent resource of writing. As the teacher's remarks on the board are commonly final, they have a 'authoritative' or 'correct' status (Pimm, 1987, p. 113). Krummheuer (1983) points out that 'writing-on-the-board' increases the 'frame differences' (Goffman, 1974) between teacher and students. He suspects that written comments on the board have a more compulsory or enforcing character than spoken comments by the teacher to the student: "The writing on the board must be correct; the writing on the board gets copied by the students into their notebooks" (p. 209; my translation).

The objective character of the writing on the board seems to be particularly related to mathematics. Not only is writing essential to mathematics: "*Being thought* in mathematics always comes woven into and inseparable from *being written*." (Rotman, 1993, p. x), but the evolution of mathematics was indissoluble tied to the evolution of inscription practices (Roth and McGinn, 1998, p. 44) . Furthermore, blackboard notes in university mathematics lectures are 'objective' or 'context free', i.e., it is possible to read them without knowing the context in which they were written — in contrast to the social sciences (Livingston, 1997, p. 422).

3.1 Electronic whiteboards in education

As in the case of office settings, it seemed natural to combine the advantages of blackboards and computer technology to overcome the limitations of boards, such as the inflexibility of prepared materials (for example, transparencies) and the difficulty of giving feedback or making use of individual exercises (Hoppe et al., 1993). As early as 1984, Higgins and Johns (1984) had a vision of an 'electronic blackboard', a computer with a large screen, that would assist teachers and stimulate whole-class activities (Friel, 1986). Similarly, Orton (1987) envisaged a 'magic blackboard' (p. 47) that would provide simulation applications and allow exploration and discovery exercises.

Once electronic whiteboard became affordable in the mid nineties, they were employed in several research projects in education. For the most part these projects were at university level, concerned with capturing lectures or aiming to make lectures more 'interactive' (see below). Consequently, e-boards were seen as just another (hopefully beneficial) resource for subject teaching. In primary and secondary schools, on the other hand, the use of e-boards concentrated on teaching IT in purpose built computer rooms, rather than teaching mathematics with new tools.

However, in the course of transforming the electronic whiteboard from a tool for office meetings to an educational tool, the fact that office and educational settings are remarkably different has been neglected. In order to successfully design educational technology, two questions should always be asked (Koschmann et al., 1996; Greiffenhagen, 2000b):

- What *capacities* does this technology offer?
- What are the *needs* in teaching and learning which this technology might support?

Although the *capacities* of e-boards are the same for office and educational settings, the *needs* are fundamentally different. For example, the number and status of participants or the style of interaction might be different between an office meeting and a school lesson.

The majority of research projects in education have focussed on exploring the *capacities* of electronic whiteboards in university settings, such as to present and capture lectures (Section 3.1.1), to offer handwriting recognition (Section 3.1.2), and to provide resources for more interaction (Section 3.1.3). The exception is the NIMIS project, which offered ubiquitous tools for a primary classroom (Section 3.1.4).

As these projects were driven by technology rather than educational needs, little *research* or *evaluation* has been conducted, except a few questionnaires. (Awwad et al., 1999; Bell, 1998). Therefore, in the last section of this paper some suggestions and initial findings from a pilot study for the potential use of e-boards in schools will be offered.

3.1.1 Presentation and capture of university lectures

The **Classroom 2000** project (Abowd et al., 1996, 1998; Abowd, 1999) was an attempt to capture as much as possible of a typical university lecture. By capturing the different streams of activity in the lecture hall (notes, audio, video) and presenting an easily accessible interface that integrated those streams, it was hoped to reduce the need for mundane note-taking[3], allowing the students to engage in and better understand the lecture discussion.

To deal with the enormous size of the lecture room and to allow items to displayed for a longer period of time, three displays were used: the display on the right was the electronic whiteboard; the middle display was an overview of the four most recent slides; the left display showed Web pages or more of the extended whiteboard (see Figure 6).

Figure 6: Classroom 2000 with three displays (Abowd, 1999)

Akin to the Classroom 2000 project, Hoppe et al. (1999) developed **electronic lec-**

[3]It is an ongoing debate whether taking notes during mathematics lectures is helpful or not. This is a problem which every mathematics undergraduate faces in her or his first year: shall he or she copy the lecturer's notes from the blackboard — although these notes are all taken from a standard textbook?

ture halls for standard, single-site undergraduate computer science lectures (Figure 7). Here, the aim was to gracefully integrate electronic whiteboards and pen-based input with the presentation of prepared electronic documents.

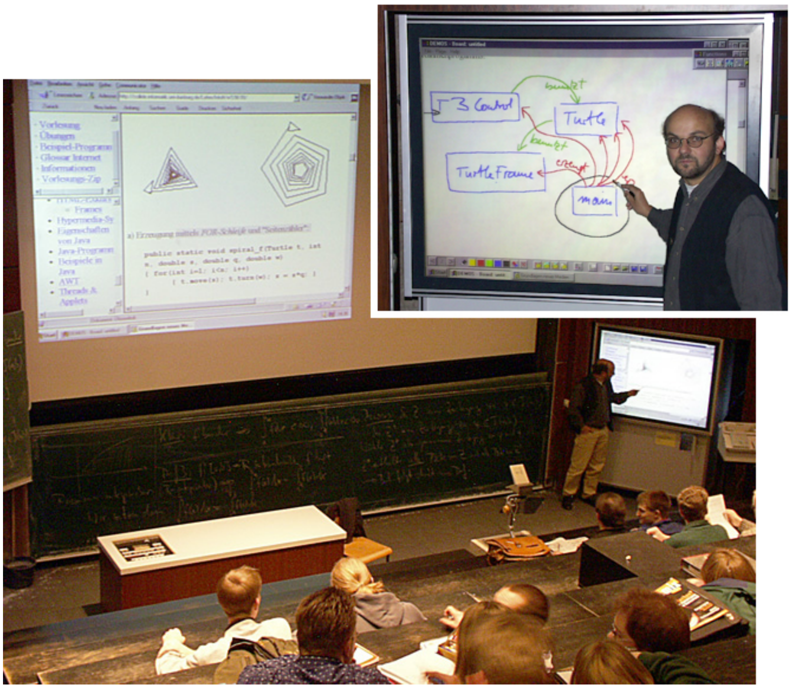


Figure 7: The 'Electronic Lecture Hall' at Duisburg University

3.1.2 Handwriting recognition

Nakagawa et al. (1996, 1997) built their own electronic whiteboards, the **IdeaBoard** (interactive, dynamic, electronic assistant board) which provided handwriting recognition software (Figure 8) to provide a facilitate computer input on the board, for example, for programming exercises or an arithmetic calculator on the board.

3.1.3 Interactive university lectures

To make university lectures more 'interactive', researchers at the Rensselaer Polytechnic Institute further developed the Design Conference Room (Section 2.1.5) into the **Col-**

Figure 8: The IdeaBoard at Nakagawa Laboratory

laborative Classroom (Ferraro et al., 1995; Geisler et al., 1999; Geisler and Rogers, 1999) which was geared at university lectures. Teams of students were provided with electronic tablets, which were connected to a public display to allow for direct control by the participants. In contrast to a 'stand-alone' e-board in a classroom, the design of the Collaborative Classroom allowed students (or the lecturer) to immediately present their work at the front. A sketched layout is displayed in Figure 9.

Figure 9: The Collaborative Classroom

The **DISCO** project (Keil-Slawik, 1999, 2000) was designed with similar goals in mind and linked all the computers in the classroom to the e-board at the front. Shneiderman et al. (1995) created an **Electronic Classroom** in which 20 workstations, built into desks, were used to support as many as 40 students. It made it possible for the lecturer to review the students' work, give individual help when necessary, and show the students' work to the entire class.

3.1.4 Ubiquitous tools for schools

Recently, researchers in Duisburg (Germany) created the **NIMIS** (Networked Interactive Media In Schools) classroom for young children in the age range 4–8 years. Their goal was to create an 'Computer-integrated Classroom' (Hoppe et al., 1993; Baloian et al., 1995) that respected the needs of children to learn in the company of other children and their teacher, while taking advantage of the creative possibilities for adaptive and highly interactive learning environments.

An electronic whiteboard was used in connection with an electronic tablet. Pupils interacted with the computer by using a special pen on for the electronic display (a picture of the whole classroom and the electronic tablets is displayed in Figure 10). Within the NIMIS project 'traditional' classroom procedures were seamlessly integrated with the new technology. Most impressively, the classroom was situated in a real school and used everyday. This makes the NIMIS project remarkably different from many other 'experimental' school environments which are based at universities.

The hardware at the NIMIS project was designed according to the needs and requests of the teachers involved. Furthermore, the focus of the project was on the *pupils* rather than the teacher. Hopefully, in the future similar research projects will help to explore the educational potential of e-boards in greater detail. For the moment, some preliminary findings from a pilot study (Greiffenhagen, 1999, 2000a) will be suggested.

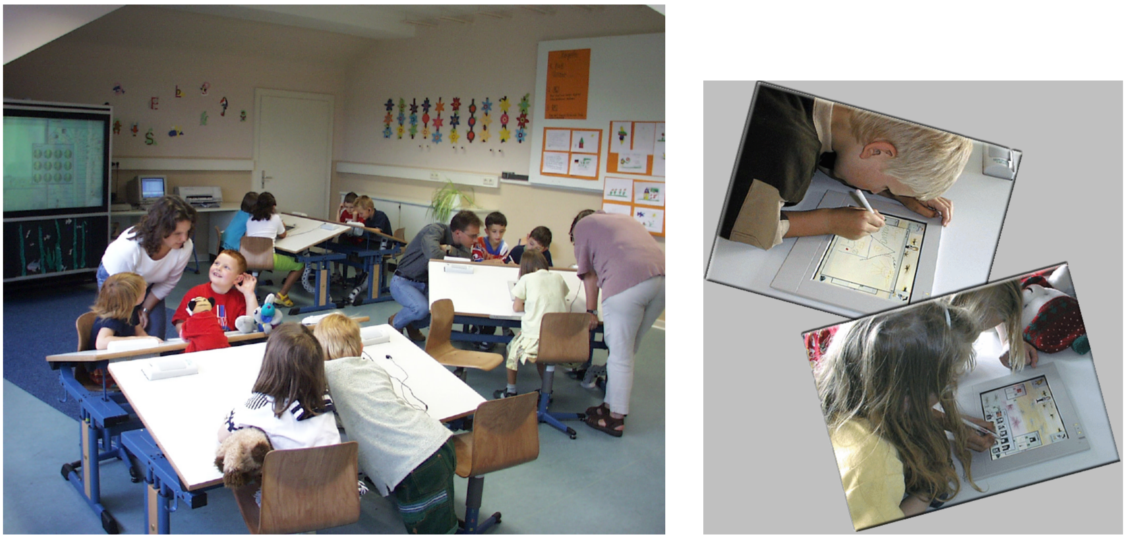


Figure 10: The NIMIS classroom

4 Educational potential of electronic whiteboards

Electronic whiteboards seem to be yet another example of a technology originating in the military or industry that has been placed into the classroom without considering the specific needs of educational settings (Selwyn, 1999), resulting in a "linear mix of old instructional methods with new technology" (Papert, 1993, p. 36). Consequently, the vision of electronic whiteboards (offered by companies) does not address the question of how electronic whiteboards might improve classrooms lessons. The mathematics teacher that I worked with during the pilot study remarked on their potential:

> That's just like facilities which a board could have, isn't it? It's not really improving the quality of the mathematics which is going on in the classroom, which would be really good, wouldn't it? If you could produce something which would improve kid's ability to communicate mathematics. Otherwise you would just produce a glorified blackboard, aren't you? A sort of high-tech blackboard. (Interview, 18.6.99, p. 11)

The electronic whiteboard by itself is generally not "any better than an overhead or chalkboard when used exclusively by the teacher in a lecture mode" (Abowd et al., 1996, p. 194). This is also the conclusion of a pilot study (Greiffenhagen, 1999, 2000a), in which the way a secondary school mathematics teacher used a traditional blackboard was investigated through observation and video recordings. Short interview were conducted after each lesson, to explore how an electronic whiteboard might be used to provide additional resources for teaching and learning of mathematics. Three main potentials were identified: animation and tactical control, instant and remote access, and providing an audience.

Animation and tactile control

One of the main differences between writing on a piece of paper with a pencil and 'writing' on a computer with a keyboard or a mouse, is the separation of 'input' and 'result' in the later. Using pen and paper, there is a sensation of 'direct manipulation'. As Sudnow (1983) puts it:

> Draw a figure on the two-dimensional surface of a blackboard, and you must stretch to reach areas in the far upper corners. The amount of pressure extended on the chalk further adds the palpable touch of a third dimension. But on the screen a magical intervention destroys all consequences of pressure and perspective. (pp. 66-7)

When using an electronic whiteboard it is possible to use a finger to write on the board or to manipulate objects on the board — thus blurring the distinction between the 'real' and the 'animated' world. This might be particularly beneficial for young children who are now able to access the computer without any additional devices except their own finger. One teacher reported to me that she had used *cabri géomètre* (a geometric drawing application) with primary students with great success.

Furthermore, e-boards present a new opportunity for animation software for subject teaching (for example, physical or chemical animation). As the objects on the board can be directly manipulated with the hand, the animation has a status between a 'real' classroom experiment and an 'ideal' textbook representation. These new kinds of 'experiments' seem like a beneficial new resource for teachers and students.

Instant or remote access

Instant or remote access, for example through electronic tablets, would allow students to write on the board from their seat, rather than having to get up and go to the front or to only say their answer. At the moment when students answer questions posed by the teacher, students can only say their answer but not write it (except if they were to get up and go to the board). In contrast to the resources available to the teacher, the ones available to students are limited.

Having access to multimodal forms of representations (talking, drawing, pointing, gazing) seems to be integral to the work of scientists and mathematicians (see, for example, Goguen (1999); McNeill (1979, 1992); Meira (1995); Roth (1996)). Goguen (1999) observes that "a discussion among a group of mathematicians at a blackboard will typically involve the integration of writing, drawing, talking and gesturing in real time multimedia interaction" (p. 38). For Meira (1995), " it seems to be common sense among professional mathematicians that one can think better with chalk in hand" (p. 311)

Consequently, for efficient communication, it seems to be essential that students have the same resources available to them as teachers or scientists do. This was also the conclusion of Roth (1996):

> When all participants had access to the representational device, here the chalkboard, efficient communication occurred. The production of marks and coordination of hands, eyes, and talk happened all at once, integrated into a multimodal development of arguments in a way that is characteristic of talk in scientific laboratories. (p. 180)

Providing an audience

The importance of different *audiences* for students has frequently been recognised (Cudmore et al., 1996; Lee and Lawson, 1996; Martin et al., 1976; Morgan, 1998; Pimm, 1987, 1991; Stewart and Palcic, 1992). At the moment, the teacher's advice "don't forget your audience" is superfluous because students are aware of their only audience — the teacher (Morgan, 1998). Mehan (1989) saw computers as a tool for students to be be writing for a purpose (other students) rather than simply for teacher evaluation. For Shneiderman et al. (1995) the breakthrough was "opening the learning process by rapidly showing many students' work to the entire class" (p. 21).

However, the public display of 'private' notes is not a benefit *per se*: shy pupils might feel pressured if they knew that the teacher could display their work at the front; there might be other good reasons why some thoughts are written in a 'private' form. It is the teacher's job to decide whether the public display of notes might have a positive effect.

The notion of 'instant feedback' has been successfully applied in purpose specific 'computer rooms', where software applications such as SynchronEyes allow the teacher to display the work of each student on the public display, monitor their progress from the front, and help students from a single location. With additional input devices, such as scanners or electronic tablets, the teacher could at any point decide to display students' private writing on the public display at the front — making the students' writing the basis for discussion. The private writing of students becomes potentially public. This might increase the students' incentive for communicating clearly through providing an audience, the whole class, in contrast to the narrow audience that they ordinarily communicate with.

4.1 Final remark

It is remarkable that Roth (1996) in a study conducted several years before and without electronic whiteboards in mind listed very similar requirements for a new technology. Roth had analysed a Grade 6/7 physics classroom in Canada from the perspective of Interaction Analysis (Jordan and Henderson, 1995). He concluded his paper (p. 185) with the challenge to build a technology that "makes possible equal, easy and rapid physical access to the shared display" (providing an audience), "affords pointing to specific parts" (remote access), and "allows animation of the design so that they can be subjected to tests of feasibility" (animation).

Following these recommendations it is hoped that electronic whiteboards will turn out to be a useful additional for teaching and learning mathematics — and not simply a "glorified blackboard".

A Useful URLs

Providers of electronic boards

- SMART Technologies: `http://www.smarttech.com`
- Promethean: `http://www.promethean.co.uk`
- Ibid: `www.ibidwhiteboards.com`

Electronic whiteboards for offices

- Ubiquitous computing: `http://www.ubiq.com/hypertext/weiser/UbiHome.html`
- ClearBoard: `http://www.media.mit.edu/people/ishii/CB.html`
- Pick-and-Drop: `http://www.csl.sony.co.jp/person/rekimoto/pickdrop/`
- Pebbles Project: `http://www.cs.cmu.edu/~pebbles/`
- CONCERT Lab: `http://www.darmstadt.gmd.de/concert/infrastructure/concertLab.html`
- i-LAND: `http://www.darmstadt.gmd.de/ambiente/activities/i-land.html`

Electronic whiteboards for education

- Classroom 2000: `http://www.cc.gatech.edu/fce/eclass`
- IdeaBoard: `http://www.tuat.ac.jp/~nakagawa/`
- Collaborative Classroom: `http://dcr.rpi.edu`
- DISCO: `http://iug.uni-paderborn.de/iug/projekte/disco/`
- Electronic Classroom: `http://www.cs.umd.edu/hcil/electronic-classroom`
- NIMIS: `http://collide.informatik.uni-duisburg.de/Projects/nimis`

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