Boundaries, barriers and borders: teaching science in a wired world

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Introd

Introduction
The Internet is now “old hat” in the media and in most schools. URLs appear in newspapers, on television and business cards. Having an email address is, at least for some as important as having a mobile telephone. If we were to accept the media accounts of the world in which we live, the expression “wired world” would seem obvious, even necessary. An important element in the stories that lionise the emergence of these new technologies is the observation that the boundaries and barriers that used to operate to separate people, institutions and information, are now disappearing. We are told a new era in access to information and knowledge has arrived. Teachers are told that they need to learn to be “the guide on the side instead of the sage on the stage”. The rhetoric of the information superhighway continues to promise, if not information heaven then at least a new kind of (digital) certainty.

It is also a time of unprecedented change in all levels of education in Australia. The forces making schools and teachers more accountable, yet at the same time, more independent are not easy to unravel. For the first time, social institutions like schools appear somehow coupled to the larger economic influences that began to operate in Australia at the time of deregulation of the financial system over a decade ago. Not only schools but many of the institutions, practices and ways of being in the world now appear swept into or at least are articulated in some way to one or other form of global computer networking in which money, information and cultural artefacts circulate.

There is a sense in schools and school systems that these changes are not connected and so the appropriate response to the Internet is for schools is to simply “get online” and that is all that is required. In this way, the other more difficult changes with which schools have to contend are partitioned and identified as a changed context or set of circumstances in which schools now must operate.

Responding to the Internet in this manner means that the Internet is simply “applied” to existing curricula. Like so many computer-based technologies before it, the Internet is seen as a “new tool”. Nothing much has changed, except that there is now an additional, and in some cases, a superior resource for the teaching of science and other subjects. Responses like this are not new. Schools have become good at taking in new technologies and domesticating them for their own purposes (Cuban 1986, Hodas 1996). In the 1980s, schools established a pattern for reacting to each significant technological development that came onto the market. Typically, a judgement was made about its desirability, usually in terms of whether or not other schools had acquired it. Parents and principals understood that it was important to have particular computer technologies in their school. They were less concerned about what was done with them. The important thing was to be part of the bandwagon, or revolution as some would have it.

Having a revolution or caught in a loop?
Computers did not arrive in schools by accident. Persuasive arguments were made to secure their acquisition. These arguments are familiar to most teachers. Computers would enhance learning, improve employability of students, and, for the Internet, improve access to information. The odd thing is that these first two claims have been used over and over for the past fifteen years and few have bothered to ask whether or not they have been achieved with a particular technology. Recycling the justifications for using computers and related technologies in schools is an important part of maintaining a coherent educational aura around them. Paradoxically, the failure of an earlier technology to live up to its promises is translated as a good reason to purchase the next generation in which all the problems of the previous generation are fixed. This is not an unreasonable approach given the instability and

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1 As Schwartz in Brand (1987) argues, most of the information is money.
complexity of current versions of system and application software. It is simply impossible to
guarantee problem-free software so the user becomes a part of the product development loop.
There is nothing wrong with this if the user is aware that this is what is going on. For many
schools, this appears to not be the case. They continue to loop through generation after
generation of hardware and software, largely accepting of the inevitability of it all. Here is a
model for the cycle that appears to operate.

1. A new technology appears on the market.

2. Arguments are made concerning the improvements the technology will make to
   existing teaching/learning practices. This is an important and necessary step in
terms of recruiting support. The technology has to be positioned so it appears as a
solution to a particular problem. So the initial story has to be constructed around
current practices. It would make little sense to claim an outcome that was
unfamiliar and impossible to foresee the unexpected outcomes. It’s only
justification can be in terms of what is already known, but importantly it has to be
in terms of a current problem of some kind or other. This is what Sproull and
Kiesler call first level effects-- “the planned efficiency gains or productivity gains
that justify an investment in new technology” (Sproull and Kiesler 1991, 4).

3. The justification for acquisition is successful and the new technology is put in
   place.²

4. Then one of two things happen. In the process of adoption, interesting things
   happen that bear little relationship to what was imagined, what Sproull and
Kiesler call second level effects, “...people pay attention to different things, have
contact with different people, and depend on one another differently” (Sproull and
Kiesler 1991, 4). There is little point or interest in evaluating the original claims.

   Alternatively, step 1, a new technology appears and new efforts go into making a
new case for its acquisition.

The cycle repeats itself with the regularity of the seasons, except that the seasons for the
information technology industries are more likely to be of the order of weeks rather than
months. I am not suggesting that participation in this loop need necessarily be construed as
evidence of mindless consumption. Though I do believe that operating in the loop with a view
that it is all inevitable is worrying to say the least.

It is not all a matter of out of control consumption by schools. There is a potential constraint
on continuing to cycle in the loop. The human costs associated with implementing and then
maintaining each innovation are high. It is not simply a matter of putting a particular piece of
technology in place and there being no or little further costs. Even the simplest piece of
classroom “edutainment”³ takes some time and effort to install and then requires ongoing
support for its ongoing use in classrooms. Suchman (1996) points to the importance of what
she terms “articulation work”, the human effort required to engineer a particular technology
into a particular setting and keep it working harmoniously. The more complex the software or
hardware the more effort is required. If a particular configuration of hardware, software and
people continues to work, then these human resources are unavailable for a newer piece of
technology. It is simply not possible to continue adding technologies without discarding ones

² Implementation is never a simple matter and is always a matter of compromise and negotiation (Latour 1996).
³ Software that is used by some teachers to occupy students who complete their class work early or as a reward for good
   behaviour.
adopted earlier. The simplest and least controversial example of this is an upgrade to a piece of application software. In a class situation, teachers know how much simpler it is to support a single operating system, common hardware configuration and standard application software. These considerations are familiar to all who juggle the resources of a school or classroom.

Nevertheless, schools do move in and out of the consumption loop described above. They do so supported by a particular view or position about the relationship of the new technologies to education. The claims made to justify each new piece of hardware or software are located in a bigger story, one which typically represents a vision or scenario for education in which the new information and communication technologies are implicated. These stories are important for they are the basis by which schools understand themselves and their curriculum vis-à-vis computers and related technologies. They constitute a kind of mindset or context in which decisions are taken. It is important to briefly outline some of them before focussing on specific issues pertaining to the most recent technology to draw the attention of schools, the Internet.

Having visions and seeing things

Broadly speaking, the relationship between education and computer technology is seen in two ways. In one view, the technology is clearly central and effectively drives and determines what takes place in education. The human, social and cultural dimensions are positioned as context, things in which the technology operates. Various forms of technological determinism manifest themselves in a variety of ways and might be recognised in terms of the predominance given to the technology in slogans, practices and (“computer” sic) policies.

The other broad view places emphasis on the social, human and cultural at the expense of the technology. In this socially determined perspective, the computer is often described as “just a tool” whose fate is determined by the circumstances in which it is used. Although less common than technological determinism, here too, slogans, practices and policies signal the predominance of the social/educational over the technological, often to the point that the technology becomes invisible.

In the technologically determined camp, the best known vision is a utopian one in which computer technology is employed to revitalise schools and schooling. Computers are clearly identified as improving student learning, improving student access to employment and improving student access to information. These claims have been made so often for so many different instances of hardware and software that they are more or less taken for granted. Underneath this vision is a firm belief in the inevitability of technological progress which translates in educational terms to there being a technological solution to most, if not all educational problems. What a computer is used to do and why it is used is of much less importance than the fact that it is being used. The important question for the utopian visionary is ‘how’, how to use a particular technology in a classroom, how to make do with limited resources, how to get the most from a particular piece of hardware.

A subset of the utopian vision is so persuaded of the power of the new information and communication technologies that it sees schools disappearing. It extends the utopian vision and identifies schools as a major obstacle to the technology achieving the claimed improvements in learning, employment and access to information. Boring old and expensive

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4 For a detailed account of these discourses and their associated groups see Bigum and Kenway (forthcoming).
5 Computers across the curriculum, integrating computers into the curriculum, computer literacy, computer-aided/supported anything.
6 It is indeed curious that even after fifteen years of working with this technology in schools that we still have policies for computers, rooms for computers and literacies for computers. As I have argued for some time, much effort has gone into making computers “comfortable” in schools.
teachers are contrasted with engaging new media. The technologically determined progress is seen as more momentous, causing the collapse of what it sees as inefficient and dated social institutions like schools. A well known proponent of this position is Lewis Perelman (1992) whose claim that putting computers into schools is akin to putting an internal combustion engine into a horse, succinctly captures this vision. The Internet is a key technology and the adjective virtual a key term in the accounts of the visionaries who promote this future of schooling.

A vision which is dystopian but which also has a strong undertone of technological determinism represents a society overrun by technology in which human interaction, sense of community and the ability to deal with issues at other than the superficial level offered by electronic media is much diminished (Slouka 1995). This vision contains strong elements of nostalgia for the institutions and practices that are being replaced by computer technologies, ie books, libraries, print literacy etc. Neil Postman (1986, 1993) is one of a number of visionaries who are proponents of this view. Schooling, in this view, has left its “golden era” in which the practices and technologies associated with print were dominant. The solution for schools is to return to these practices. Schooling, along with the rest of society has no future unless the technological juggernaut is reversed.

The fourth position is broadly critical of developments in computer use in schools. it is not opposed to computer use in schools per se, but is critical of the manner in which computerisation has occurred and the assumptions that are employed to justify their use. This position offers a vision which is much less certain, reflecting a belief that the social will determine a future which is highly contingent and likely to be increasingly inequitable in its distribution of the benefits of computerisation. Proponents of this position tend to ask ‘what’ and ‘why’ questions about computer use in schools, emphasising the human costs of widespread computerisation and arguing for a more balanced assessment when computers are to be employed in any situation (Cooley 1992). They raise questions associated with the implications of new communications and information technologies for the ways in which we live, work and play and observe that if such matters are ignored by schools, students will be ill equipped to be critical consumers of new technologies (Mackay, et al. 1991). Technology is identified as a resource for learning but also as a context for learning and it is a context about which learning must occur (Bigum and Green 1995).

Each of these visions can usually be found represented in the staff of most schools, although most schools and the proponents of computer technology in schools tend to be more commonly associated with a version of the utopian vision. As mobilising devices, visions are important in securing the support necessary for acquiring and implementing new technologies but they also provide a sharp ordering of people. As Law puts it:

> Visionary orderings don't leave much room for delegation: who can be trusted who is not already graced? The answer is: only those who touch the hem and partake of the state of grace. ... So here's the moral. The orderings of vision tell that there are three states, three levels of possible hierarchy. There is the visionary. There are those who partake indirectly of the vision. And then there are those who do not.

(Law 1994, 118)

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7 See for example Tiffin and Rajasingham (1995).
8 Clifford Stoll (1995) offers an interesting argument re the Internet in respect of education and other social institutions.
Those who have participated in debates about technology in schools will have experienced or witnessed what it is to be one who does not share “the vision” or whose personal vision counters that being promoted in the school. That any one vision of itself is limited and limiting in the way it frames the way that the new technologies are understood is not easily conceded by the supporters of a particular vision. Yet, what we already know about the ways in which technologies are adopted and resisted in schools (Cuban 1986, Hodas 1996) and more broadly in society (Franklin 1990, Kling 1996a, Latour 1996, Marvin 1988) suggests that a more pluralistic approach, one that is more open minded about these matters is a much wiser option for schools.

The future of computer and related technologies in education will likely remain uncertain for a long period to come. If we are witnessing something akin to the replacement of steam with electric power then it may be many decades before the impact of the digital revolution becomes clear. Pursuing narrowly based and focussed visions is unlikely to deliver anticipated or significant educational outcomes largely because the basis of the vision, either technological or social determinism, is flawed. Relying on a technologically or socially determined dynamic to explain the complex set of interactions and relationships between human and non humans is like watching a football game in which one team remains invisible to the eye. The opposing team is merely context, something well understood that has an insignificant bearing on the outcome. The term one-eyed supporter applies as well to the use of computers in schools as it does to football games. But as Bijker and Law argue,

Purely social relations are found only in the imaginations of sociologists, among baboons, or possibly, just possibly on nudist beaches; and purely technical relations are found only in the wilder reaches of science fiction. (Bijker and Law 1992, 290)

There is not the space to detail the rationale for an approach which does away with the boundary between human and non human in describing technological innovation. The work of Latour, Callon, Law and others⁹ in describing and analysing a wide range of innovations is marked by insights which are unavailable to the technologically or socially determined positions described above. The heterogeneous nature of these phenomena is captured in the term sociotechnical (Callon and Latour 1981, Hughes 1983, Latour 1986a) which is used to describe messy assemblages of people, things and natural objects.

This approach known as actor-network theory employs a notion of heterogeneity as a means of describing innovations and projects, heterogeneity referring to the mixed nature of all sociotechnical ensembles, that is, they are made up of people and things and embody “social, political, psychological, economic, and professional commitments, skills, prejudices, possibilities, and constraints” (Bijker and Law 1992, 7). How ensembles are made up and come into being, how they emerge and compete with other ensembles and how they are made more durable over time is the research interest of actor-network theorists. In ANT distinctions between, for example, human and non human are irrelevant.¹⁰ The processes of power are explored through examination of the way networks of relations are constructed and maintained.¹¹

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¹⁰ Callon’s (1986b) extension of Bloor’s (1976) principle of symmetry--that projects that succeed and fail be studied in the same terms--requires that the social, the technical and objects from the natural world be analysed in the same terms.

¹¹ See for example, Law (1991).
Actor-network theory has been used to study a broad range of technical innovations, including the development of the Electric Vehicle in France in the 1970's (Callon 1986a); the ‘domestication of the scallops and fisherman of St Brieuc Bay’ (Callon 1986b); the demise of the TRS2 aeroplane project (Law 1988); the role of General Practitioners in the UK Cervical Cancer Screening Program (Singleton and Michael 1993); the introduction of a multimedia product for primary schools (Bigum, et al. 1993); and a study of tertiary students building expert systems (Gilding 1997).

Blackboxes and other enclosing objects
Understanding educational innovations associated with computer use in schools is faced with the problem of how to deal with the roles and behaviour of the many inanimate objects which make up elements of an innovation. In most analyses, they are treated in one of two ways. When the focus is on the social interactions of use, the technology becomes context, something that can be contained, simply described or blackboxed. Accounts of this type describe educational processes in the new technologised context, for example studies of computer-mediated communication, computer-aided instruction, video-assisted learning or even distance education in which the still dominant technologies of print are context.

Understandings that are based upon aspects of a technology partition the remainder of the technology, other technologies and the social, generally treating them as constants or givens, effectively blackboxing them. Studies based on this interest include studies of the human-computer interface, software evaluations, and programming studies. Both sets of understandings are based on using boundaries to simplify the messy, heterogeneous nature of the assemblage of people and machines.

Drawing artificial boundaries around elements of innovations may meet the requirements of particular, often academic interests but the practitioner, much as she/he might like to, cannot partition out any particular elements of an innovation, no matter how troublesome or difficult they are to manage. The innovator’s interests are in making it work and so she/he has to deal with the messy, heterogeneous complexity of the sociotechnical assemblage she/he wants to build. Listen carefully to the stories teachers tell of how they implemented a particular application in their science class. They are stories of managing messes, sociotechnical messes of machines, software, students, curriculum, administration, timetables, classroom resources etc.

There are ways of thinking about classroom work which limit the scope of the problem by blackboxing one or more of the elements. This leads to bizarre representations of the problems that teachers face. It is as if all the elements of a classroom are unrelated and that “the problem” can be identified and remedied. But when one element of the assemblage is altered, the other elements adjust, often unpredictably. The desire to reduce classrooms to the equivalent of a two-body problem is strong. For example, a piece of simulation software may be used by students in a way that is deemed inappropriate or not leading to the intended learning outcomes by their teacher. The software is identified as the problem and attempts are made to limit and control student choice in using the software by modifying some of the software parameters. This move is partly successful but not entirely, the teacher then alters the conditions of the assignment to further tighten control and obtain the desired outcome. For each move made there is a countermove, by students, by the software, perhaps the hardware, perhaps other elements of the classroom. It’s like playing billiards but with balls that have a mind of their own. Talking about classroom work in this way ought to be familiar to many teachers who use computer software in their classroom, indeed, take the software out and the stepwise negotiation of classroom work should be familiar to all teachers.
Of course, blackboxing is an important strategy in coping with the messiness of assemblages like classrooms, computers and students. There is a limit to the attention a teacher’s can give. Roles have to be assigned to software, students, desks, keyboards, mice, books, notes, overhead lighting etc. in order to develop an assemblage that behaves in a manner that the teacher desires. It is when particular elements or actors don’t follow their assigned roles that the teacher has to attempt to reassign roles, making adjustments to the earlier roles.

What I am advocating is that classroom use of computers be described in terms that more closely capture the messiness, the potential instability, the moves made by each of the actors, including the articulation work required to hold all things together. Such accounts make nonsense of claims that teachers are not “getting the best” out of the computers they are using in their classrooms. They support teachers who point to the importance of skills, knowledge and experience necessary to do this kind of work. They cast the resistance of teachers to using this technology in a different light.

I now want to develop these somewhat difficult ideas in terms of an approach that I have developed with others over the past decade in working with teachers and student-teachers. I specifically want to illustrate these points drawing on the Internet and science teaching.

Sociotechnical communities of teachers and learners

The proposition is that students and teachers can usefully think about what is worth knowing along three dimensions — the operational, cultural and critical. The use of the term dimension is intended to emphasise the inter-related nature of these three ways of knowing. An operational dimension attends to the skills that are necessary to use the new information technologies, ie. computers, modems, networks and so on. How these skills are acquired is just as important as what is acquired. I believe it is important to model the learning of these skills on the way in which computer professionals learn and work. They employ an elaborate human network of support, and learn to rely upon a ‘collective’ approach to knowing and problem solving. This ethos, clearly evident in the early days of the Internet and still evident in some parts of it, is also a rich and powerful way to learn and to know. Instead of everyone trying to know everything, individuals have a basis for specialist and shared knowledge that enables them to participate in a collective knowing.

You can find these kinds of practices in some classrooms. You will also find it among groups of boys who are video game aficionados. Invariably you find an elaborate support network which trades freely in cheats, advice, support and technical trouble-shooting information. Individuals are known for their expertise in solving the high level puzzles of particular games. The Internet for these students has become a means of extending their support network. There are a number of science-based examples of this kind of support to be found on the Net, mostly around collecting and reporting of environmental data.

The cultural dimension involves stepping into the culture that supports the practices of using computers for educational purposes— no matter what one's level of expertise or orientation. It acknowledges the importance of multiple perspectives and of the human processes that build, sustain and maintain the use of particular technologies in classrooms and elsewhere. For the novice what is required is a kind of cultural apprenticeship in which they learn to mimic expert performance (Lave and Wenger 1991). Knowing and being able to tell stories that both critically and supportively sustain the use of computers in schools is essential. This requires

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12 I refer to people with whom I worked with on these questions while at Deakin, including Peter Evans, Bill Green, Jane Kenway and Lindsay Fitzclarence.

13 This framework was initially developed by Green (1988) in the context of subject-specific literacies and was further developed by Green and Lee (Green and Lee 1994). Most recently it has been generalised to computing in education.
It might be argued that many students already participate in some kind of high technology culture having grown up in an environment in which these technologies were more or less ‘natural’ (Green and Bigum 1993). As the Internet continues to integrate with other media forms and more and more institutions, people and organisations have URLs, it will be increasingly difficult for teachers to not engage with this new medium. There may be important lessons for science teachers to learn from the various, specialised science communities that are now sustained by Net-based communication and sharing of information. Indeed, there are important debates about the nature of knowledge, community and the potential for the Balkanization of science because of the Net. Doing science is changing. It is unclear about the impact of the net on teaching science.

The critical dimension invites the teacher and student to step outside the culture and read “against the grain” and learn to ask questions about the taken for granted assumptions in the stories about computer technologies in and outside of schools. This is the most difficult component of the three components because it calls for time for reflection and talking, asking difficult questions of oneself, and engaging scholarly resources to provoke and expand one’s thinking. It is particularly difficult to do with new technologies like the Internet. It is also difficult to contemplate when the focus is on getting something, virtually anything done with or in this new medium. In the enthusiasm to make use of the Internet for science teaching, it is therefore important to acknowledge the nature and difficulty of the articulation work required by a teacher. Promotional accounts of the Internet necessarily paint pictures of the ease associated with using this technology. They are at odds with the stories that Net-experienced teachers tell of the time, effort and sociotechnical juggling they did in order to make “easy” use of the Net in their teaching.

Identifying dimensions other than those associated with learning how to do it is important. Collectively they pick up the approach based upon actor-network theory in which these tasks are considerably more complex and tricky than is normally represented. From this point it is possible to consider a set of principles to support the development and use of the new information and communication technologies in science teaching and in education generally.

Teachers first
There is a small but growing realisation in Australia that we may have gotten our priorities wrong in arguing that the importance of the needs of the young in learning to use computers. Teachers’ needs are often neglected because of the widespread perception that students needs are especially urgent; that if they are not properly prepared in the classroom for living in a world with computers then they will be disadvantaged. Concern about students has been a powerful influence in shaping how schools have come to terms with computer technology. In the 1980s it lead to a spate of computer literacy courses and programs in schools. In the 1990s, the Internet has prompted a fresh wave of anxiety about students with calls for ‘Net literacy’. In retrospect, literacy courses about particular technologies can be seen as educational panics, sometimes prompted and promoted by sections of the computer industry, more often than not reflecting adult concerns over a new technology.

Computers have become more commonplace in the home and increasing numbers of children now grow up in environments in which they have access to an array of electronic media

14 Stoll (1995), and Brook and Boal (1995) provide useful starting points.
devices and computers of various types outside school. By the time some children reach school they have considerable skills in using computers and have little or no fear of them. Many teachers on the other hand grew up in an environment that had far fewer electronic technologies available and find the adaption to working with computers more difficult than their students.

Adopting a principle of teachers first means supporting teachers to make use of computer and communication technologies to support their personal work before using the technology in their classrooms. It encourages teachers to attend to their own needs and interests before those of their students. It means that teachers should be encouraged to keep computers out of their classrooms and use them to support their work. This may be as simple as keeping copies of tests and worksheets on floppy disk so they are easily edited year in year out. It may mean encouraging a science teacher to pursue their own science interests on the Net without any direct application of this work to the classroom. It is worth noting how most teachers find it difficult to find time to participate fully in so-called ‘on-line teacher communities’. The exceptions are teachers of computer studies and librarians whose professional work dictates a higher level of Net usage than other teachers. Attempts to stimulate teacher interest in the Net have met with limited success and is of concern to those who have invested heavily in computer infrastructure for this purpose, for example the Commonwealth government’s investment in EdNA.

Complementarity
A principle of complementarity emphasises the importance of understanding the adoption of a particular technology in as broad a context as possible, ie acknowledging the connectedness of all the sociotechnical elements. For example, at one level, for each high technology ‘tool’ that is employed in the classroom, it is critical to ensure that skills that complement its use are also taught. Take the case of the hand held calculator. In order to use this technology a student requires at least two complementary skills, an ability to approximate or estimate an answer and a knowledge of significant figures. For a technology like the Internet, the complementary skills are less obvious. The Internet poses unique problems for students and teachers in learning how to find, select and appraise information that for the most part has none of the quality assurance methods normally associated with print publications. There are few useful precedents for working with information in a medium like this and it will take time to identify the necessary complementary skills a student needs in order to use the resources of the Internet in an educationally sound manner.

There is already advice for teachers in this respect. In celebrating the volume of information available on the Net, it is suggested that the role of the teacher changes to one of guide rather than expert. It is a good example of easily new technologies can be misread. It is worth considering what will be the most important resource in a world in which information is bountiful and inexpensive. As a number of commentators have pointed out, it will be point of view, expertise, knowledge, a capacity to make sense of and interpret from a particular perspective the information made available. So rather than seeing teachers reduced to some kind of assistant, a role easily automated, there is a good indication that expert knowledge will matter and matter a good deal than ever before. As has always been the case for good teachers, passion about teaching students coupled with a passion for a particular knowledge domain is what will count.

This principle is useful at a number of levels. The steady, and in countries like Australia, dramatic rise of home computer ownership to support the school education of children, makes

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It might also be argued that a knowledge of the way the calculator rounds off is also important in some cases.
a consideration of new complementary relationships between school and home important. Here we do not mean the trivial notion of enabling compatibility between the two sites. In an era of limited resources, it makes little sense for schools to duplicate what is in the home, particularly if the student has better access at home to better technology. In this vein, schools may offer access to computer resources that are more specialised, such as computer-aided environmental monitoring equipment, expensive modelling and simulation software or robotics. An important aspect of considering complementarity between home and school is what to do for students who have little or no access to computers. Schools clearly have a critical role to play here in ensuring that the least advantaged of the school community receive support and this may well mean giving privileged access in school time to the ‘have-nots’.

In terms of teaching science this principle draws attention to other computer-based resources that may be available on the Net or locally. The provision of a number of remote telescope services on the Net is a forerunner of access to other specialised and expensive equipment that may become available to schools.

Workability
A key test for the implementation of a new technology is “does it improve the working conditions for student or teacher?” This is not a simple matter because inevitably the nature of work is changed when a new technology is added. The sociotechnical mix is given another actor or, from the point of view of the innovation, the hardware or software, the innovation works to give itself a context (Latour 1996, 133). The time-scale over which such matters are judged are also important given the costs associated with learning to adapt a workplace to the requirements of computer technology (Kling 1996b). The use of a spreadsheet for modelling purposes is clearly of value for many science teaching tasks but unless students have regular and easy access to such software, there is a ‘startup cost’ each time it is used. Unlike calculators, spreadsheets have yet to become ubiquitous among students.

The adoption of computers in schools has often been a matter of direct or implied compulsion. It is important to affirm that the work of teachers and students ought to be a priority in determining whether or not to adopt or implement a particular technology. All too often the technology and its educational claims are the major basis for making judgements about whether or not to purchase. At best the costs of hardware and software are a consideration, but expenditure on these items is always much less than the cost of teachers’ and students’ time in learning how to use the technology, and then, for the teacher, designing and implementing classroom activities. At very least, consideration of this principle draws attention to the complex and unpredictable nature of sociotechnological change and provides an additional basis for decision making in ways that will lead to practical benefits for teachers and students.

Equity
The use of computers in schools always involves choices about resource allocation. The logic behind much of the resource allocation in schools is driven by prior access to information and resources. The technically able and well-equipped are able to make more compelling cases for re-equipping ahead of those who have poor or no resources. In classrooms, just as elsewhere technology tends to amplify advantage. An equity principle acknowledges this and supports an alternative basis for the access to information and allocation of resources.

16 Becker (1996) puts the costs for employing computers across the curriculum in a meaningful manner at $2,000 (US) per student, per year. His assumptions are such that the calculation would apply well to Australian schools.
The history of computers in Australian schools gives little cause for hope in seeing a more equitable distribution of resources. Those with access to the Internet want more. Web access leads to a “need” for publishing student or school home pages, which in time leads to the need for a local Web server and so on. Those who are unable or are stopped from taking that first step are excluded from the loop. How can you “need” a Web server if you don’t even surf the Net?

As Negroponte suggests (1995, 6) “Computing is not about computers any more. It is about living”. Given this, technological competence has become a new basics of education, equal access and robust competence must be a key concern for educators. Such competence will eventually have an impact on students’ quality of education, their access to jobs (no matter how menial) and retraining, to government information and to learning about critical issues which affect their lives. Be it in the workplace, the home or elsewhere, students need to be in a position to assess the costs and benefits of the new information technologies and to make wise choices which maximise the economic, social and cultural benefits and minimise the risks and costs. Teaching students about technology is just as important as giving them access and teaching them to use it. For, in the words of Mitch Kapor from the Electronic Frontier Foundation,

We are not just consumers, we are also citizens. With all this talk about markets and profits in the new digital world-order perhaps its time to start thinking about what kind of world we want it to be. (quoted in Burstein and Kline (1995, 17))

Whose responsibility is to do that teaching? In using technologies like the Internet to support the teaching of science, it is clearly essential that the Net is not merely blackboxed and treated unproblematically as just another information resource. Teachers of science need to teach about their resources as much as teach with them. The Internet will never be easily blackboxed17 and it will be dangerous to do so. A medium in which all may publish represents unique challenges for the teaching of the sciences. Teaching students about the new medium and its capacity to support all kinds of ‘science’ will be a necessary first step in supporting students make wise use of this information source.

Teaching science in a wired world: looking in or looking out

The theme of this conference, “extending the boundaries” points to important changes in the world outside the science classroom as well as that within. Careful consideration of the ‘wired world’ suggests more barriers, boundaries and borders await the teacher of science than was ever faced in the science classroom. A key barrier is the largely technically oriented, ‘heads in’ approach adopted by teachers over the past fifteen years to the use of the new information and communication technologies. The transformation of computers into communication devices with a global range and the implications that these developments have more generally for the future of schools (Kenway, et al. 1995) requires a ‘heads up’ approach instead,

—one that examines the social choices of whether and how to computerise an activity, and the relationships between computerized activity and other parts of our social world.

(Kling 1996c,2 )

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17 Its early history supports this point. The Net enjoys an almost infinite set of descriptions ranging from socially dangerous to educationally essential. Its nature will ensure that those who read it will continue to add to the long list of categorisations it currently enjoys.
Such an approach is mindful of a new interrelatedness of a sociotechnical world. It is only with such an approach that schools can move beyond their current tendency to imagine that if they adopt computer use and networking they have dealt with the issues associated with being in a global, wired world (Williams and Bigum 1994). This ‘immunisation’ stance is untenable as schools are deeply implicated in the economic and cultural changes associated with globalisation. Teachers must therefore pull their heads out of their schools to some extent and critically consider the educational issues associated with the changes associated with living in a world ringed by global computer networks. Blind faith in technological progress has not served schools well. It has limited the ways teachers have for thinking about the complex and confusing issues associated with the new information and communication technologies. Schools must be informed, critical and creative in how they use these technologies if they are to create worthwhile and workable educational futures for their students.

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