Teaching and learning with information and communication technologies (ICT) for numeracy in the early childhood and primary years of schooling

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Report prepared for:
Research and Evaluation Branch
International Analysis and Evaluation Division
Department of Education, Training and Youth Affairs

June 2001

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ISBN 0 642 51886 6

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Printed by J S McMillan Printing Group (02) 6230 6200

Executive Summary

This report is a review of the research literature pertaining to the ways in which information and communication technologies (ICT) impact on teaching and learning contexts in schools.

This review is timely since we live in ‘the information age’ at a time when the use of ICT permeates all aspects of our lives. Yet it would seem that even though specific policy directives have articulated clear and unambiguous statements about encouraging the use of ICT in schools, (e.g. DETYA 2000a; DETYA 2000b: EdNA, 2000) the use of ICT in educational settings is marginal and often peripheral, acting as an 'add on' to regular classroom work in many instances.

A search of the literature regarding the impact of ICT in general, and particularly the use of computers, reveals that there has been a large number of studies that have focused on measuring, in some way, the impact of machines on the complex environments we call classrooms, and on learning outcomes. In fact, there have been a number of meta analyses of the literature (see for example, Kulik and Kulik (1991) cited in this report), although it is apparent that acceptance of the evidence is strongly influenced by the stance or viewpoint that one takes.

Detractors of the use of computers in schools cite research that showed no impact on learning outcomes in contexts where the use of computers was considered as a 'treatment' for a set period of time, and where learning outcomes were compared with those of a non-computer group, often on the basis of a single, standardised test. Even though some studies do in fact show gains on test scores, these results are rarely cited by those who do not want computers in schools. Supporters of the use of ICT provide case study material rich in detail but lacking in quantitative analyses that are the currency for determining effectiveness in a simple way. It is interesting to note that in the USA the President's committee of advisers on mathematics and technology (1997) recognised that although there were some excellent examples of innovative practices and learning with ICT, they felt that there was insufficient data that could support an argument for allocating large amounts of funding for new forms of educational software, content, and technology-enabled pedagogy.

Summaries of findings are presented from empirical research projects to illustrate that the effective use of ICT in schools can not only influence learning outcomes in terms of the quality of work produced by students but also predisposes them to engagement with mathematical ideas and affords the opportunity to learn in new and dynamic ways that were not possible without the technologies.

Research recommendations

The review leads to the formulation of six research recommendations:

1. The use of ICT is a fundamental aspect of learning, and funding needs to be specifically targeted to its successful implementation in the schools and universities that provide teacher education programs in Australia.
2. There is a need for *Australian* research about the impact of ICT on learning, especially with regard to literacy and numeracy outcomes and the concept of multi-literacies that incorporate the use of ICT.
3. We need to identify relevant research questions that support the successful use of ICT in schools.
4. Funding should support a variety of research methodologies that include quantitative and qualitative approaches as well as mixed methods research designs.
5. A longitudinal study to complement research in literacy and numeracy research would be beneficial.
6. A set of exemplary teaching practices incorporating the use of ICT like those developed by the Indigenous Branch in *What works?* should be commissioned.

Introduction

The brief of this report was to conduct a literature review related to the ways in which technology can be incorporated into early mathematical experiences to maximise mathematical achievement, and numeracy outcomes. This was to be completed in order to conduct a discussion about the possible impact this may have on school policy and curricula. The report was to assist DETYA in identifying appropriate areas for further research that would be relevant to the Commonwealth.

In order to do this it will be necessary to first examine what the research literature reveals about the role of information and communication technologies (ICT) in society and in particular in educational contexts. Next, a review of research regarding the impact of ICT on learning in schools will be considered, prior to reviewing those studies specifically related to mathematics education contexts and concepts. Finally, concluding statements will be made and recommendations for future research projects considered.

The majority of this research emanates from the United States (where the term numeracy is not commonly used — US researchers often prefer the term mathematical literacy). The reform movement led by the National Council for the Teachers of Mathematics (NCTM) has been successful in creating an agenda for reform of mathematics teaching, which has included advocacy for the embedded use of ICT in curriculum. The implication of the research cited and described here on numeracy outcomes will be highlighted in the conclusions and recommendations of this report. Yet it needs to be stressed that effective teaching of mathematics in schools represents only one opportunity in the process of becoming numerate. Students need a variety of experiences and contexts to integrate ideas and skills and these occur both in school and out.

Background

This review is timely since we live in ‘the information age’ at a time when the use of ICT permeates all aspects of our lives. Yet it would seem that even though specific policy directives have articulated clear and unambiguous statements about encouraging the use of ICT in schools (e.g. DETYA 2000a; DETYA 2000b; EdNA 2000), the use of ICT in educational settings is marginal and often peripheral, acting as an 'add on' to regular classroom work in many instances. In reviewing the research on the impact of computers in early childhood education, Clements, Nastasi and Swaminathan (1993) noted that we were at a crossroads in terms of their use in schools, where we could use technologies to perpetuate and reinforce what we have been doing in traditional ways for decades, or we could use the machines as artefacts of innovation for teaching and learning in new ways.

However, it is apparent seven years later, that much of school uses of computers are for reinforcement of specific skills or as a ‘tool' for word processing. That is, for supporting long held practices of teaching. We seem to have ignored the potential of the machines to engage students with concepts in ways that were not possible without the technology; further we have continued trying to map the new technologies onto old curriculum, when what is needed is a new look at curricula in light of what research informs us about learning with ICT. This was clearly articulated by Papert (1996, p.25) who criticised policy makers who were:

> …determined to use computers but can only imagine using them in the framework of the school system as they know it: children following a predetermined curriculum mapped out year by year and lesson by lesson. This is quite perverse: new technology being used to strengthen a poor method of education that was invented only because there were no computers when school was designed.

Cuban (1993) argued that there were two main reasons why schooling was less vulnerable to electronic technologies than other social institutions. The first reason was related to the cultural beliefs about how teaching and learning are conceptualised, what knowledge is appropriate in schools, and the nature of the teacher-student relationship. Second, Cuban maintained that the existing age-graded school determined the nature of teaching and learning more than any other feature and shaped what teachers did in classrooms so that any innovation that was under discussion for implementation had to be fitted into the existing structure or be rejected. In this 1993 article, Cuban noted that students spent on average '… a little more than one hour a week (or four per cent of all instruction time) with computers' (p. 186). There is not any evidence to suggest that this has increased in the interim. Further, what children do with computers varies considerably across schools and classrooms, and Cuban also reported some disturbing finding from the Office of Technology Assessment which indicated:

- students from high income families had far more access to computers in schools than their peers from low income families;
- black students use computers less in schools than white students;
- students with English as a second language had the least amount of access to computers; and

- low-achieving students used computers mainly for drill and practice activity.

Cuban highlighted that it is interesting to note that of all of the reforms that have occurred in education since the middle of the nineteenth century '… none were dependent on instructional technologies beyond teacher, blackboard, textbook, pen and paper' (p. 168). He noted that the influential changes that were brought about in society and business by new technologies in the 1980s and 1990s were not followed through by school reformers. It was as if educators lost an opportunity to reinforce how important schools are to the nation's economic success. If they had capitalised on this, one can imagine that more would have been done both in terms of providing finance for the hardware and software, and more critically for the professional development of teachers. This could have then been linked with a realisation that teacher education courses need to be re-crafted to ensure that the new generations of teachers were confident and competent with integrating ICT into their teaching and learning contexts. Cuban suggested that three imperatives coalesced, in the desire to reform schools through ICT. They were:

- That citizens should be prepared for life and work in a technological society.
- The need for learners to have opportunities to structure their own understandings in self directed learning contexts that empower them to be active knowledge builders.
- That students and citizens should be productive in terms of output.

A report by the Kaiser Family Foundation (1999) entitled *Kids and media: the new millennium* highlights the large amount of time that children spend interacting with media. Yet interestingly this tended to be traditional media, like television, rather than with computers. In fact they reported that children in the age group of 2 to 18 years of age only spent about half an hour a day using computers, including the use of computers in school time. They spent 21 minutes on average using computers for 'fun' while they spent two and three quarters hours watching television. Approximately nine per ce nt of the children surveyed spent more than an hour a day using computers for fun and only three per cent spent more than an hour on line each day. Thus the perception reported by the Alliance for Childhood (2000) — of children spending inordinate amounts of time at the computer to the detriment of other more physical pursuits, and developing poor health and repetitive strain injury as a consequence — would seem to be spurious. The Kaiser Family Foundation report revealed that 'even those who use computers spend substantially less time at the keyboard than they do watching TV' (p. 24).

The relevance of this for educators is considerable. Children are not gaining access nor developing skills in the use of ICT for authentic learning tasks but instead are mainly using computers for 'fun', often in out-of-school contexts. This occurs at a time when there would seem to be 'a consensus among business leaders, educators, policymakers and parents that our current traditional practices are not delivering the skills our students need to thrive in the 21st century' (CEO forum 1999, p. 6), and it is evident that traditional education environments do not seem to be appropriate for preparing students to function in today's society or to be productive in the workplaces of the 21st century. In fact as Becker (1992, p.1) reported:

> …although most elementary school students use computers, that use has mainly been occasional and for purposes of lending variety and "enrichment" to the school day, rather than as a central component of teachers' instructional programs.

Schacter (2000) noted that every year policymakers have to make decisions regarding the funding of an array of educational options, including funding the purchasing of various technolgies, and often their primary concern relates to the effectiveness of the approach or product in terms of educational outcomes. In this regard the demonstrated potential of computers is significant. Schacter (2000) reported on five large-scale projects concerned with major innovations in the use of computers in classroom contexts. The results were impressive and positive in terms of the impact of the use of computers, with the final paragraph (p. 9) reporting:

> These studies show that in over 700 empirical research studies, in the study of the entire state of West Virginia, in a national sample of fourth and eighth-grade students, and in an analysis of newer educational technologies that students with access to:
>
> a) computer assisted instruction, or
> b) integrated learning systems technology, or
> c) simulations and software that teaches higher order thinking, or
> d) collaborative networked technologies, or
> e) design and programming technologies,
>
> show positive gains in achievement on researcher constructed tests, standardised tests, and national tests.

The review considered Kulik's meta-analyses research pertaining to educational outcomes and the use of technology, which reported that on average students who had worked with computer-based learning tasks scored on the 64th percentile compared to students in a control group who scored on the 50th, but also found that students who used computers enjoyed school more and had a more positive attitude to their work when computers were a part of it. The report also considered data from studies such as the 1998 Apple Computers of Tomorrow project and a study (conducted by the Educational Testing Service) of nearly 14 000 students in 4th and 8th grade in the USA. Both projects reported beneficial impact in terms of the use of higher order thinking skills. Additionally, the ETS study reported developmental gains of 13 to 15 weeks for students using technologies compared to those who did not.

In spite of such support this report did not receive as much press as the more recent *Fools Gold: A critical use of computers in childhood,* released by the Alliance for Childhood, an organisation which has strong links with an educational approach called Waldorf education. The authors of *Fools Gold* asserted that not only were computers a threat to childhood, but also that they were a health hazard and responsible for the production of the most sedentary generation of our time. Further, they maintained that ‘The sheer power of information technologies may actually hamper young children's intellectual growth’ (p. 3) and quoted Prof Larry Cuban as saying 'there is no clear, commanding body of evidence that students' sustained use of multimedia machines, the Internet, word processing, spreadsheets, and other popular applications has any impact on academic

achievement' (p. 3). There is little empirical work cited in the report to support their notions. In this report Alliance for Childhood does, however, advocate for ‘hands on’ curriculum that would be supported by most people who use computers in education. Yet what was amazing was the amount of press that this report achieved even without the basic conventions of critical research being adhered to. The emotive language and rhetoric around the arguments were continuous. For example, the report’s authors only quoted people who supported their ideals while they selectively quoted out of context some major scholars who advocate the use of technology, thus demeaning their arguments or observations. Yet 85 ‘experts’ supported the Alliance's call for a moratorium on the further introduction of computers into elementary schools in the USA, until the effect on young children is addressed more carefully.

The rationale around much of the argument against the use of computers in school focuses more on the deployment of critical resources at times of economic and fiscal hardship than it does on a discussion of research projects, which seem to be selected according to specific agendas. Additionally, Clark (1985) argued that there is no medium (including computers) which has any distinct advantage over any other. He maintained that it is the uncontrolled effects of instructional method and content, together with a novelty effect, which account for any learning improvements that may be observed. A meta-analysis by Fletcher-Flinn and Gravatt (1995) revealed a learning advantage for Computer Assisted Instruction (CAI), but they stated that this gain in proficiency was often the result of poor research design which did not discriminate between the quality of software and computer use. They remind us that achievement gains are only one of a number of criteria from which we should determine the advantages of any educational intervention. They recommend the consideration of other issues such as time savings for students and teachers; cost effectiveness; the presentation of realistic problems which require inquiry and collaborative problem solving; and forms of evaluation as equal and valid measures of any instructional program

It is thus apparent that discussions of the important issues surrounding the use of ICT in schools are emotional and the results of research studies about their impact are equivocal. What is generally recognised is that ICT are an important part of our lives today, but there are divergent views about the role that schools should play in promoting fluency and use of the machines, and their primacy as resources in our classrooms. Generally, the arguments against computers tend to focus on the fact that in times when financial resources are limited policy makers should not be spending money on machines, but rather on people and on maintaining the status quo in teaching and learning practices. At the other end of the spectrum supporters of the use of ICT in schools say that they need to be integrated into education so that our children can learn in new and dynamic ways and be prepared for the challenges of life in the 21st century. They would contend that ICT play a fundamental role in our lives and cannot be ignored, and that to exclude or marginalise it in educational contexts would be foolish. So what does research tell us more specifically about learning with ICT in schools?

ICT and learning

When discussing the impact of technology in education, Schofield (1995) suggested that as educators we needed to recognise that there are a variety of issues ranging from the economic realities, which determine the number of computers in schools, through to issues related to the type and quality of training with ICT that teachers have access to, and to everyday practical decisions about how and when computers can be used and with what software. In terms of outcomes Schofield (1995) also contended that her work demonstrated using computers for instructional purposes in class will change '… potentially important aspects of the classrooms social functioning' (p. 191). This has been noted elsewhere (e.g. Bracy 1988; Schofield, Eurich-Fulcer, and Britt 1994) but generally studies have shown that effective computer integration is not found in classrooms that are traditional and use didactic teaching methods. Rather, effective integration of ICT occurs in environments where teachers and learners engage in new partnerships for learning. These are collaborative, problem-solving settings where all participants learn, the relationships between learners are dynamic, and ICT complement engagement in authentic learning tasks.

This then highlights the complex nature of the environments of which computers are but a part. Kozma (1994) recognised this and criticised research that claims to determine the amount of learning improvement as a result of computer use. He maintained that such studies view learning from a narrow, behavioural perspective which he considers to be superficial as it concentrates on the trivial use of technologies and only measures learning using responses in tests. Kozma (1994) pointed out that learning theory, which takes into account cognitive, social and affective features, is largely ignored in this conceptualisation. He added that 'Also missing are descriptions of the underlying structure and functions of media which might serve as causal mechanisms' (p. 8).

Kozma asserted that we must situate theories of learning with ICT 'in the cognitive and social processes by which knowledge is constructed' (p.8), and subsequently, that we should conduct research that investigates the mechanisms by which students learn with ICT in contexts characterised by curriculum that have technology embedded in them. This is a critical point since many researchers believe that ICT will only have an impact on learning in schools if they are integrated into the complex social and cultural contexts that are apparent in schools in the 21st century. At the same time this will require school reform in curriculum and pedagogy since traditional forms of schooling were not designed to address the issues associated with such complex interrelationships. Today it would seem that school use of computers work, in a way that is the reverse of this. We are fitting new technologies into old curricula which were developed prior to their existence.

Lally and Macleod (1984) suggested over 17 years ago that it was evident that one explanation of why computer aided instruction (CAI) programs were limited in their effectiveness or impact was due to the fact that some applications did not lead to improved teaching procedures, but rather that they simply computerised existing techniques. If this was evident 17 years ago why do we still seem to think this process will work? Lally and Macleod were critical of CAI programs that minimised the level of teacher involvement needed, and suggested that the most effective

programs were those that encouraged teachers to work with their students on computer-based activities in an active manner.

It has been suggested that when digital content is *integrated* into curriculum, a change in the learning process occurs (CEO Forum 1999), which is characterised as being:

- *Problem or project oriented* — whereby investigations are authentic and there will be a variety of solutions to a problem.
- *Student-centred* — so that students feel empowered in their work and participate in creating and developing their own investigations while their teacher's guide, facilitate and provide them with materials to support their learning. Teachers remain the cornerstone of the educational process in a learning partnership with their students, parents, peers and other professionals, but adopt a role which is less authoritarian and more one of encouraging and guiding the learning of their students towards goals that have been defined by them and the curriculum.
- *Collaborative* — since learning with authentic tasks is an interactive experience between students and their teachers, as students acquire and use information, exchange ideas with each other and create relationships with professionals relevant to their work.
- *Relevant* — learning with ICT has the potential to create educational opportunities that meet the needs of individuals and groups in diverse ways and allow them to work according to their needs and interests. For teachers, they can additionally use digital devices to record and report on their students' performance in enhanced ways, tracking achievement using databases or using video captures for observation of skill development. Additionally, teachers may develop on-line content for use by students when they have specific learning opportunities in mind.
- *Productive* — as the use of ICT encourages both students and teachers to become 'content producers' (CEO 1999, p. 10), this has the added benefit that the level and quality of the productions is usually high; in turn this encourages students to engage with learning more effectively. The productions are not only in terms of quality presentations and reports but also in creating relationships extending beyond those in the immediate locality. Issues of copyright and plagiarism become important discussion points in this context.
- *Lifelong* — students develop skill in learning how to learn, which will benefit them in the long term and enable them to interact with people and ideas in a borderless manner. Skill in determining when and where to seek out information and people, and in how to use the information in context, becomes a fundamental part of the learning process.

Schofield, Eurich-Fulcer and Britt (1994) found that there was an emerging literature that appeared to indicate that one of the major benefits of using computer aided instruction (CAI) was an increase in students' general enthusiasm, which seemed to help average students in particular to learn more than if they had not used the technology. In fact Schofield et al. reported that the literature supported the notion of computer learning contexts effecting in a positive way a

broad set of variables, including students' attitudes towards themselves and school in general (e.g. Becker 1987), and overall student motivation and interest in learning (e.g. Sandholts, Ringstaff & Dwyer 1990). Also, computer-based work seems to inculcate high levels of task involvement and persistence to the conclusion of tasks. This often encourages collaborative learning — that is, to interactions that are posited as being essentially beneficial to learning, rather than a distraction. Such interactions also mean that teaching and learning environments in these contexts are student-, rather than teacher-centred, and students often scaffold each other as well as receiving support from their teacher on an individual or group basis when engaged with tasks. In this way the research shows that the effective use of computers in classrooms can not only effect learning, but also has the potential to change the social processes.

In considering the role of teachers, Becker (1993) articulated the characteristics of exemplary computer-using teachers. He found that they integrated computers into their program and created an environment for learning in which the computer use was not only directly related to their curriculum goals, but also incorporated a wide variety of uses for the machine that were relevant to knowledge building across the curriculum. In an important finding, Becker noted that exemplary computer-using teachers had greater access to formal professional development activities than other computer users. He noted specifically that when directly related to specific subject areas, staff development in the use of generic software programs (e.g. word processors) was beneficial. The exemplary computing teachers also functioned in environments that were resource-rich — not necessarily with more computers, but via the use of a wider variety of software. Of particular significance was the finding that the exemplary computer-using teachers had smaller class sises and that this variable was the main one that distinguished them from their contemporaries. In his work Becker (1993) asserted that his 'assumption of the exemplary teaching practice label was based on the important academic outcomes which result from systematic and frequent use of computer software for activities that involve higher order thinking, such as interpreting data, reasoning, writing, solving real world problems and conducting scientific investigations' (p. 316). This is a key point since many of the studies about the benefits (or otherwise) of computer use and learning pertain to limited, and sometimes even marginal, uses of computers. In this way the results are often misleading because it is difficult to attribute causes specifically to the presence of computer-based learning, or to the range of other variables present in the teaching–learning context.

Callister, Thomas and Dunne (1992) noted an important point when they stated that: 'If computers are used to import and amplify poor pedagogy, they can do great harm' (p. 326). Many of the studies trying to develop causal links between computers and achievement often fail to take into consideration the physical and pedagogical features of classrooms. These studies involve short periods of time and tend to be clinical in their approach. Why are we not surprised that there is no effect on outcomes in such instances? Have we ever thought that by reading six poems children will come to appreciate and love poetry, or that providing a teacher with an overhead projector for six weeks will suddenly result in improved teaching and learning for the students? Callister, Thomas and Dunne (1992) contended that much of the research done in relation to the use of computers in schools is '…rooted in disregard, if not contempt, for teachers' (p. 326) — in this way

confirming to Apple's (1982) notion of de-skilling and re-skilling where a craft (teaching) is replaced by a new imperative, in this example a submission to the machine on the basis of the predominance of economic, management and efficiency criteria.

In fact, it is the role and style of the teacher that seems to be a major feature of successful integration of computers into the teaching and learning process, thus effecting outcomes for students. This was realised long ago by scholars such as Negroponte (1995) and Papert (1980, 1996) in discussions surrounding the use of ICT in educational contexts. As Negroponte (1995, p. 199) stated:

> While a significant part of learning certainly comes from teaching — but good teaching by good teachers — a major measure comes from exploration, from reinventing the wheel and finding out for oneself. Until the computer, the technology for teaching was limited to audiovisual devices and distance learning by television, which simply amplified the activity of teachers and the passivity of children.

Moreover, it is also evident that the use of computers has to be an integral part of classroom life. Marginal use of computers will obviously not effect outcomes. Johnson (2000) stated that any computer-effect study had to take into account two things in order to be relevant: the first was that computers had to be available and accessible to both students and teachers. Second, teachers using the computer should be confident and competent with the range of applications that are available to support their teaching and students' learning. Moreover, he argued that:

> The interaction of computer availability and teacher preparation is critical to understanding the effectiveness of computers in the classroom… It is impossible to assess accurately the effectiveness of any teaching tool if the tool is not used often enough to have some pedagogical effect. Further, if teachers are not qualified to teach with computers, the effect of the availability of computers alone might generate biased achievement that would be limited in their usefulness (p. 6).

As Kulik and Kulik (1991) stated, it 'would be as pointless to judge all CBI [computer-based instruction] programs by a single outcome as it would be to judge all textbooks, lectures or films by a single comparison' (p. 76). Further, Schofield et al. (1995, p. 603) argued that:

> …in predicting or assessing the impact of technological innovations on the educational process, it is crucial to go beyond a narrow focus on the intended subject-matter learning effects to a broader examination of how utilising the software changed the content, process, and context of student learning.

Their study also highlighted the importance of realising that different computer applications will have varying effects depending not only on their design but also on the ways in which they are used in classroom contexts. In their study using the Geometry Tutor program, the data supported the notion of increased enthusiasm and interest in their work as well as *new* classroom dynamics, whereby students helped each other and supported their peers in the learning process more frequently.

Swan and Mitrani (1993) observed that most of the 'effect' studies that were conducted focused on the role of computers in reinforcing or enhancing basic skills, and were measured by testing outcomes in standardised tests. Further, many of these studies have demonstrated that when such skills were presented on the computer they were learned more effectively. Swan and Mitrani (1993) maintained that such restricted uses of computers was detrimental to a broader vision of the impact that they could have in transforming the actual processes of teaching and learning. When computers are effectively embedded in curriculum, and when teachers incorporate them as a natural part of the teaching process, Swan and Mitrani (1993) contended that computers have the potential to change schools so that learning in them is more student-centred and collaborative and more successful in terms of outcomes. Their research indicated that teaching and learning in computer-based classrooms is significantly more student centred and collaborative than teaching and learning in traditional classroom settings. They noted that in their work, the *interactions* between teachers and students changed with the introduction and use of computers — and thus the effect was more far-reaching than just altering the mode of delivery. Their work has important implications since it suggested that 'technology alone will not change schools' (p. 52). There has to be a corresponding change in classroom climate and pedagogy for the use of technologies to have an impact.

The reasons why technologies have failed to have had a major impact in schools (as compared to other disciplines like medicine and communications, and in society more generally) was explored by Means and Owens (1994). They claimed that early efforts to introduce technology into schools failed because they were based on flawed models of teaching with technology which assured the primacy of *content* over pedagogy, mainly in an attempt by designers to ensure that programs were "teacher-proof" (p. 15). Such programs were in fact not consistent with the core curriculum in terms of content and advocated "crummy" (Negroponte, 1995) drill and practice methods rather than encouraging the exploration of ideas and collaborative problem solving. In the early days of computers in school, Means and Owens (1994) noted that even though software such as simulations and intelligent tutoring systems had potential to change education, they were largely ignored because they were relevant to only a small part of existing curricula, and were not essential to content in state curriculum documents.

Means and Owens (1994) suggested that a new climate of school reform, evident since the early 1990s, resulted in discussions about the nature of teaching and learning and that this was conducive to the use of more opened examples of software. Along with the reform agenda came the view that students needed to be challenged with complex authentic tasks, which are often multi-disciplinary and require extended periods of time for effective completion. There is also a role for the use of technologies to support project development and the need for more flexible timetabling and authentic assessment. In this scenario, ICT are used to support students and teachers in obtaining, organising, manipulating and displaying information, not simply to play repetitive games with the aim of increasing a specific skill, such as addition in mathematics. Means and Owens (1994, p. 16) summarised this impact effectively when they stated:

> When technology is used as a tool for accomplishing complex tasks, the issue of the mismatch between technology content and curriculum disappears altogether. Technological tools can be used to organise and present any kind of information. Moreover, it is not necessary for the teacher to know everything about the tools that students use: teachers and students can acquire whatever technology skills they need for specific projects.

In summary, Means and Owens (1994) listed five characteristics of a reformed classroom:

- Authentic and challenging tasks are the catalyst for inquiry
- All students are engaged and have practice with advanced skills (e.g. interviews, using technologies and analysing data)
- Projects are carried out in heterogeneous, collaborative groups
- The teacher is a coach / facilitator
- The students work for extended periods of time

In classrooms such as this, ICT enhance what is possible by amplifying what teachers are able to do, by providing an entry point to content and inquiries that were not possible without the use of ICT, by extending what students are able to produce as a result of their investigations, and finally by providing teachers with the opportunity to become learners again.

ICT and mathematics

Many educators adopt a constructivist approach to their teaching, and this is especially relevant in the context of mathematics education. It is apparent, however, that most mathematics curriculum that children experience:

> …is narrow in scope, fails to foster mathematical insight, reasoning, and problem solving; and emphasises rote activities… Children … become passive receivers of rules and procedures rather than active participants in creating knowledge… Computers play an important role in reforming this curriculum (NCTM, 1989, p. 15, p. 19).

It has been shown that the use of computers can increase the mathematical achievement of children in pre-school and primary grades (Clements et al. 1993). In fact the largest gains have been with the use of mathematical drill and practice software (Clements 1987a & b; Clements & Nastasi 1992). Yet as educators are we satisfied with this limited conceptualisation of what constitutes performance in mathematical achievement? One of the main goals of the National Council for Teachers of Mathematics has been to create a vision for mathematical literacy in an increasingly technological world, which requires application of skills and knowledge across diverse disciplines. Children of the 21st century do not need the skills of times past, which required competence in, for example, adding up long columns of numbers. What is needed now are mathematical *thinkers* — students who can work collaboratively and who are good problem solvers. As Clements et al. (1993, p. 59) stipulated:

> Technology actuated the world of tomorrow. Technology — used thoughtfully and creatively rather than as a teaching machine — can engender and support educational environments that will empower children to flourish in this intensively mathematical world

In a similar vein, Tinker (1999, p. 1) stated that:

> To date, the major implementations of learning technologies have been within the traditional curriculum context: the graphing calculator is used when graphs are addressed in the curriculum, the geometry visualisers are used to improve geometry whenever the students usually encounter it… Potentially revolutionary technologies have not been used to create fundamental improvements in the traditional sequence of topics.

Tinker's (1999) argument is persuasive when he states '… if technology helps fourth grade students gain an understanding of graphs and decimals, then the entire curriculum thereafter should build on that understanding' (p. 1).

We are now beginning to gather research which illustrates that the widespread use of technology can cause advantages in learning, which means that we should be changing the structure of the curriculum that we offer in schools. As Tinker (1999) has noted 'If technology makes it possible to teach difficult central concepts earlier and with greater understanding, then the traditional sequence of topics needs a complete overhaul' (p. 2).

Tinker (1999) cited projects where researchers have explored the impact of ICT, which demonstrated that students can learn 'far more, better and earlier' (p. 2). For example, two projects — SimCalc and ThinkerTools — use probeware so that students can explore the concept of decimals and interpret graphs respectively. Middle school students are able to create dynamic models using Model-It and Stella and use a range of other examples of software which include spreadsheets, Logo, data packages, Computer Assisted Drawing (CAD) tools and image analysis so that their demonstrated learning potential has improved. Yelland (1998b) provided examples of Year 3 students engaging with ideas about variables, quadrants and negative numbers to 250 which were not traditionally a part of mathematics curriculum in Australia until around Year 9. This is not to say that they demonstrated understandings at that level but rather that their experiences with such concepts in an interactive environment at this early age should have some impact — and indeed change the nature of — their later experiences. It is interesting to note however that even though the innovation of such projects is apparent, such projects are usually studied independently of each other and implemented within existing and traditional curriculum. Tinker suggested that it would be unlikely that curriculum would be changed even if the results from research data were compelling. Therefore, he suggested that an alternative might be to have technology enhance strands in Mathematics curricula, which would include sequences of activities that are planned across year levels so that there is continuity in the conceptual development.

Mayer, Schustack and Blanton (1999) examined the cognitive consequences of children’s learning to use educational technology in an informal, collaborative context, through an after-school computer club called the Fifth Dimension. The authors were particularly interested in the ways in which computer programs could promote problem solving transfer. Their study confirmed that children who used educational software in this context learned content knowledge about computer literacy, became skilled in focussing on salient aspect of instructions, developed planning strategies for learning new games and also made gains in basic academic skills. They also reported that the students in the program also improved their performance on basic reading and mathematics achievement standardised tests, so that they outperformed their peers who did not participate with greater levels of improvement over their prior year's score. Mayer et al. (1999) contended that their results were 'consistent with the idea that participation in an educational computing environment results in transfer — that is, learning that goes beyond simple retention of specific computer facts and procedures.

Thomas, Tyrrell and Bullock (1996) explored the issues involved in assisting teachers in their implementation of computers in mathematics classrooms. They documented the use of computers by the teachers in a year-long study and their results revealed that simply placing a computer in a mathematics classroom is unlikely to result in changes in learning or teaching unless the teacher makes a major shift in their teaching philosophy, which is consistent with active inquiry into learning. They noted that the change process is typically a slow process and that teachers' transition to a positive view of computer use takes a great deal of time. The authors contended that 'knowledge of and experience with computers is not, in itself, sufficient to ensure that teachers will make use of them in their

teaching…the experiences of the teachers involved in using computers in their own mathematics classrooms were vital and produced a significant positive shift in their perception of the value of using the computer' (p. 54). This 'shift' took up to a year to occur and it was, according to Thomas, Tyrrell and Bullock (1996) due to two major factors: firstly the constant availability of the computer in classrooms; and secondly the support and encouragement of those around the teachers, who consistently encouraged and motivated them to maintain their energy and use the computers in dynamic ways.

They also found that the change in mindset that they observed towards the use of computers was characterised by:

- a willingness to lessen teacher control in the classroom to enable greater discussion and group work, resulting in a pedagogical move to guided discovery learning;
- a willingness to become a learner alongside their students;
- a desire to plan lessons which incorporate the computer as another tool for learning; and
- an ability to focus on the mathematics and its implications, rather than on the computer (p. 56).

Olive (1990) argued that technology-driven reform would have little success unless teachers were given the opportunity, and provided with support, to transform their teaching and learning environments. They cited the fact that even though many educators knew that ICT could act as a catalyst for school reform in the area of mathematics, its potential to transform curriculum has not been realised. They maintained that the main use of computers has been in the context of drill and practice activities and that ICT that gives teachers and students potential for doing mathematics in new and dynamic ways has gone largely unrecognised. Dynamic environments exist that encourage the exploration of mathematical ideas and afford the opportunity for students to engage in experimentation, conjecturing, and other high level processes, but these tend to be largely ignored by mainstream mathematics educators who feel more comfortable with traditional curricula that ignore the potential of ICT and perpetuate non-computer applications for problem solving.

Wiske and Houde (1988) noted that computer technology was a powerful support of teaching via guided inquiry; however the extent to which the computer provided support for learners was dependent on the way that it was used by classroom teachers. In their study with secondary teachers, Wiske and Houde found that the shift in instruction towards guided instruction was aligned with computer software implementation, but that the process was a slow one. They contented that a *recitation* paradigm was reinforced by curriculum guides, textbooks, and tests that required teachers and students to 'cover' content in prescribed sequences so that it could be recalled on demand. This paradigm resulted in a didactic approach to teaching, exemplified by whole-class teaching, organisation in terms of discrete lessons each day in sessions or lessons and the imparting of content knowledge as deemed by authority. In contrast they say that the successful implementation of technology required a different paradigm which they called the *construction*

paradigm. This incorporated guided inquiry and posed significant intellectual, emotional and moral challenges as well as technological and practical ones for both students and their teachers.

Clements and his collaborators (e.g. Clements & Battista 1986; Clements, Battista, Sarama & Swaminathan 1996; Clements & Nastasi 1988, 1992) have conducted the most extensive investigations related to the use of computer environments and applications. They have sought to understand and explain the effect of new applications on mathematical learning and understanding, especially in the area of geometry, which was the one mathematical concept where Australian children did not perform competitively in the Third International Mathematics and Sciency Study (TIMSS) recent test results. Clements has primarily worked within a Logo context — Logo started as a programming language but is really considered as a learning context, or *microworld,* that has revolutionised the ways in which students can engage with mathematical ideas using ICT. Clements, Sarama, Yelland & Glass (forthcoming) outlined the numerous features of Logo environments which research has found facilitate mathematical learning. They include:

- The commands and structure of the Logo language can be consistent with geometric symbols and structures in ways that are pedagogically useful. For example, turtle geometry commands such as Forward (FD) and Right (RT) focus students' attention on critical aspects of figures.
- Drawing, and the code that creates the graphics, have meaning and interest for students; this then motivates the use and learning of geometric and other mathematical ideas (Ainley 1997; Yelland, 1995a).
- The microworld context incorporates measures that are visible, quantifiable, and adhere to conventional mathematics, which helps students to connect spatial and numeric thinking (Clements et al. 1997; Clements et al. 1996; Clements, in press; Moreira & Noss 1992).
- Manipulation of screen objects is possible in ways that facilitate students' thinking of them as mathematical objects representative of a class. In this way, Logo can evoke more abstract geometric thinking (Clements, in press; Yelland & Masters 1994).
- Logo can promote the connection of symbolic with visual representations, which supports the construction of mathematical strategies and ideas from initial intuitions and visual approaches (Clements 1995; Clements 2000; Noss 1992; Yelland 1994b). Thus, it can serve as a transitional device from physical movements to more abstract mathematical conceptualisations. It can make mathematics more concrete, while simultaneously supporting students' formalisation of actions algebraically as a computer program (Hoyles 1993).
- Working in Logo contexts affords opportunities to try out ideas and modify plans. Interactions can direct attention to key points in mathematical problem solving (Yelland 1994a; Yelland & Masters 1997).
- Students can use Logo's symbolic code to reduce the cognitive load of a task, so that they can deal with one relationship at a time and synthesise them all into a final procedure (Hoyles 1987; Yelland 1998).

- Logo can be a medium for the expression of mathematical ideas (Hoyles, Healy & Pozzi, in press; Yelland 1998, 1995b). It can assist students to make relationships explicit (Clements & Sarama 1995).
- Logo can serve as a medium for communication of mathematical relationships (Hoyles 1993).
- Students' plans and their creations can become objects of mathematisation and reflection (Clements et al. 1997; Kieren 1992; Noss 1992).
- Logo can help document student actions, leading to meaningful mathematical symbolisation. Students can then build a symbolic mathematical language based on this documentation (Yelland 1994a; Yelland & Masters 1997).
- The structure of Logo can provide scaffolding for mathematical analysis; that is, a symbolic representation on the computer can act as a support for deconstructing and testing ideas (Noss 1992).
- Students get instant feedback when they try out their code. The nature of this feedback means that they can reflect on each part of the object they have drawn and make decisions about its effectiveness and make modifications as desired (Clements & Sarama 1995).
- When creating figures in Logo, accuracy of measure is usually important — thus precision and exactness in mathematical thinking is encouraged.
- For teachers, Logo can provide a window to students' mathematical thinking (Noss 1997; Weir 1987).
- The Logo environment aids reflection and helps students to move from naive to empirical to logical thinking. They also encourage students to make and test conjectures. In this way, Logo can facilitate students' development of autonomy in learning, as well as assist to promote positive attitudes towards mathematical thinking (Yelland 1998).
- Logo encourages students to be playful in their exploration (Hoyles 1993). The play is mathematical and supports the development of mathematical understandings.
- Logo allows students to search for relationships that seem beyond their current level of understanding; they can try a range of possibilities on the computer (Battista & Clements 1986; Hoyles & Sutherland 1989; Yelland 1999) that are not possible using pen and paper.

Clements et al. (in press) noted that one of the enduring features about using a Logo environment with students is the finding that teachers play a critical role in its implementation and effectiveness. Further, if its use is embedded in a curriculum, and its design includes on-screen utensils to support learning, it has been found to be more effective and achieve a greater impact on learning outcomes. Clements et al. have also considered the benefits of a mathematics curriculum which includes embedded Logo activities as part of the sequence of learning, and provided suggestions for teachers to help them to use such a curriculum effectively. They stated that it was essential that the mathematics curriculum:

- included carefully-planned (and researched) sequences of activities that would lead to improved learning outcomes (Borer 1993; Clements, in press);
- was intrinsically rewarding and encouraged analysis;

- used versions of Logo with tools specifically designed to enhance mathematical activity, since this leads to greater likelihood of mathematical learning occurring (Clements 1995; Kynigos 1993; Clements & Sarama 1995);
- incorporated suitable time allocations for tasks in order to realise the maximum benefits of the facilities; and
- contained the appropriate levels of representation that were meaningful for students. For example, it may not be an efficient use of time to have students write Logo procedures to perform geometric motions, but they can use tools available in enhanced logo environments to do so (Clements et al.1996; du Boulay 1986).

The best use of applications such as Logo, may involve full integration into the mathematics curriculum. Clements et al (in press) contended that too much school mathematics involved exercises that were devoid of meaning. Logo is an environment in which students can use mathematics meaningfully to achieve their own purposes. The language provides a formal symbolisation aspect that students can invoke, manipulate, and understand (Hoyles 1987). Using Logo in this way can help fulfill the early vision of ‘teaching students to be mathematicians vs. teaching about mathematics’ (Papert 1980, p. 177).

Effective teacher mediation requires multiple actions. Teachers must be involved in planning and overseeing such computer based experiences to ensure that students reflect on and understand the mathematical concepts inherent to them. Clements suggested that teachers might use the following approaches:

- focus students’ attention on particular aspects of their experiences;
- educe informal language and help connect this informal language to Logo representations and to formal mathematical language for the mathematical concepts;
- suggest paths to pursue;
- facilitate dis-equilibrium by using computer feedback as a catalyst;
- encourage mathematical analysis; and
- continually connect the ideas developed by the students to those from other contexts, such as real-world situations.

Several studies (Yelland 1994a, 1994b; Yelland & Masters 1995) have noted children's engagement with learning and involvement within a Logo environment and the activities that were part of it. When analysing these, Yelland (1999) contended that it was apparent that there were a number of factors which contributed to the quality of the environment in terms of affect and specific performance outcomes. For example, in one study with Year 3 children (Yelland & Masters 1994) the environment was structured so that it promoted collaboration and was conducive to problem solving in the following ways:

- the children were encouraged to work *collaboratively* in their pairs and actively encouraged in this if it was apparent that they were not doing so;

- the children were asked to *think and discuss their plans* before they started to direct the turtle in order to ensure that they might choose the most efficient route;
- the researchers *supported exploration with questions* about moves that were designed to facilitate not only reflection about strategies, but also to consider the modification of strategies that were not optimal;
- group sessions took place in which the children brainstormed ideas and shared problem-solving strategies;
- researchers provided *models* as a base that children could build from; and
- open-ended tasks were provided that had initial structure but then the children could decide their own strategies for completion.

In contrast, in another study (Yelland 1998) the children were only given the instructions for specific tasks and adult intervention was minimal. They were advised that they would receive help if they needed it if they experienced difficulties in using the computer (technological scaffolding) — and they frequently needed assistance when they seemed to be totally stuck (affective scaffolding) — but no strategies for solutions (cognitive scaffolding) were provided.

Some of the differences in outcomes between the two situations were clear and unambiguous. The children in the earlier study:

- completed the tasks quickly and efficiently because they were highly motivated;
- demonstrated high levels of collaboration in order to solve the task;
- spent more time on task and levels of concentration were high;
- were able to explain their strategies and articulate what they were doing and planning in a very effective manner; and
- did not become frustrated when things did not go as planned or they made errors. We were able to support them in their thinking so they could extricate the turtle from the problem situation and this gave them increased levels of confidence and experience so that if the same or similar situation emerged later in the task they were able to gradually figure out the solution independently.

In contrast, in the second study the children:

- rarely spent time planning and launched into the task immediately without consideration or concern about what might be the best way to complete the task requirements;
- spent a great deal of time off task;
- would leave a task unfinished rather than work through problems or attempt to rectify errors;
- displayed a sense of frustration, loss of confidence and motivation for the task when they did not meet the task requirements; and

- did not demonstrate high levels of collaboration. However, it was evident that the gender composition of the pair was of importance when considering this aspect of performance, with girl pairs showing more collaborative behaviours than boy or boy/girl pairs

The research thus supported the use of *scaffolded learning* in the technological environment, so that learning experiences were not only more meaningful and engaging for young children, but also so that children may use metacognitive strategies more effectively and consistently. Furthermore, two of the most outstanding observations of these studies has been the high level of engagement that the children had with the tasks and their applied use of mathematical concepts well beyond that expected of them in traditional curriculum documents. This was particularly salient when the children planned their own designs for computer projects. When they did this it was evident that they were:

- analysing geometric figures in order to determine their role/ place in the final product;
- understanding that shapes can be moved to new locations, and flipped and turned without losing their essential properties; that is, the angles in a square would always be 90 degrees even when the square was tilted; and
- using their mathematical knowledge, especially related to number and operating on them to produce length and turns for different functions.

At the planning stage, a planning sheet was developed and proved to be particularly useful in assisting the children to organise their ideas in a coherent form. It also served the function of helping the children to decide what constituted a viable project. At first when they made elaborate drawings they did not appear to recognise how difficult they would be to develop as Geo-Logo designs. However, when they came to record their ideas as component parts and procedures it became immediately apparent that the plans would have to be considerably modified in order to enter them as code. The resulting graphics not only indicated a sound understanding of basic mathematical ideas, but also a well developed skill in programming involving the development and combination of procedures.

What we often see in classrooms today is almost the complete opposite of this. Computers are used to keep children who have completed their required work early or as a reward for good work in many cases. Research (Clements 1994; Yelland & Masters 1997) has shown that not only does the computer work need to be embedded within the curriculum, but it also needs the teacher to take on an active role in the process, not only to scaffold learning but also to provide opportunities for children to brainstorm problem-solving strategies and to discuss and share solutions and techniques.

It is a long-held contention in early childhood mathematics that children benefit from manipulatives to develop understandings of concepts. The work of Clements (e.g. Clements 1999) has also illustrated the ways in which computer manipulatives can not only act as viable learning 'tools', but can also help children to make the transition to abstract thinking in mathematics. He outlined a number of advantages of computer manipulatives, which included the fact that they are a

medium that can be stored and retrieved easily, as well as have their configuration changed (e.g. in size). Clements also considered the psychological benefits of using computer manipulatives, in that they afford the opportunity for bringing mathematical ideas and processes to a level of conscious awareness and they allow a constant and consistent replaying of actions, which can be a useful stimulus for reflection. Their dynamic nature means that they can be easily acted upon and this in turn motivates students to make changes as they are exploring.

In fact Clements et al. (in press) have suggested that manipulatives should be used before formal symbolic instruction such as teaching algorithms. However, other common perspectives on using manipulatives in mathematics teaching should be re-considered. Clements et al. stated that teachers and students should avoid using manipulatives as an end — and without careful thought — rather than as a means to that end. A manipulative's physical nature does not carry the meaning of a mathematical idea. Manipulatives alone are not sufficient: they must be used in the context of educational tasks to actively engage children's thinking with teacher guidance. In addition, definitions of what constitutes a 'manipulative' may need to be expanded to include computer manipulatives which, at certain phases of learning, may be more efficacious than their physical counterparts.

Clements et al (in press) stresses the critical importance of considering both physical and computer manipulatives. They suggested in order to optimise learning, we should choose meaningful representations in which the objects and actions available to the student parallel the *mathematical* objects (ideas) and actions (processes or algorithms). We then need to guide students to make connections between these representations (Lesh 1990). Research does not clearly indicate what modes of presentations are crucial and what sequence of representations we should use before symbols are introduced (Baroody 1989; Clements 1989; Metz 1995). It is evident that as mathematics educators we should be careful about adhering blindly to the widely accepted but unproven 'concrete → pictorial → abstract' sequence, especially when there is more than one way of thinking about 'concrete'. A search of the literature has not found any studies that actually have evaluated the usefulness of this sequence, as opposed to any other combination (Parmar & Crawley 1997). When students connect manipulative models to their intuitive, informal understanding of concepts and abstract symbols, when they learn to translate between representations, and when they reflect on the constraints of the manipulatives that embody the principles of a mathematics system (Thompson & Thompson 1990), they build *integrated–concrete* ideas. This should be the goal of our use of manipulatives, an area in which research is needed, since it would lead to more effective teaching and learning of mathematical concepts and processes.

Computer contexts such as Geo-Logo and Shapes, and software such as Tabletop or games like the Logical Journey of the Zoombinis have all revealed potential for children to develop and use higher order thinking skills in dynamic learning contexts. Effective problem-solving environments are characterised by the use of higher order thinking skills and the use of metastrategic processes (Davidson & Sternberg 1985), and involve activity that:

- is authentic, and therefore meaningful;

- is interesting and engaging;
- is sensitive to the needs of diverse populations of students;
- is able to be achieved at different levels of understanding;
- allows for initiative;
- can be extended in a variety of ways;
- can be discussed and summarised into statements that have meaning for the child;
- allows the child to use what knowledge he or she has and then to explore new concepts; and
- does not have one path to solution or has a variety of acceptable solutions.

There are a variety of computer-based activities that can be regarded as being conducive to the development of problem-solving skills. As already noted, research (e.g. Clements 1994; Yelland & Masters 1994) has shown that the role of the teacher in scaffolding children's learning is crucial to the development of such skills. The importance of the role of the teacher in supporting learning is not only apparent while the children are engaged in the task, but also leads to the creation of a problem-solving environment that encourages young children to actively play and/or explore the objects and ideas that they encounter. Research has indicated that the support of the teacher is essential in a variety of computer-based learning contexts which have included the programming language Logo, interactive fiction on CD-ROMs, graphics and presentation packages, and the use of the Internet. The use of scaffolding techniques resonates with the Vygotskian (Vygotsky 1978) perspective which suggested that learning occurs on a social plane before it is internalised and made sense of by the individual learner.

Conclusions

A search of the literature regarding the impact of ICT in general, and particularly the use of computers, reveals that there has been a large number of studies that have focussed on measuring, in some way, the impact of machines on the complex environments we call classrooms and on learning outcomes. In fact, there have been a number of meta-analyses of the literature (see for example Kulik and Kulik 1991, cited in this report). However, it is apparent that acceptance of the evidence is strongly influenced by the stance or viewpoint that one takes.

Detractors of the use of computers in schools cite research that showed no impact on learning outcomes in contexts where the use of computers was considered as a 'treatment' for a set period of time, and where learning outcomes were compared with those of a non-computer group, often on the basis of a single, standardised test. Even though some studies do in fact show gains on test scores, these results are rarely cited by those who do not want computers in schools. Supporters of the use of ICT provide case study material rich in detail but lacking in quantitative analyses that are the currency for determining effectiveness in a simple way. It is interesting to note that in the USA the President's committee of advisers on mathematics and technology (1997) recognised that although there were some excellent examples of innovative practices and learning with ICT, they felt that there was insufficient data that could support an argument for allocating large amounts of funding for new forms of educational software, content, and technology-enabled pedagogy.

It would be difficult not to call the results of the thousands of studies, equivocal and open to a variety of interpretations. Yet it remains salient to query; Are we asking the right questions? And who decides what the 'right' questions should be?

For example, Kirkpatrick and Cuban (1998) recommended that we should be seeking to discover the following:

1. What do we want to use computers for in our classrooms?
2. Can we reach our goals at lower cost — without additional investments in technology?
3. Through what means can we achieve our desired ends?

They go on to provide evidence which supports both sides of the argument for and against the use of computers in education to illustrate the difficulties of posing such questions.

Another fundamental issue seems to be the question of cost as shown in question 2 above. Getting value for money, and providing accountability for money spent, is a high priority in the current economic climate. Associated with this concern about expenditure should be a recognition of the fundamental value of education in providing and supporting the economic growth of the country so that spending is commensurate with value added. An education that does not incorporate the use of ICT cannot seriously claim to prepare students for life in the 21st century, however there is a cost associated with using ICT effectively in schools.

Evaluation of the outcome of this outlay is difficult since many of the benefits may only be seen in the long term and be related to behaviours which are not easy to measure, such as critical thinking and increased problem-solving skill. It is impossible to evaluate in terms of a treatment that will produce precise and specific outcomes as defined by governments. This view as to the difficulty of measuring outcomes was supported by Mayer et al. (1999): 'It is easy to find strong claims for the power of computers to improve students' minds but difficult to find scientifically valid research testing these claims' (p. 30–31). The complexity of the problem was recognised by Schofield (1995, p. 191):

> It is vital to recognise the exent to which any impact is likely to depend on factors all the way from economic realities that determine the number of computers available, to assumptions that determine the nature and amount of training teachers receive; to organisational norms, values, and practices that influences when, how, and by whom the computers are used; to a very specific design decisions made on the part of software developers. One can then attempts to understand the influence of these factors rather than assuming that the important decisions have been made once the equipment has been purchased.

Thus, as Clements et al. (1993) suggested, we are at a point in time where we have a choice of three paths to follow in terms of the use of ICT in education:

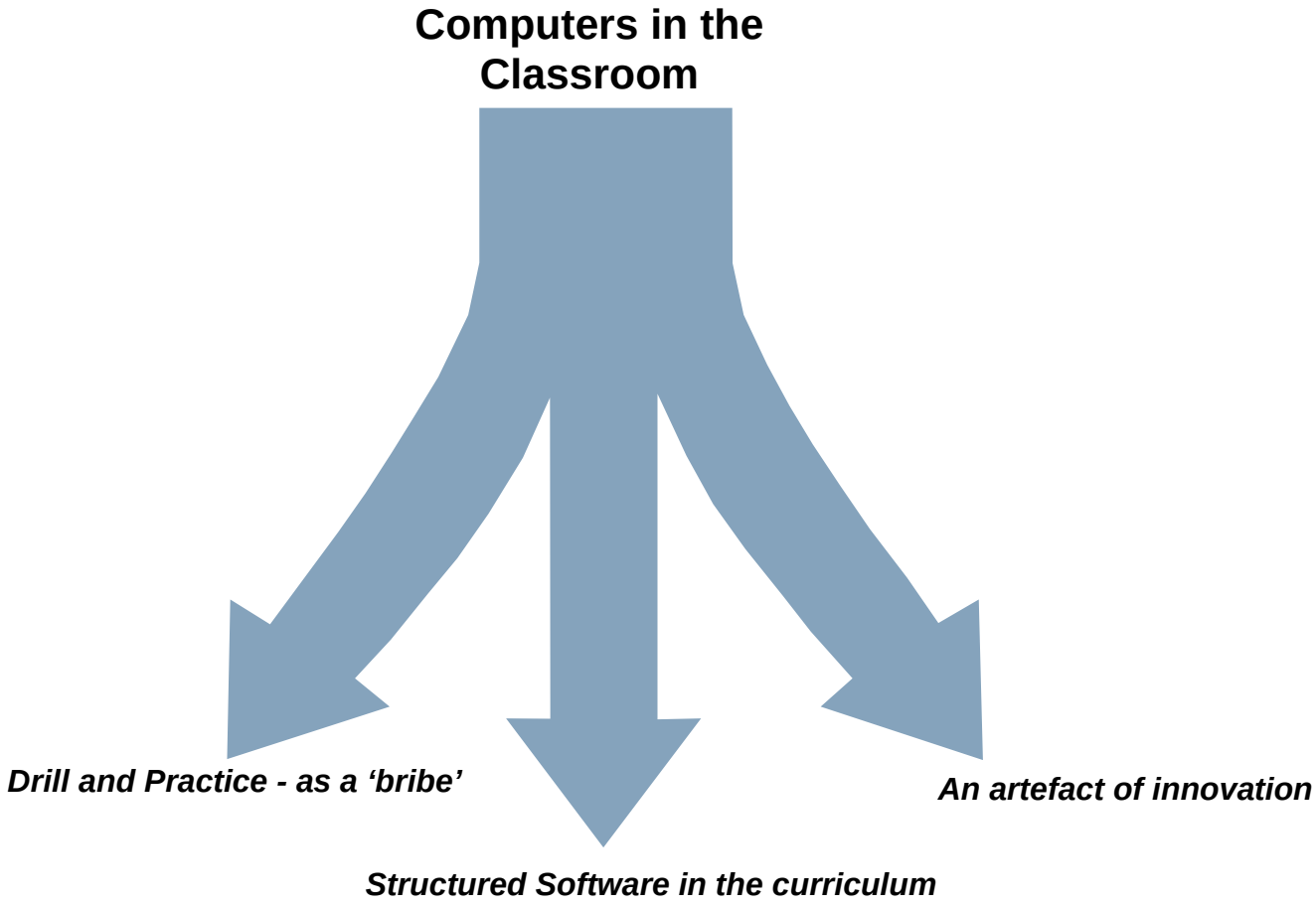

Figure 1: Computers in the classroom

The first path using drill and practice software is clearly not an option. If we use computers as a reward for completion of regular work they can have no added value to education. The second path is a little longer. It suggests that we use some of the better examples of computer software and accommodate them into our existing curricula. The problem is that we are attempting to mould new technologies onto old paradigms — and there is a mismatch. This needs to be recognised and dealt with by teachers and curriculum developers. The third path, however, is 'the road less travelled' and the view is much better! It is a scenario characterised by the use of problem-solving software and generic applications that can encourage problem solving in new and dynamic ways, and afford opportunities to present material in sophisticated ways.

Papert (1980) has been an avid critic of mundane uses of ICT in education. He has accused educators and designers of :

> …inventing new technologies to teach the same old stuff in a thinly disguised version of the same old way. Moreover, if the gadgets are computers the same old teaching becomes incredibly more expensive and biased towards its dullest parts, namely the kind of rote learning in which measurable results can be obtained by doing and thinking. In this regime skills such as problem solving and creativity are frowned upon and results of studies are revealed that illustrate the influence of the final year of school.

Thus, if educators want to take the path of innovation they not only need the support of policy makers and curriculum developers, but also of software designers who should listen to their experienced voices.

Schofield (1995, p.225) recognised that the potential of ICT to transform education will only be realised when:

> …teachers who desire change have the knowledge that they need to incorporate the technology into the curriculum, as well as the interpersonal and pedagogical skills they need to function effectively in their new roles.

Even when computers are present in schools it has been demonstrated that the need for professional development of teachers is critical to their successful implementation. It is essential to ensure that teachers are confident and competent to use software that is available to them in an integrated way, and they should be supported in doing so. Much of the research cited here reinforces the need for this support, and should provide ample evidence for a demonstrated need for funds.

Tinker (1999) has suggested that in the years to come, as learning technologies become more widespread, the gap between what we could teach with ICT and what we do will widen and ultimately become intolerable. He recognised, however, that creating new teaching sequences that incorporate and embed the use of ICT is a massive task, and it will need an informed research base in order to be sound and effective. Tinker contended that what is needed are 'research-based responses that are reliable enough to use as a basis for policies that may well influence an entire generation of learners' (p. 4). It would not be ethically possible to utilise cause and effect research methods so the situation is problematic since studies that demonstrate improved teaching and learning in qualitative ways are

generally admonished by positivist research who demand generalisability and statistical tests to prove that learning has taken place.

What is evident is that traditional forms of research need to be supplemented with new research paradigms so that we can achieve a clearer picture of possible effects and their impact on outcomes. We live in liminal times where old structures – in place before ICT permeated our lives in such a dramatic way – are breaking down, but are yet to be replaced with new supports. The nature of educational environments are complex and each child and teacher are different. We can maintain general or community-based standards in our quest for quality, excellence, equity and positive outcomes for all Australian children. However, we should also recognise that we need a variety of indicators which will assist us to determine the extent of the success.

Recommendations

This review of research leads to six recommendations:

1. **The use of ICT is a fundamental aspect of learning, and funding needs to be specifically targeted to its successful implementation in the schools and universities in Australia that provide teacher education programs.**

We live in the information age where the use of ICT permeate all aspects of our lives. Schools cannot be the only place where they are not used effectively. It has been shown that the use of ICT can be catalyst for learning and engagement with activities in school and it would be relevant to explore the precise mechanisms that influence the inter-relationships between learning and media. The use of ICT hold great potential to generate new ways of teaching and learning and we need research to identify these. It is imperative that ICT and teacher resources are equally distributed so that all Australian students have access to the new ways of learning and knowledge acquisition.

2. **There is a need for *Australian* research about the impact of ICT on learning, especially with regard to literacy and numeracy outcomes and the concept of multi-literacies that incorporate the use of ICT.**

The majority of influential studies originate from the US, although recently more are coming out of the UK. There is a great need for quality Australian-based research, which will inform educational practice and improve outcomes for all students in Australian schools. It is evident that we should be looking for ways to improve learning and educational outcomes that include the use of appropriate technologies as an integral part of learning, *not* as an add on to existing practices which were in place before ICT were invented.

3. **We need to identify relevant research questions which support the successful use of ICT in schools**

It is evident that we need to ascertain if we are focussing on appropriate research questions. In an economic climate that seeks to ascertain value for money, questions are often phrased to support control/treatment studies, often for short periods of time, which attempt to find cause and effect features to support their arguments for the use of computers or not. It would seem that there is a need to demonstrate increases in (test) performances commensurate with the amount of dollars spent. With such marginal use of computers for learning it is of little surprise they often have minimal impact since their use is not integrated into the curriculum.

Concurrently, curriculum developers seem to continue their work as though computers serve only a marginal purpose in subject areas and need to mimic popular culture. The design and approaches of developers reflect content and suggest pedagogies more suited to traditional curriculum. In this way the power of potentially revolutionary technologies are often ignored and we miss opportunities to create new sequenced topics that incorporate the embedded use of new information technologies. We should seek new ways to reconceptualise curricula that illustrate the important benefits that ICT can bring to education, rather than continue with our practice of fitting new technologies into old curriculum or within the context of traditional didactic teaching methods.

4. Funding should support a variety of research methodologies which include quantitative and qualitative approaches as well as mixed-method research designs.

Schofield et al. (1994) asserted that what is required is ‘theoretical work delineating how subject matter learning and classroom social processes are likely to be influenced by specific features of the software itself and of the social context of technology use' (p. 606). They contended that unless this research occurs we will be inhibited from achieving the full potential of computers in schools. Such research would recognise positive effects and identify any negative influences. In this way we could determine how best to promote effective learning so that outcomes are improved. However, because teaching and learning contexts are complex it is essential that we recognise all the influential elements and as Tinker (1999) noted create research that will inform the educational community about the interdependencies in the environments, so we can 'create alternative curricula that exploit the power of modern learning technologies’ (p. 1).

5. A longitudinal study to complement research in literacy and numeracy research would be beneficial

The variety of results from short-term studies, which can be as little as 4 weeks 'treatment', highlights the necessity for longitudinal work that not only documents the effective use and integration of ICT, but which links them to a variety of outcome measures. Sources of funding for longitudinal research on a large scale is difficult to obtain via research granting schemes such as the ARC, where monies provided are traditionally much less in the Social Sciences than other disciplines.

6. A set of exemplary teaching practices incorporating the use of ICT — such as those developed by DETYA's Indigenous Education Branch in *What works?* — should be commissioned.

If a set of exemplary case studies that outlined effective practices with ICT was developed, it would enable student teachers and teachers to view/read/share the practices and adapt them to their own situation. This could then be incorporated in professional development programs, where it has been proven to be an excellent strategy for change (e.g. Yelland & Bigum 1996). The contention is that by seeing 'what works' for others, teachers can adapt and adopt these to their own context more effectively. Teachers are more willing to try new practices that have been demonstrated as successful for other teachers, albeit in different environments yet in the same State or Australia-wide schooling system.

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