Technological Solutions for Teacher Education in Science and Mathematics

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Online technologies have the potential to exponentially increase the availability of information to classrooms, alter the nature of communications and extend the environment in which individuals think, communicate, process data and learn. In the hands of able and informed teachers, they can play a prominent role in student learning. Schools are responding at a rapid rate to the changes in thinking and communicating that digital technologies bring. Computers in classrooms are increasingly used as Mindtools that require students to think in meaningful ways in order to represent what they know or have learnt. This paper describes an approach to creating interactive multimedia (IMM) science and mathematics resources for use at both tertiary and primary levels. The multimedia resources replicate and enhance quality "traditional" science and mathematics materials and pedagogy, and have been used extensively and successfully with tertiary teacher education students at Griffith University, Queensland. The materials aim to engage students from primary to tertiary in meaningful scientific and mathematical thinking. It is the contention of the researchers that students of all ages "learn" science and mathematics when they are actively engaged in the learning process and they are encouraged to think scientifically and mathematically. Further, teacher education students gain valuable pedagogical understanding of the role IMM materials can play in science and mathematics classrooms, as a result of their development and use of these materials.

Introduction

The emergence of new technologies does not mean that old technologies become redundant (Luke, Matters, Herschell, Grace, Barrett, & Land, 2000). Learning technologies have not replaced print and oral language or basic disciplinary understanding. Instead, they are modifying, reshaping, and blending the ways in which humankind speaks, reads, writes, and works scientifically and mathematically.

Contemporary constructivist theories of science and mathematics learning contend that students develop understanding by moving along a path from concrete to abstract. Students firstly build up various mental representations of knowledge (e.g., concrete, pictorial and symbolic). They then progress towards relational understandings of scientific and mathematical concepts by making connections between these various modes of representation. Current pedagogical beliefs emphasise that this abstraction process is best served by a combination of (a) work with appropriate manipulatives, and (b) discussion and reflection (English & Halford, 1995). Ultimately, science and mathematics *learning* is about refinement and abstraction of ideas and concepts, and science and mathematics *teaching* is about facilitating this process of refinement and abstraction. Therefore, by seamlessly integrating the use of concrete materials and computer-based materials, an opportunity arises to enhance the teaching and learning value of both materials (Lewis, 1996).

With specific reference to mathematics there is a general expectation for learning technologies to enhance teaching and learning (Gentile, Clements & Battista, 1994). For instance, it has been suggested that computer use can improve mathematical modelling ability (Zbiek, 1998), increase construction of higher level conceptualisation in geometry (Gentile et al., 1994), and motivate students by providing them with interesting learning activities, which help them better prepare for post-schooling activities (Sandholtz, Ringstaff & Dwyer, 1997). A possible explanation for the expectation that learning technologies will enhance students' mathematical understanding lies in the belief that learning power is increased each time knowledge is transformed from one form into another. Lemke (1996) stated that human communication normally deploys the resources of multiple "semiotic systems and combines them according to essentially functional principles" (p. 1). He believed that the ability to integrate text and visual-graphical representations offered great potential in formulating concepts and relationships. As computers are able to present information textually and graphically, they potentially provide more effective learning environments.

Reilly (1997) claimed that successful teaching with computers tended to focus on knowledge-construction activities that actively engaged students in solving problems both as individuals and as members of a team. Successful learning tended to change significantly students' conceptions about the nature and discourse of the subject matter being studied (Clements, 1994) with accompanying qualitative changes to students' mental models of the phenomena being studied (Woodruff & Meyer, 1997).

According to Proctor, Baturo and Cooper (2002), the majority of activities undertaken in elementary mathematics classrooms with *real/concrete* materials can be replicated with virtual materials, although there are some slight differences between the materials. *Real* materials are multisensory (i.e., they can be seen, smelt, moved, picked up, touched, weighed), whereas *virtual* materials are bisensory (seen and moved), so virtual materials are more abstract to students developing mathematical concepts than are real materials. Therefore, real materials may develop a more detailed memory structure (schema) than virtual materials. However, mathematising is ultimately about the refinement and abstraction of ideas and concepts, so that virtual materials may in fact assist students to develop appropriate abstract understandings. Some virtual actions are neither as overt as they are with concrete representations nor as covert as they are with pictorial representations and therefore virtual materials could provide a conceptual bridge from concrete to pictorial representations.

The spread of digital technologies has impacted upon what it means to be numerate. New digital technologies can enable students to construct new kinds of mathematical knowledge, in particular by constructing relationships, extending and applying mathematical knowledge, personifying or making mathematics one's own and articulating mathematics in different ways (Romberg, 2000). These "reform curricula" have increasingly articulated a shift from teaching skills routines and procedures toward understanding, creativity and an ability to model and solve problems (Romberg, 2000).

Hence it is not surprising that digital technologies are part of the impetus for changing the nature of mathematics, and that such technologies are increasingly recommended to become part of the pedagogical process. Thus, there is wide support for the use of digital learning technologies in teaching and learning mathematics to solve problems, develop skills of analysis and to communicate (e.g., Australian Educational Council [AEC], 1990). Norton (1999) has stated however, that much of the use of digital technologies in mathematics tends to be calculational, with a low level of interactivity and not conceptual in its focus. In reality, much of the so-called interactive learning materials currently available are not all that "interactive".

As with mathematics the emergence of digital resources is changing what it means to do science and to teach science. Digital technology in science teaching and learning has been used in a number of major ways. Firstly, as a source of general science information, numerous CD-ROMs exist that contain domain-specific science content and science websites. Secondly, the Internet has been used to facilitate the access to authentic data such as the NASA Astronomy Resources site (http://space.about.com/cs/nasaastronomy/index) or the Australian CSIRO web site (http://www.csiro.au/). Thirdly, science teaching has a well-established pattern of participation in online projects. Early results of research into the learning outcomes of students engaged in learning science through digital means indicate that students spend their time productively, prefer such activities over traditional science labs and learn both content and scientific inquiry skills (Reeves, 1998). Critics of digital-based teaching projects, on the other hand, say that students and teachers "confuse access to information with real knowledge, and mistakenly elevate the capacity to compile data above the ability to analyse and understand it" (Conte, 2000, p. 7).

However, science simulations have potential use in all grades (Gorsky & Finegold, 1992; Lewis, Stern, & Lynn, 1993). Generally, digital technology has the same potential to enhance science understandings as it does in mathematics and for the same reasons. The use of mindtools such as spreadsheets has been recommended (Pushkin & Zheng, 1995). Research into the use of simulations in enhancing understanding have generally been positive (Windschilt & Thomas, 1998). The static presentation of difficult-to-grasp concepts such as relating temperature to particle movement, or more abstract biology topics such as sustainability are enhanced when students can control the variables and see effects directly (Akpan, 2001).

This paper discusses the development of interactive multimedia science resources at Griffith University for upper primary and lower secondary school children that help them to understand the science, technology and social issues behind the global greenhouse effect as well as interactive multimedia mathematics resources that provide a stepping stone between concrete manipulatives and abstract concepts such as place value and common fractions.

The interactive multimedia science resources

The global greenhouse problem is arguably the most damaging environmental problem facing humankind. Climate change is now widely accepted by scientists, many politicians and other informed individuals as being directly linked to society's selfish and extravagant reliance on fossil fuels. Within democracies like Australia, education will be the key to the widespread acceptance of the difficult and expensive steps needed for society to adopt large-scale conservation measures and acceptance of environmentally sustainable energy practices. A number of student-centred interactive multimedia learning objects specifically designed to help primary and secondary age children to understand the causes and consequences of, and possible solutions to, global climate change are currently under development by the authors at Griffith University.

These materials are being developed in response to growing numbers of requests from teachers and members of the public from many parts of Australia for greenhouse curriculum materials and renewable energy information. In 2000 Swindell and Richmond were awarded a teaching grant from the Faculty of Education, Griffith University specifically to develop web-based interactive materials that promote understanding of science and social issues relating to global climate change. Stage one of this project was completed early 2002 and four of the interactive modules are currently mounted on the Griffith University primary science home page. No similar materials are currently available on the Internet. This resource has the potential to reach a very large number of teachers and children across the globe. Preliminary evaluations from students rate these interactives highly. Table 1 displays the results of a questionnaire completed by 48 Bachelor of Education (Primary) students who were asked to view and evaluate Module 1: The Greenhouse Effect.

Table 1

Bachelor of Education (Primary) students' reaction to a web-based interactive (*N* = 48)

MODULE 1: THE GREENHOUSE EFFECT	SA	A	N	D	SD
It is more effective than traditional lesson format	5	22	15	6	
It would be better used as an addition to normal lessons	18	29	1		
It is more interesting than the traditional lesson format	11	26	8	3	
It would be suitable for primary age children	18	27	2		1
Operating instructions caused no problems	31	17			
Language used was easily understood	26	20		2	
Diagrams were effective in presenting the concepts	38	8	2		
There is an appropriate balance between text and diagrams	25	19	3	1	
Navigation within the site was easy	33	15			

Note. SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree.

Similar positive responses were obtained from different groups of students to identical questions asked about Module 2: House Design and the Greenhouse Effect, and Module 3: Colour and the Greenhouse Effect. As the feedback from teacher trainees was positive and it appeared that these prototype materials were pitched at an appropriate level to be of value to upper primary school/lower secondary school students and their teachers, it was decided to apply for a second Teaching Grant in 2003 to complete the series of materials dealing with the Global Greenhouse Effect.

This grant will provide the funding to complete the final 3 modules: "Some Consequences of the Greenhouse Effect", "House Design and the Greenhouse Effect - Insulation, Windows and Orientation" and "Coloured Surfaces and Heat – Solar Heater" over the next 12 months. Graduates of the Griffith University Bachelor of Multimedia degree have been commissioned to work with the authors and an instructional designer from Griffith University's Flexible Learning Service to complete the series. Based on the literature pertaining to sound instructional design for interactive multimedia, the level of interactivity built into the stage 2 modules will be a prime design consideration. The overall interface and navigation through the modules will conform to the original modules. Thus, together, the complete series of modules will provide students with a comprehensive learning experience in relation to the global greenhouse effect, its causes, consequences and their options to select environmentally sustainable energy practices. Figure 1 displays one of the interactives. Others are currently on the Griffith University *Blackboard* site.

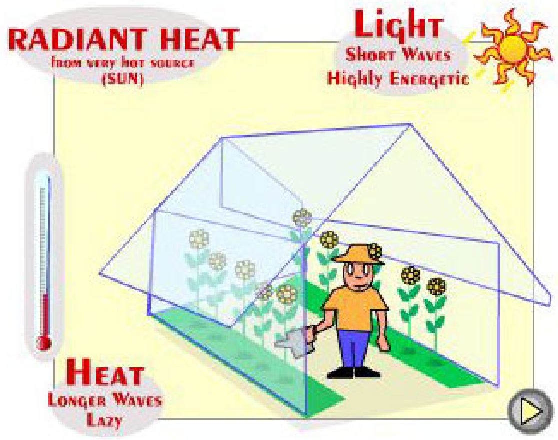


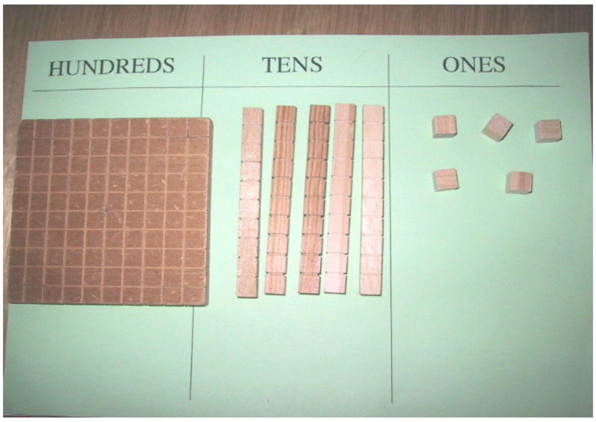
Figure 1.

A digital interactive demonstrating the effect on temperature of short light waves entering a greenhouse.

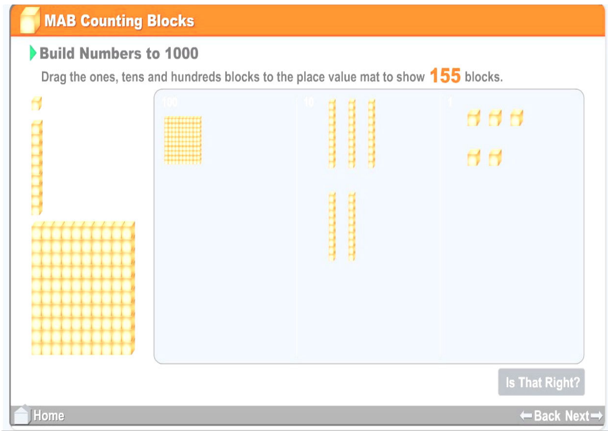
The interactive multimedia mathematics resources

For students to develop an understanding of abstract mathematical concepts such as place value they must be actively engaged in activities that require them to build and regroup numbers, name and use the symbol for numbers and for common fractions they must partition wholes into equal parts. For example, 155 can be represented concretely

(3-dimensionally) by building the number on a place value card using Multibase Arithmetic Blocks (MABs) or pictorially (2-dimensionally) by dragging and dropping the appropriate MAB pictures onto a virtual place value card. Figure 2 contrasts the two approaches.



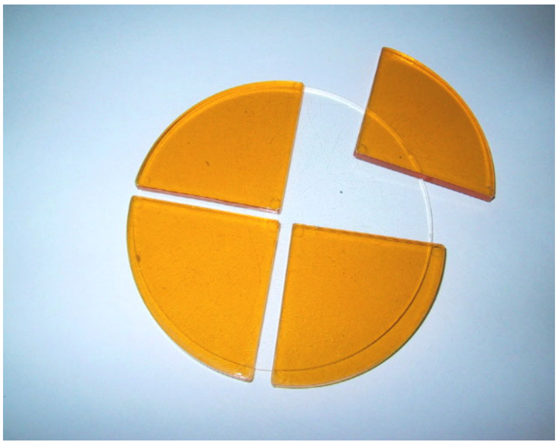
Concrete representation of 155



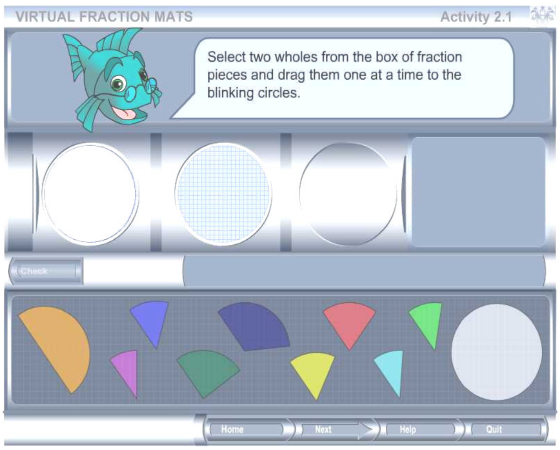
Digital representation of 155

Figure 2.
Real (concrete) MAB materials and virtual MAB materials.

Similarly, $^4/_4$ can be represented concretely by cutting a rectangular piece of paper into four equal parts or by joining together 4 equally-sized plastic circle sections. It can be represented pictorially by dragging and dropping 4 equally-sized circle sections onto a whole circle. Figure 3 illustrates the creation of $^4/_4$ with concrete plastic circle pieces and their digital equivalent.



Concrete representation of fractions



Digital representation of fractions

Figure 3.
Real (concrete) and virtual materials for common fractions.

Hence, virtually all of the building, regrouping, partitioning and comparing activities that are done with concrete ("real") materials can be replicated digitally. The only difference is that students can't hold the digital MABs or fraction pieces in their hands. They can however select them and pick them up with the mouse pointer and drop them to build the required number. Further, FLASH-based animations can be used to demonstrate concepts such as 10 ones equal 1 ten or $^4/_4 = 1$ whole.

Development of these web-based Mathematics interactives is an expensive and time-consuming process. However, the first author teaches Instructional Design for Interactive Multimedia to Bachelor of Multimedia and Bachelor of Education students at the Gold Coast campus of Griffith University. In their final semester, multimedia students are required to undertake a life-like project in which they are coupled with an "employer" for whom they are to create a multimedia solution. The author has played the role of employer for 3 student groups so far and has storyboarded the development of several digital mathematics manipulatives including Digital Fraction Mats, Digital MABs, Counting With Teddy, and Tessellating 2D shapes. These resources replicate the concrete materials students and teachers are already familiar with and use extensively in mathematics classrooms. As such, teacher instruction on the application of these interactives is minimised. They are all discrete learning objects that can be used as stand-alone mathematical resources or they can be integrated with other digital and concrete resources as required by individual teachers to cater for their students' learning needs.

Each set of objects has been evaluated in classrooms by students and teachers and they have all been found to be very useful additions to the pool of mathematical manipulatives already in use. Student comments on questionnaires include "I understand fractions a lot better now…I wish we had of had this program before" (Student evaluation of Fraction Mats, Oct. 2002). Further, the mathematical learning objects have been designed to comply with the recommendations made by Cooper, Proctor, Crawford, Nuyen and Norton (2001) in the Schools Online Curriculum Corporation (SOCCI) Market Research Report namely, the materials

1. bridge the divide between instructional design in mathematics and digital learning object design
2. support the current syllabus statements and frameworks
3. are accessible, generative, adaptable and scalable
4. support any place and any pace learning as they are web delivered
5. are authentic and engage students in synthesis, analysis and evaluation
6. are readily integrated by teachers into the mathematics curriculum
7. will facilitate communication and collaborative learning.

Conclusion

The science and mathematics digital materials described in this paper support the current mathematics and science pedagogy (e.g., Akpan, 2001; English & Halford, 1996) and support the integration of on and off computer tasks indicated by Lewis (1996) and Luke et al. (2000). They also support research findings on effective use of computers for example the efficacy of knowledge construction tasks and group problem solving (Reilly, 1997); changes that result in students' subject-matter knowledge (Clements, 1994); and, mental models (Woodruff & Meyer, 1997). The design of the resources supports contemporary approaches to learning and teaching in which learners are viewed as active constructors of knowledge. In particular, the digital representations of complex scientific concepts such as convection and conduction and mathematical concepts such as place value and equivalent fractions provide a change in the form of knowledge that should facilitate enhanced student learning outcomes in mathematics and science. In other words, the strengths of both real and digital mathematical and science activities, together should reinforce a richer understanding of mathematical and scientific ideas than either form could alone. As well, each form compensates for the weaknesses of the other.

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