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Journal Owner:

Dr. Esma USAK

Mailing Address:

Mareşal Cakmak Mh. Göktug Sk. No: 23/4
Sincan, Ankara – TURKEY
Email: ejmste@ejmste.com

Editorial Office:
Mehmet Fatih TAŞAR (**Editor-in-Chief**)
Gazi Universitesi, Gazi Eğitim Fakültesi,
İlköğretim Bölümü,
K Blok 228, 06500, Teknikokullar,
Ankara – TURKEY

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CONTENTS

Eurasia Journal of Mathematics, Science & Technology Education, 2009, **5**(3), 187-196

Challenges in Environmental Education: A Conversation with Annette Gough

Mehmet Fatih Taşar
Gazi Üniversitesi, Ankara, TURKEY

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The conversation between Professor Annette Gough and Fatih Taşar took place in her office at RMIT University, on May 26, 2008. The purpose of this conversation was to highlight development of Professor Gough's career in environmental education and her research in the field. We talked about the history and development of environmental education and whether it is a separate field or accepted as such. She explained why she thinks environmental education is important, what the future awaits in terms of environmental education research, and Australia's position in such matters. We lastly focused on her achievements so far and her research interests. This manuscript includes the transcription of our conversation and also references of the works that were mentioned together with Professor Gough's selected scholarly works.

Keywords: Environmental Education, Gender Equity, Feminist Poststructuralist Analysis, Curriculum

INTRODUCTION

Professor Annette Gough is an editor of this journal since 2007. She has an immense experience in the field of environmental education as the reader may see throughout this paper. As an Endeavour Executive Award Holder I spent four months in Melbourne and was hosted by RMIT's School of Education. Endeavour Awards are given to high achieving individuals from education, government, business, or industry to provide professional development opportunities in Australia and abroad. The focus is on building skills and knowledge through a host work environment. I intended to observe school environments and curricula, teacher education, teacher professional development and related issues in Melbourne and elsewhere in Victoria. My other goal was to establish strong links with the Australian colleagues in order to continue a mutually beneficial partnership in the future.

Correspondence to: M. Fatih Taşar, Assocaite Professor of Science Education
Gazi Üniversitesi, Gazi Eğitim Fakültesi,
K-Blok 210, Teknikokullar 06500 Ankara, TURKEY
E-mail: *mftasar@gazi.edu.tr*

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This opportunity also gave me a unique firsthand experience to observe the Turkish immigrants' status in education and social life in Melbourne. It was also remarkable to note the 40th anniversary of the arrival of first Turkish immigrants to the city in 2008. While in Melbourne professor Gough and I also planned a half day seminar named "Looking to the future of MSTE Education" which was held on 16 June 2008 with participation of several colleagues to discuss issues related to mathematics, science, technology, and environmental education at RMIT's School of Education at the Bundoora West Campus. Hence the seeds of this special issue were planted. It is very meaningful to have this conversation published together with the other two in the Australia Special Issue of the EURASIA Journal.

PROFESSOR GOUGH'S VITA

Annette Gough is Professor of Education and Head of the School of Education at RMIT University. Prior to this she was Associate Professor of Science and Environmental Education at Deakin University. She is also an adjunct professor at the University of Victoria, British Columbia, Canada and a visiting professor at Rhodes University in Grahamstown, South Africa.

Figure 1. Professor Annette Gough in her office at RMIT University as the Head of School of Education.

Annette has been involved in environmental education for most of her professional life. Initially trained as a biology and science teacher at the University of Melbourne, Annette taught biology, geography and science in Victorian secondary schools before joining the Commonwealth Government's Curriculum Development Centre (CDC). Here she conducted Australia's first national needs for environmental education survey in 1974 and then coordinated the CDC's national environmental education projects implemented between 1978 and 1981, including Australia's first nationally agreed statement on environmental education for schools in 1980 (Environmental Education for Schools or how to catch environmental education). She was then Director of Environmental Education in the Commonwealth environment department (under numerous titles) before moving to Deakin University in 1990.

Annette completed her Master of Education at the University of Melbourne in 1980 and her Doctor of Philosophy at Deakin University in 1994. Her theses in both instances were concerned with deconstructing the history of environmental education in Australia and internationally since 1970. Her Master's thesis was published by the Curriculum Development Centre in 1981 (Environmental Education in Australia: Phenomenon of the Seventies) and her doctoral dissertation formed the basis of the Australian Education Review published by the Australian Council for Educational Research in 1997 entitled Education and the Environment: Policy, Trends and the Problems of Marginalisation.

Annette was the third president of the Australian Association for Environmental Education (1984-1986), and was made a life fellow of the Association for her contribution to the field in 1992. Her contributions to environmental education in Victoria were recognised in 2000 by the Victorian Association of Environmental Education when she was awarded Environmental Educator of the Year and made a life fellow. She was also the first female President of the Gould League of Victoria (2000-2002) and chair of the American Educational Research Association's Special Interest Group on Ecological and Environmental Education (1996-97) where she continues to be a member of the executive committee.

Since the mid 1990s Annette has been a member of both examination and accreditation panels for the Victorian Certificate of Education subjects Outdoor and Environmental Studies and Environmental Science (and their predecessor subjects) for the Victorian Curriculum and Assessment Authority. She has also been a judge for the Eureka Prize for Environmental Education and is currently a member of the editorial board of eight international journals related to environmental education, science education and international understanding.

In addition to the publications previously mentioned, and a large number of journal articles and book chapters, Annette's books include Environmental Education Teachers' Handbook (Longman Cheshire, 1978), Taking to the Streets and Pollution in Focus (Educational Media Australia, 1982 and 1983 respectively), Founders in Environmental Education (Deakin University Press, 1993), and co-authoring Outdoor and Environmental Studies: VCE Units 1 to 4 (Thomson, 2002 and 2005) and Educating for a Sustainable Future: A National Statement on Environmental Education for Schools (with Brian Sharpley, Curriculum Corporation, 2005) and Development of Environmental Education in Australia - Key Issues (1977, Curriculum Development Centre).

THE DIALOGUE

FT: Good morning Professor Annette Gough (AG). Today is May 26, 2008 and we are in your office in Melbourne at RMIT University, and I am very glad to have this interview for the Eurasia Journal.

I would like to begin with this question - how did you begin researching at RMIT Education and what kind of a background did you come from?

AG: Good morning Fatih (FT) and thank you very much for inviting me for this interview. I am very honoured by the opportunity.

I started my career as a high school biology and science teacher. My first degree was a Bachelor of Science (Education) from the University of Melbourne, but I was also a frustrated historian. The way our education system was structured in Victoria, when you get to the last 2 years of high school, you had to choose a pathway. One was the humanities pathway and the other was a science pathway, and you couldn't mix the two if you actually wanted to pursue a science career. So, although I was very interested in science, I also loved history and so it was with great reluctance that I stopped studying history at school and pursued a biology career. I was fortunate to be able to do history and philosophy of science as one of the subjects in my Bachelor of Science (Education) studies. I became so passionate about that, that when I finished my undergraduate course I started a Master of Science in History and Philosophy of Science.

FT: I was interested in History and Philosophy of Science when I was doing my PhD as well. It is a very interesting topic.

AG: It is. It is really quite fascinating. I got to the stage where I did all the coursework and was up to writing the thesis and at that point I changed careers from being a classroom teacher to working with the Australian Science Education Project. I realised that if I was going to do a Masters degree then I was probably better off doing a Masters degree in education rather than a Masters in science because my career was heading that way, and so I switched to the Master of Education. Perhaps when I have time I will go back to studying history and philosophy in science.

I also have continued my interest in history through my Masters and PhD. My Masters (1981) was a history of the first ten years of environmental education in Australia. called, "Environmental Education in Australia – Phenomenon of the Seventies", which of course it wasn't because 30 years on we're still talking about environmental education! My PhD (1995) then looked at environmental education from the 1960s through to the early 1990s so again it was a historical study. My master's was an interpretive into critical case study, what was happening nationally with and around the Curriculum Development Centre, which is where I was working at the time. My PhD was very much a critical into poststructural study in terms of it being a feminist poststructuralist analysis of the foundations of the field. So I've been involved with a range of different types of educational research methodologies and with environmental education for many years, but also I've managed to keep an historical perspective and interest in the environment and science in there at the same time.

You did ask me the question of how did I begin researching in the field. It really started when I switched to working for the Australian Science Education Project which was part of the National Curriculum Development Centre. At that time the Curriculum Development Centre was in its early days and the government had given it five priority areas, one of which was environmental education. So I was sent off around Australia in late 1974 to do the first National Needs for Environmental Education Survey in Australia, which formed the basis for the related programs of the Curriculum Development Centre during the 1970s, so my history in the field goes back a long way.

FT: Just out of curiosity, and I'm not familiar with the works and do not know if they exist at all, is there any work related to history and philosophy of the environmental movement or perhaps related works to environmental education?

AG: There's a lot of work around the history of the environmental movement. Here in Australia, Drew Hutton has written a couple of books (e.g. Hutton & Connors, 1999) and Libby Robbins has done some work (e.g. Griffith& Robbins, 1997) and so on, so there's been quite a bit of work around the history of the environmental movement in Australia. Internationally Peter Hay (e.g. Hay, 2002) has done some work in that area.

FT: So it does exist in the field?

AG: It does exist in the field. In terms of the history of the environmental education field, I've probably been one of the more prolific writers. It has sort of fallen to me over the years to write about it. I've done a book on the Founders in Environmental Education that actually came out of my doctoral studies but was published separately by Deakin University (1993) and many journal articles.

FT: My next question is, when you consider the history of environmental education and the environmental movement, what marked the beginning of environmental consciousness, and the beginning of environmental education in the world as a separate area?

AG: The cliché around what marked the beginning of environmental consciousness, most people put it down as Rachel Carson and Silent Spring, Garrett Hardin and the Tragedy of the Commons and Paul Ehrlich's book on the Population Bomb and so on. They were all scientists in the 1960s who were concerned about the state of the environment: increasing levels of pollution - air pollution, water pollution; destruction of forests and wetlands. Of course Rachel Carson was looking at the effect of the use of DDT on the environment and its accumulation through food chains, all those sorts of topics. In 1970 in the US and soon after in Australia we had the Clean Air and Clean Water Acts and the US Environmental Education Act was 1970 as well.

Environmental education as a movement started around the same time because with most social issues education is seen as the required response to something. If we've got some motor vehicle accidents, we need driver education in schools. If we've got lots of people going bankrupt, we need finance education in schools. In the case of environmental education we had things going wrong with the environment so we need environmental education in schools. The first use of the term that I've been able to track was to 1965 at a conference in England but very soon after it became very widely known in the US as well and Bill Stapp and a group of colleagues at the University of Michigan, came up with one of the early definitions of environmental education.

FT: Is the definition now, different to the definition then?

AG: Not really. If you go back to Stapp et al's original objectives for environmental education (1969), and you do have to accept that the language was very sexist at that time because they were scientists and they tended to use 'man' as the universal, which as a feminist researcher I would very much resent. So I tend to translate 'man' to 'human' in these. His four objectives were that:

- we have a clear understanding that humans are an inseparable part of the system, consisting of humans, culture and the bio-physical environment and, that humans have the ability to alter the inter-relationships of this system.
- Secondly, a broad understanding that the bio-physical environment, both natural man-made in its role in contemporary society.
- Thirdly, a fundamental understanding that bio-physical environmental problems confronting humans and how these problems can be solved, and the responsibility of citizens and government towards their solution.
- Fourthly, attitudes of concern for the quality of the bio-physical environment which will motivate citizens to participate in bio-physical environmental problem-solving.

The heritage of those is still very much with us today, that people talk about environmental education being about behaviour change, that people need to act differently for the environment but also that depth of understanding that we need of ecological concepts but also economic, social, political, that there's not simple solutions. I think that the heritage of what we say now is environmental education is very much in that set of objectives.

FT: I see that there is also reference to biology. It reminds me that many people, if not most, tend to think that, for example, that technology is a subfield of physics and likewise I see many people tend to think that environmental education is a subfield of biology or biology education. What's your position? What's your take in this debate sort of? Is it really a part of or subfield of biology or has it grown to be a different, stand-alone field?

AG: I don't think it has grown to be; I think it has always been a different, stand-alone field. There's really been a love-hate relationship between environmental education and science education over the years. Although the roots of environmental education are very much in the calls by scientists that we need to do something about our behaviour towards the environment and what human activity and technology was doing to the environment, the social side of environmental problems, and environmental problems are social problems because they are to do with people and people's survival and so on.

FT: Do you think that science and technology are social acts as well?

AG: Yes, but traditionally science teachers want 'nothing but the facts, ma'am' and can't cope with looking at the actual impact of activities or the social side of things. They're very happy to study ecosystems and they might look at changes in ecosystems but they're not willing to move into that problem-solving stage with students. Scientists in real life might move into those sorts of situations but science teachers wouldn't, so within a schools context, environmental education and science education grew very rapidly to be different animals and you'll have people like Arthur Lucas (1979) writing about the problems of science education and why science education shouldn't get too involved with environmental education. His paper, back in 1980, included discussions about science being a limited vehicle for environmental education and these were very common discussions during the 1980s. I think we have moved to the point now where environmental education meets science education because environmental education does need that ecological understanding but that's just one aspect of it. But at the other end I think science education needs environmental education because there's such declining interests in science and science education in the western world that the one way that you can hook students' interests in science is through studying the environment.

FT: It can be a vehicle, you think?

AG: Oh, I think so. The environment is an enormous vehicle for engaging students' interests with science because environmental education is multi-disciplinary. You can take an environmental problem – you can study the ecological concepts that underpin it and you can also perhaps look at the chemistry that is involved, the physics that is involved, the geology that is involved but also the history, the geography, the mathematics, the artistic responses. You can sort of build all of that and students are responding much more to the environment than they are to the straight conventional sciences, so I think it's a huge area for bringing the two back closer together where they have been divorced for a while.

FT: When you consider the history of environmental education, how do you think the research agendas have changed over the years and what do you expect to see in the future? What emphasis will be given or should be given in the future?

AG: The environmental education research agenda has certainly moved. Nowadays the everyday concerns are with how successful the program's been in engaging students' interests in the environment and particularly the long term effects of the programs: how do we know that people are going to change their behaviours and continue to sustain that behaviour.

FT: What about in those days?

AG: If you go back to the 3 way approach to environment education that Arthur Lucas used as the basis of his thesis back in 1972 (see Lucas, 1979) - Education in the Environment, Education about the Environment and Education for the Environment - and it came to be part of the slogan that it's only when there's education for the environment is environmental education really happening, that education in the environment was already happening through biology and outdoor education and things like that. Education about the environment was happening through traditional schooling but there was very little education for the environment where you've got people engaged in values clarification, problem solving, all those sorts of things. So, it was looking at how you can educate people for the environment and whether there's sustaining of any changes that happened. That focus continues through to today. People still say "how do we know that program works?" and we've got public education programs around - saving water is a good example in Melbourne, where we are still in a drought.

FT: We are having that in Turkey as well.

AG: That's right. So you've got to make people very water conscious so that's part of environmental education because you're giving them the knowledge as to why they need to be making a change but you're trying to change their attitudes and their behaviour so they do save water, when they do have 3 minute showers rather than 10 minute showers.

FT: We also have some hazards in Turkey because of over-using of water in the croplands.

AG: Yes, and we've got issues around our irrigated areas too, so the focus in environmental education research, and again, because it came out of science, in lots of ways was a very psycho-statistical type of approach to educational research. It's gradually evolved into … you know, case studies are now very common in the environmental education research for the future.

FT: Does it compare with science education shifting from more quantitative to qualitative?

AG: Yes, very similar trends, I think gender as an issue in environmental education actually came later than in science education.

FT: That's surprising.

AG: Yes, it was back in the early 1980s that people were really looking at gender as an issue in science education, whereas it was really in the late 1980s and early 1990s before it crept into environmental education. But I think at the other level there's probably been more critical and poststructuralist research happening in environmental education than you'll see in science education. Just because, once you've made that leap into environmental problems or social problems that a lot of the research methods of the social sciences become much easier to use and much more acceptable in the field. So if you look at the program for the special interest group on ecological and environmental education at the annual meeting of the American Education and Research Association, you might see a rainbow of research methodologies in the papers related to environmental education. But basically the focus is still very much on changing attitudes, changing behaviours as being the focus of environmental education research.

FT: So what is remaining to be done in the future?

AG: Where do you start?

FT: A lot of things?

AG: A lot! It's still a small field compared with science education and there are still lots of strategies that have happened. I think there's increasing awareness of the needs of different societies. There's no 'one-size-fits-all' in environmental education that what works for one social group isn't necessarily going to work with another social group.

FT: In one part of the world it doesn't necessarily …

AG: … translate to another part. No, no. And I think in some ways environmental education is ahead of science education in that way because I think science is still seeking for the one true story as Sandra Harding would say.

FT: So, if you continue in that line, what do you think environmental education researchers have achieved so far and what else is awaiting them in the future? What are they still achieving?

AG: I think one of the things that environmental education researchers have done is increase the profile of multi-disciplinary research in education.

FT: If I go back to my question before - Is it dominated by the environment people or is it still, I mean how you talk about being multi-disciplinary, is it really a multi-disciplinary program or dominated by one group?

AG: I think it is getting to be much more multi-disciplinary. Up until probably 10 years ago if you dug down you'd probably find a science educator at the root of someone who's in environmental education. Now I'm supervising doctoral theses of people coming out of the arts and drama, people who are coming out of geography, you know, people are coming out of different areas into environmental education research. It's not just people coming out of science education and sociologists are getting very involved in environmental education as well because of the social implications of environmental problems. I think one of the other contributions that environmental education research has made, has been to rekindle awareness of the importance of experiential education, For a long time, going back to John Dewey, when experiential education was very important, but then we seem to retreat to the classrooms and I think environmental education has shown the importance of connecting children with nature and giving opportunities for outdoor experiences, whether it's having farm animals in school grounds or having field trips to the local creek, just the whole importance of getting out of the classroom and in touch with the world.

FT: My next question is being far from the rest of the world, how integrated is Australia to the world in the field of science education?

AG: Very connected. I think Australians have played a significant role in science education developments. Most people in science education would know Peter Fensham's name. Peter is really internationally revered in the field and, of course, he's someone who's straddled the science/environmental education nexus too. He has spearheaded movements such as Science for All. He's still very involved with PISA. There are other examples as well, people like Barry Fraser and Ken Tobin have been President of NARST, a North American bastion. So Australia has a very small population, just over 20 million, but we seem to make a big splash in areas where we get engaged, whether it's the sporting field or academia and we've taken a lead in science education in various ways over the years and in environmental education too, I think.

FT: How are environmental problems in Australia similar or different from the other places on earth?

AG: Well, you've already talked about Australia being far from the rest of the world. It depends on how you define far, but the majority of the world's population sits not that far from Australia. We're surrounded by China, India and Indonesia but we do have a unique, natural environment because of a long geographic isolation from the rest of the world. The land bridges to Asia were covered by the sea quite a while ago and so we had some - I don't like very unique, but - unique flora and fauna with our monotremes and marsupials and so on, and insects that probably still haven't even been investigated. Going with that, we also have one of the world's highest rates of extinction of our native flora and fauna because imposed on that very ancient, natural environment, we've got a very rapidly advancing industrialised western civilisation which is just totally in conflict with the sort of land that we've got. A lot of damage has been done over the last 200 odd years through the introduction of cloved and hoofed animals. Sheep do enormous damage to our soils by breaking them up so we've got big erosion problems. We've got big cattle populations through the rural areas and the outback that have done all sorts of damage to our grasses, our shrubs as well as our soil. Then in our cities, and we're one of the world's most urbanised populations, I think something like 90% of our population lives in cities of more than 10,000 people, so it's an incredibly urbanised population down the eastern seaboard with the little pockets over in Western Australia around Perth. But because we are so urbanised, we have enormous air and water pollution problems too, and traffic problems and all those things that go together, so …

FT: Carbon emissions…

AG: Huge carbon emissions, huge smog problems on certain days, so we've got very similar problems but also we've got our own set of problems that go with our unique natural environment.

FT: At this point, when we shift from the problems of environment to the problems of environmental education, how do you see the difference or similarity with the rest of the world?

AG: Environmental education got off to a very early start in Australia. We had our first national conference on education and the environmental crisis in 1970 convened of course by the Australian Academy of Science because at that time it was the scientists that were making the calls, but that early start by the scientists coincided with a change of government in 1972 that brought in our first Labor government in 23 years and that Labor government was very socially aware and the environment was very high on the agenda. Moss Cass was the first Minister for the Environment and as I mentioned earlier, the Curriculum Development Centre that was set up by the Labor government and was given environmental education as one of its priority areas in 1974. So when Peter Fensham represented the Australian government at the UNESCO-UNEP Belgrade workshop in 1975, that formulated the Belgrade Charter which is one of those icon documents of the field, he was able to come back and report that he felt Australia was really out there in terms of how fast we were developing environmental education (Fensham, 1976). When he went to the UNESCO-UNEP Tbilisi Conference two years later, we had had a change of government, back to a Liberal government, and he came back thinking that the rest of the world was fast catching up with us so it's interesting to see what effect a government can have on the advancement of a field. The environment was much higher on the Labor agenda in those days than on the Liberal agenda. But Australia has followed various events like the World Conservation Strategy in 1980 with, in 1983, our National Conservation Strategy which highlighted the importance of education. We had our first national statement on environmental education and in 1980 (Greenall for the Curriculum Development Centre) and our second one in 2005 (Gough & Sharpley for the Department of the Environment and Heritage)- but it's interesting it took 25 years for the second one to appear. So we've had an interesting history and I think sometimes we've been leading the world and sometimes we've been following the world but I think, in most cases, we've been keeping pace with the world. I think one of our problems at the moment is that the environmental education agenda is being pushed by the environment ministry not by the education ministry…

FT: So you have a different environment ministry?

AG: Yes, yes

FT: Federal government or?

AG: Federal government and State level. Education is a state responsibility, but environmental education seems to be mainly the responsibility of Sustainability Victoria at the state level. Nationally, environmental education has always been pushed by the environment ministry (Department of the Environment, Water, Hertiage and the Arts at present) whereas education is with employment education and work relations and environmental education has no profile there. At the moment you've got to keep remembering what the associations are but …

FT: In Turkey, it's the Minister of Environment and Forests.

AG: Ok, in Victoria, it's the Department of Sustainability and Environment and the State Department is Education and Early Childhood Development so they're very different agendas. So the United Nations Decade of Education for Sustainable Development agenda is being totally pushed through the environment agencies not the education agencies.

FT: Ok. How is the importance of environmental education recognised in Australia and elsewhere? You probably answered it already.

AG: Yes I have answered it to a certain extent. I think the most prominent event for environmental education is probably the US Environmental Education Act but that sort of gave a beacon for other people to follow - and not many others have unfortunately.

FT: I think the US has lost that interest.

AG: Oh hopeless, yes, totally, and in fact that Act only lasted five years and it's never really been particularly renewed.

FT: Their reluctance with the Kyoto Protocol?

AG: Yes, yes exactly and as Ronald Reagan's saying "if you've seen one tree, you've seen them all" didn't do much for the environment movement. At the moment we've got the Decade on Education for Sustainable Development which provides prominence at the international level but behind that there's very little happening if you go country by country. Certainly in Australia that would be probably less than 1,000 people would even know that we are in a Decade of Education for Sustainable Development (ESD).

FT: I didn't know either.

AG: No, so it would be interesting to have a look and see what the US and Turkey are doing. In Australia I mentioned that CDC was given environmental education as a brief in 1974. In 1975 we had an Australian National Commission for UNESCO seminar on Education in the Human Environment (Linke, 1977). In the late 1980s the Curriculum Development Centre had a range of projects in environmental education. In 1988 for our bi-centenary, environmental education was one of the themes that was promoted in schools there. In the early 1990s, in the early days of the previous National Curriculum, environmental education was to be a stabilised area but then it was included within the studies of society and environment which was a humanities social science type subject but included history, geography, economics and all sorts of multicultural education, global studies, aboriginal studies, legal studies and environmental education. So it was lumped into that and then, in 2005, as a part of the beginnings of the Decade, the government, through the Curriculum Corporation, released their national statement on environmental education for schools so that was the beginning of what we were hoping was going to be a new movement for environmental education from the federal level, but there was nothing to follow it at all and now we've had another change of government. It's sort of hard to know where environmental education is sitting at the moment. I think that is probably the same, it's hard to generalise to the rest of the world and the countries I'm most familiar with are the US and England and Canada and I think we've got lots of similarities with those. I think we're a lot stronger than Canada and the US. England has had a lot of activity around education for sustainability but I'm not sure that much of it is filtered down. There's lots of documents on websites and there's been lots of meetings but if you look at the penetration into the schools, there seems to be very little at all.

FT: What have you achieved personally in the field and what else do you expect to do in the future because I know you have moved to a more administrative position right now, you are the Head of the School of Education at RMIT, but I also know that you are still active in your research and publishing and attending conferences and that sort of thing? So being still active, what are you still interested in and what do you expect to do in the future?

AG: In terms of achievement, yes you're right, it has been a life long career for me, dating back to 1974 which was only my second year out of undergraduate studies at university, so it is a long time. I'm sort of unofficially recognised as probably the "mother" of the field in environmental education in Australia which is sort of nice, and I've got a lifetime fellow award from the Australian Association for Environmental Education from 1992 that recognises that contribution. I was the first female president of the Gould League in its 90 year history, and I think I'm still the only female president, so that was a nice honour and I've certainly pioneered for feminist research in environmental education and been a strong advocate of socially critical environmental education work and I've written both national statements for environmental education - on my own in 1980 and with my colleague, Brian Sharpley, in 2005. It is quite a long period of involvement. For the future I think I would like to continue to push for environmental education as part of the education agenda rather than the environment agenda. Good environmental education is really just good education. If we encourage our children and students in schools and in universities to be good critical thinkers, to be concerned with problem-solving, to think about their actions then we're really just educating good citizens. So I think that's where I would like to continue working. I'm still involved in Australian Research Council grant projects in the area too.

FT: When it comes to environmental education, it is not the citizens of a specific country but the citizens of the world. You should rather regard it that way.

AG: Yes, that's right, in fact a project that I'm involved in at the moment is an Australian Research Council funded project on global connections which is focused on connecting students in schools in Melbourne with students in schools in Indonesia to try and develop some international understanding that has an environmental component to it. I would certainly like to do more work in that area. I've had fantastic experiences working in South Africa on an AusAID research project for capacity building in environmental education and I'd certainly like to continue working in that area too. But it is hard to find the hours in the week when I'm a full-time administrator as well.

FT: My last question will be – what suggestions do you have for future researchers?

AG: There's a huge amount of resistance to environmental education within the formal education area because it's seen as just another thing to be fitted into the curriculum rather than them seeing it, as I wrote back in 1980 – an orientation in the curriculum. I mean I think everything can feed into environmental education. It can be an umbrella, it doesn't have to be another hour or two hours a week to be fitted into the curriculum. It's more a world view, a way of approaching the world that needs to infiltrate everything that we do in the curriculum. At the moment we have such a capitalist market driven philosophy that underpins everything that we do and we don't even consciously engage with it and I think we have to engage with that and replace it with a more ecologically friendly way of approaching the world and that's the revolution I would like to see.

FT: So, as I understand, you don't want to see environmental education under a different umbrella but you would like to see environmental education as an umbrella for a lot of fields.

AG: Yes, yes, as a way of life.

FT: Ok, all right. Thank you very much for this conversation.

AG: Thank you

FT: I hope this will be useful for the other colleagues around the world and thank you very much.

AG: I look forward to maintaining contact.

FT: Thank you

AG: Bye

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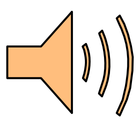

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Expanding the field of science education: A conversation with Ken Tobin

Christina Siry
University of Luxembourg, Walferdange, LUXEMBOURG

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This paper focuses on a conversation with Dr. Kenneth Tobin, which took place in June 2009 at The Graduate Center of the City University of New York (CUNY), where he is Presidential Professor in the Urban Education Program. Our purpose was to focus on Ken's career in science education, and to discuss the past, present, and future of his research interests. During our conversation, we explored the various trajectories of his career, focusing on the ways in which his research has evolved through the years. Further, Ken shared his thoughts on the field of science education, and provided salient advice for early career scholars. This manuscript includes an introductory summary of Ken's career achievements to this point, a record of our conversation (the audio-recording can be downloaded at the journal's website) and a list of selected publications that highlight Ken's key works.

Keywords: Science Education, Teacher Education, Urban Education, Theoretical Frameworks, Research Methods

INTRODUCTION

This paper focuses on a conversation with Dr. Kenneth Tobin (hereafter Ken), which took place in June 2009 at The Graduate Center of the City University of New York (CUNY), where he is Presidential Professor in the Urban Education Program. Our purpose was to focus on Ken's career in science education, and to discuss the past, present, and future of his research interests. During our conversation, we explored the various trajectories of his career, focusing on the ways in which his research has evolved through the years. Further, Ken shared his thoughts on the field of science education, and provided salient advice for early career scholars. This manuscript includes an introductory summary of Ken's career achievements to this point, a record of our conversation (the audio-recording can be downloaded at the journal's website) and a list of selected publications that highlight Ken's key works.

Correspondence to: Christina Siry,
Faculty of Humanities, Arts and Educational Sciences, Unit for Sociocultural Research on Learning and Development - LCMI (Language, Culture, Media and Identities), University of Luxembourg,
Route de Diekirch, L-7220 Walferdange, LUXEMBOURG
E-mail: *chrissiry@gmail.com*

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FOREWORD – about Kenneth Tobin

Dr. Kenneth Tobin is a key figure in science education, and his research has had a significant impact on the field. In this section, I provide a brief biographical summary to highlight key accomplishments and to emphasize the multiplicity of his contributions. This is by no means an exhaustive summary of his career. Rather, I have chosen to highlight central components that provide evidence of the diversity of his endeavors, as well as the evolution of his research, teaching, and professional commitments.

Ken began his career as a science teacher in Australia, and earned his doctorate in Science Education at the University of Georgia in 1980. After receiving his doctorate, Ken returned to Western Australia, and was a science educator in two Australian universities (now known as Edith Cowan and Curtin) until he relocated with his family to Florida to a position as professor of science education at Florida State University. He held this position from 1989 until 1997, after which he

Figure 1. Ken Tobin teaching while researching in an urban high school

transitioned to a position as professor at the University of Pennsylvania, from 1997 until 2003, where he served as Director of Teacher Education for the first three of these years. In fall 2003 Ken accepted a position as Presidential Professor in the Urban Education Program at The Graduate Center, City University of New York, a position he has now held for six years. He also has been an Honorary Adjunct Professor at Curtin University in Australia, and as such, he has supervised beginning researchers as they complete their doctoral theses.

Ken's publications number more than 700, and selected works are included in the appendix of this paper. He has, to date, 330 refereed publications, as well as 379 non-refereed publications. Among his books are two that have received the American Library Association (ALA) Choice Award for Outstanding Academic Titles. This prestigious award was granted in 2002 for the book At the elbow of another: Learning to teach through coteaching, which he coauthored with Wolff-Michael Roth, and in 2006, the book Improving urban science education: New roles for teachers, students and researchers, edited with Rowhea Elmesky and Gale Seiler received the Choice Award as well.

He is the founding editor of five book series, including the founding co-editor, with Joe Kincheloe, of Bold Visions in Educational Research, which is published in the Netherlands by Sense Publishers. At present Ken edits two book series with Springer and two with Sense. Also, he is Editor-in-Chief of a journal he co-founded—Cultural Studies of Science Education.

Throughout his career, Ken has been actively involved in professional organizations, including the American Association for the Advancement of Science (AAAS), American Educational Research Association (AERA), National Association for Research in Science Teaching (NARST), National Science Teachers Association (NSTA), and the Association for Science Teacher Educators (ASTE). His service to these organizations includes being past President of NARST and having served, and continuing to serve, on various committees.

Ken has been awarded numerous awards to recognize his scholarship over the years, including multiple best paper awards from organizations including AERA and NARST. Of particular note is his 1987 article published with Jim Gallagher in the Journal of Research in Science Teaching (JRST), The role of target students in the science classroom which was recently selected as one of the 13 most influential articles published in the Journal of Research in Science Teaching.

His professional contributions include having been appointed to eleven journal editorial boards, of which he now serves on five, including International Journal of

Science & Mathematics Education, Educational Researcher, Journal of Teacher Education, Research in Science Education, and Research in Science & Technological Education. Further professional distinctions and contributions include participating as a Fellow of American Association for the Advancement of Science (FAAAS) from 1999 until today, and multiple distinguished appointments internationally including most recently as visiting professor in the Departament de Didàctica de la Matemàtica i de les Ciències Experimentals, Universitat Autònoma de Barcelona, in Spain, where he collaborated with Mariona Espinet on sociocultural theory in science education and science teacher education. His substantial support of graduate students includes having successfully guided 42 students through their dissertations, myself included, and having many more students in the process of completion at The Graduate Center, CUNY, as well as Curtin University. His seemingly never-ending guidance to early-, as well as mid-, career scholars has earned him two Mentoring Awards, one in 2007 from ASTE, and one in 2008 from Division G: Social Contexts in Education Research, American Educational Research Association.

Ken has received numerous grants through the years focusing on improving teaching and learning, including his most recent NSF grant received while at The Graduate Center, titled "Use of Research to Improve the Quality of Science Education in Urban High Schools." The purpose of this grant was to expand classroom research in science and mathematics classes in New York City, especially those in which teachers and urban youth undertook research on the teaching and learning that occurred in their own classrooms. Ken has several current research projects underway, which are in part the focus of the conversation that serves as the focal point of this paper, and is introduced in the next section.

INTRODUCTION – about the interview

Kenneth Tobin and I both attended the 2009 National Association for Research in Science Teaching conference in Garden Grove, California. At this conference, Mehmet Fatih Tasar, the associate editor of the Eurasia Journal of Mathematics, Science & Technology Education asked Ken to consider being interviewed for the Conversation / Interview series of the journal. Shortly thereafter, Ken asked me to engage in this conversation with him, and I readily accepted. I found the invitation to interview him exciting, as this would provide a relevant way to engage readers, especially early-career researchers, into considering the variety of possibilities and directions that can emerge through a career that spans several decades. Further, the interview would provide me a chance to highlight one of the things that has always struck me about him, his continually evolving theoretical and methodological perspectives. Ken facilitates several research squads at The Graduate Center, in which I have been fortunate to participate through the last several years. Through collaboration and a vertical alignment structure, he manages to create a forum for researchers to support, and learn from, each other. It is through these squads that I have learned to embrace the importance of seeking polysemic perspectives on science teaching and learning, and I expected that an opportunity to interview Ken would provide further examples of the development of this focus in his work with beginning researchers, and that this would in turn be extremely relevant for others in the field to consider in relation to their own work.

During our conversation, the focus for discussion included several strands of his trajectory as a researcher. The following points served to organize our conversation, and provide a biographical narrative of Ken's career and accomplishments to today:

- His early career in Australia and the use of quantitative approaches in research,
- The beginnings of ethnography in his work in science education, as well as his focus on radical constructivism,
- The sociocultural turn in his research and focus on collaborative classroom research.

In considering the overarching theme of Ken's contributions to science education, we discussed, among other things, the role of research squads and vertical alignment and the importance of polysemicity and polyvocality in teaching, researching, and writing. We spoke about how his perspectives have changed over time and with experience, as well as how those perspectives have changed the field of science education. Our conversation ended with his advice for early career scholars, science educators and students. The section that follows is a record of our conversation. We have chosen to retain the format of an interview, so that a reader can have a sense of the ways in which our conversation unfolded.

THE CONVERSATION

Beginning a Career in Science Education

Chris: You began your career in Australia in the late seventies, and your research perspectives have changed significantly since then. Can you speak a bit about how you began your career, and what was the field like?

Ken: At the time, I was particularly taken with the research that was going on in inquiry and problem solving, and we were coming through the era of big curriculum development in the United States.

Australians were coming to the US to do their Ph.D.s, and I heard about this research on wait time and I just thought it was fantastic. It was a series of studies that were looking at the way that classrooms change as a result of teachers pausing for longer periods of time and I figured that if that was the case, probably achievement was going up as well. So my initial studies looked at the relationship between teachers extending their wait time and students achieving at a higher level.

Chris: So when you think about that, and your move to the States then, one of the things that you have mentioned to me that I think is really interesting is how from there you then went into ethnographic work. Which, from my understanding of what was happening at that time, was new in educational research.

Ken: Right. I came to the states to do my doctoral degree around 1978 and came into a bastion of positivist thinking at the University of Georgia. They were neo-behaviorists, and I was more or less required to be that way. My interest has always been in teaching and learning and how to better teach science, so I was focused not just on learning, but also on teaching. In a way, that was a bit unusual in science education at the time. I think the focus had largely been on learning, and probably because of this emphasis on curriculum and "teacher-proofing" the curriculum, I think they were more inclined to have the teachers do scripts and then to produce learning through curriculum work. So the behaviorist way of thinking about it fueled into that a bit. I did some work on teacher assessment at that time which was another way to hold teachers accountable and control what teachers were doing.

The thing that was really of interest to me was how we can work with teacher models of sorts and have teachers teach more in an inquiry mode, and it really struck me that it was hard to get from the model to the teaching. We would use strategy analysis and video analysis and things like that, but there was always this gap between what was in the teacher's head and what the teacher would do. So that was issue number one. Issue number two was that in order to do the kind of research that we needed to do, which was quasi-experimental, you needed to control a lot of things. I spent a lot of time at the University of Georgia designing lessons plans; sequences of lessons that teachers would be able to use to produce process skill learning, concept learning, inquiry, things like that. At one point, I was giving a talk out at the University of Texas and there was this researcher called Walter Doyle in the audience, and he asked me a question that was like this: he said, "Ken, this is all well and good. I understand how wait time works. What I'm really interested in though is what the teachers do when they are not teaching your lessons." I thought that was a fairly interesting question as well, and that started the process.

On the trip back to Australia from Texas, I was sitting with a fellow called Rob Baker, an ethnographer that had worked with Harry Wolcott, and we argued a lot about what ethnography could look like. By the time we got back to Australia, I had decided that I would run an ethnography back in Australia on the teaching and learning of science that basically would be called "What's happening in High School Science?" So it was very similar to Doyle's query of me. Jim Gallagher came from Michigan State to work with me on this study in Perth, and we worked in an inner-city school (to the extent that they have those) in Perth. It was a school that was really starting to go "downhill" in the sense that the kids were from conditions of relative poverty and unsettled homes, and we started to get a glimpse of what we were going to see later in urban education. That was our first ethnography, and it was a transition from doing quasi-experimental designs to doing ethnography. We had way too many teachers involved and things like that, but it was intensive and we did learn a lot.

Chris: How do you think that was received initially in the field? That was very innovative, wasn't it, at the time?

Ken: There had already been ethnographies published in science education. As a matter of fact, the first ethnography that had been done was done by Barbara Spector, but that didn't show up in my literature reviews. Also, other people like Tom Russell from Canada were doing ethnography, but that didn't show up either. When Jim Gallagher and I submitted our work for publication, Russell Yeany was the editor of the Journal of Research in Science Teaching, fortunately I suppose, and he accepted the work, which ended up winning an award (it was our research on target students). So, oddly enough, it was well received in the literature, although at the time we didn't expect it would be. At NARST it was less well received; it tended to divide the community into qualitative and quantitative. Gallagher and I did some things at NARST to spread the growth of the community and I suppose that drew attention to what we were doing. This was also tied up with another move that I was associated with, and that was radical constructivism.

The move to ethnography was really grounded in dissatisfaction with answering important questions in science education and the inadequacy of behaviorism and positivism as frameworks for thinking of that. So, there were two "against the tide" trends that I got associated with, one being the move away from positivism toward constructivism, and the other was what people would describe as a move towards qualitative research. However, we saw it as interpretive and the award winning paper was both qualitative and quantitative, so I never saw myself as moving towards qualitative as much as moving toward interpretive, which is a theoretical shift.

I think ethnography, when I initially came to it, was a way to look at big questions without this reductionism of variables and things like that. As we went along, issues of methodology (theory of method) became more important. So, we began to question whether the theory of our method was consistent with the theory being used to make sense of teaching and learning, for example, and usually the answer to that was no. So, that was one driver for change. Initially we started to use the model for ethnography that was informed by Guba and Lincoln, because they adopted a radical constructivist view of life. Ontologically, they were dealing with a situation where there was no reality. Virtually, that's what they were saying. So, from a methodological point of view, that had real implications for this idea of triangulation, for example; that you could get different data sources, and the reason to do that was to converge; to triangulate on "social truths" and then the contradictions were errors that had to be understood. With Guba and Lincoln, they had the idea that the contradictions had to be resolved through negotiation and consensus building, which is the old Piagetian model. Once we made that move toward using the authenticity criteria it becomes a slippery slope and we started to then really challenge this idea of, how do you deal with difference? Within my research group we started to look at retaining the differences rather than focusing on the convergences or the patterns of coherence. Then, people like William Sewell and his view of culture became a primary part of our methodology, where instead of looking for thick coherence and explaining away contradictions, we were looking for patterns that had thin coherence and always searching for contradictions. What that does is give you a different set of outcomes from research. We also realized that the outcomes from doing research couldn't just be theoretical. There were always two parts, one was the production of change and improvement, and the other was the production of theory.

Evolving theoretical perspectives

Chris: So then from there, from radical constructivism and your emerging theories, how then did the turn towards sociocultural research in your work right now in urban classrooms come about? What are some ways that you shifted from radical constructivism in that direction?

Ken: I think that radical constructivism was associated very much with Ernst von Glasersfeld, who was an intellectual tower of thinking. He did wonderful theoretical work that was post-Piagetian. What was radical about radical constructivism was that the knowledge didn't exist anywhere outside of a cognizing being, so it was embodied. Now this necessarily brings the focus onto the individual. So, very early on one of the criticisms of Ernst's work was that, just as it was with Piaget, the focus was on the individual learner and didn't say much about the social processes. I was close with Ernst and we would talk about this, and his response was always a bit glib. He would say, "it's constructed, the social is constructed, it's all the mind of the learner" which is solipsistic; it's all inside, nothing is outside. So there are various ways to get around that as an issue. Von Glasersfeld would always say that Piaget was never individualistic; he wrote a whole book on the social. Of course Piaget probably wrote 20 to 30 books, and one was on the social. But Ernst would point out, how many people wrote a book on the social aspects of learning? Piaget wrote one, so you can't say he ignored it. And yet, for me, classrooms are radically social. Just as we couldn't claim independence of learners in statistical research, we couldn't say one learner is independent of another because any teacher knows that's not the case. You couldn't do that either in ethnography because we were looking at the way that individuals work together to produce learning, and yet our theories of learning were not social.

So I started to look at social constructivism, and the work I did with Deborah Tippins was about social constructivism. We got very interested in metaphors and the ways they were used to organize knowledge within individuals, and the way they could be taught. We did several studies on the metaphors teachers used to construct teaching and the way you could change teaching by teaching them new metaphors, or they could change their teaching by constructing new metaphors. Power started to be an issue. It's always an issue, but some of the work I did with Sarah Ulerick and her struggles to get on top of middle school teaching down in Florida taught us that what we needed to do was to think a lot about power relationships and how they might be embodied or structured by metaphors. That led us to different researchers, and Jacques Desautels, a researcher in Quebec, reminded me of the work of Pierre Bourdieu. In particular, he reminded me of the work of Bourdieu and symbolic violence. We were thinking of symbolic violence in relation to why kids would become emotionally down in a classroom. We were starting to look at science as a form of symbolic violence because repeated failure, even though it was not intended that they would fail, students would receive this failure, and give meaning to the failure in terms of unintended violence. That really got me into the work of Bourdieu, and I became an eclectic social scientist of sorts. It really bothered me that I would find out what some people were doing, but I didn't know systematically about the field of sociology or cultural anthropology. At Florida I was sending my doctoral students to take courses in the sociology PhD program, and I realized that the sociology of knowledge was an important place to be and that they were learning about people like Erving Goffman. So my doctoral students were starting to get a good background in sociology and in cultural anthropology, and at that stage I got to know a new researcher, Wolff-Michael Roth, who had just come into the field. He struck me as incredibly bright and well read in the realm of Piaget and within philosophy. So Michael's trajectory and my trajectory sort of came together, and in a way we worked together to move into sociocultural models.

Chris: So when you went from Florida State to the University of Pennsylvania, is that when your focus on urban teaching and learning really solidified when you were in Philadelphia?

Ken: Not really. It started a little bit before that because the state of Florida has Miami in it. It's a long way from Tallahassee where I was, but I got a big grant to work with teachers in Miami and it was part of a feeling that I needed to do more than just mainstream work that led me to do this. I was working with Alejandro Gallard who we had hired, one of Gallagher's students. As a Hispanic male, Gallard was constantly speaking to me about the necessity for people like me and Jay Lemke to do work with minorities. Otherwise, he was afraid, the minorities were not getting any attention. So it was kind of constant nagging from Alejandro that made this important in my mind. We had one of the biggest metropolitan areas in the United States in Miami. Certainly, with all of the immigration coming in, it was going to be a big issue. So we created a huge cohort of teacher researchers who were looking at what was going on in their elementary and middle school classes and they did a whole degree with us.

At the University of Pennsylvania there were two key thrusts in education—urban and international. I was interested in both and it took a year or so before I really focused on urban education in the US. Since about 1998 my key focus has been on urban schools, especially in Philadelphia and New York.

Sustaining research squads

Chris: That's interesting. So, one of the things that you were just talking about was that when you were in Miami you worked with groups of teachers conducting action research in their own classrooms. Is that where you developed the focus, on maintaining research squads and having that be a part of the work that you do?

Ken: No, it actually began long before that. I think it really began through my work in physics. When I was studying in physics, the tradition is to have research squads, and I was becoming affiliated with a mass spectrometry group that was working on astrophysics. So I understood the idea that you did a certain amount of course work toward a masters and then the coursework stopped and you attached yourself to a research team. You continued to get credit for courses, but what you did was to actually turn up for work, and do research that ultimately got submitted for publication. That was the way that graduate education was organized in Australia, where coursework was seen as rather a lesser kind of an entity and in the sciences (especially in physics). Groups, or squads, were pretty much the way things were organized.

When I did the ethnography with Gallagher, it was a group effort that wasn't only Gallagher and myself. Pam Garnett worked on that particular study, and before we finished that study, Barry Fraser and I organized a very large study that involved a group of 12 or more researchers. It was an ethnography that looked at exemplary teaching of mathematics and science. That was the first book I wrote too; a little homegrown book out of Curtin University that consisted of these ethnographic pieces, and it was the embryonic structure for squad work. We would meet regularly but not often, and talk about what we were doing, why we were doing it, what we were learning, and Gallagher and I met every day. Then, before I came to the University of Georgia on a Fulbright award, we started a study down in Perth that led to a book "Windows into Science Classrooms" that also had a research team. Jane Butler Kahle was involved in that, and Robin White, who now is a principal of a high school "down under." That was a big team study; I think there were seven researchers involved, and we studied two teachers and wrote the book Windows into Science Classrooms. At the same time that I went to Georgia in 1984, we set up a study with a squad that had all people that were not senior, like Hsiao-Lin Tuan and Chao-Ti Hsiung from Taiwan, Mariona Espinet from Spain, Antonio Bettencourt from Portugal, Elisabeth Swanson (Montana State University) and Linda Cronin Jones (University of Florida). So by the time I came to Florida State I had already done maybe three or four studies and we were starting to learn not to do research on teaching. What taught me that was Windows into Science Classrooms, where one of the teachers that we did research on - so many researchers, so few teachers - I think was harmed by the research. In a lot of ways I don't think that study was quite fair, even though we did the study as best we knew how to do it at the time.

Our research evolved on an ethical plane. I think we looked at power relationships, so that by the time we got to the Sarah Ulerick study, which was at Florida State University, it was a team approach again, and that study was very much framed by Sarah. "Why can't Sarah do what she wants to do" was the research focus, a very broad focus, and we met several times a week, if not every day. It was an emotional roller coaster because she was very upset at what she was having to go through.

That was when we were learning that good teaching didn't necessarily transfer in any ontological sense from one field to another; it needed to be reproduced every single time.

Chris: You know Ken, when I think about your leadership in forming and maintaining research squads, I think about how being able to participate in the NY squad has been so important for me and my own development as a researcher. You've talked already about some of the perspectives on ethical issues that have evolved through participating in squads, are there other ways that your involvement in these many squads through the years has shifted your trajectory, or has helped your growth as a researcher.

Ken: That's really a good question. The idea of being a mentor is something that basically I reject. It might sound a bit heretical, but I think that if you are alive; you are learning. It's an epistemological issue - what's going to count as learning? Every single activity we get involved in is an opportunity to learn, both agentically and passively, by being with the other. So, your good questions today are helping me to learn, even though I may not have come to this conversation as a learner necessarily, but I like to think that I come to every conversation as a learner.

I think I have learned an enormous amount in my squads even though I don't necessarily come with the intention of learning something, and I might not even enjoy the process of learning something new, because often times learning something new necessitates changes in direction when you were perfectly happy with the way you were going. A couple of quick examples; I think that I learned a whole lot about emotions in working with Sarah Ulerick. Sarah was so emotional, and she was such a creative person that you could see when she was thinking - she would turn her eyes up to the left and you could see she was actually taking time out to think. She taught me a lot about (a) emotion, and (b) using metaphors, and she was a great conceptualizer in lots of ways. I think working very closely with doctoral students, I'm thinking right now at the University of Pennsylvania, was fascinating. Gale Seiler was always taking the view of the underdog[1], she always saw herself more closely attuned with the agendas of the urban youth than the agenda of me as the struggling teacher who was trying to make it work. I resented it at times, with her coteaching with me I never felt that she had my back[2], and I felt continuously that she may have had the back of the students. Sometimes I felt, oh gosh, it's like a conspiracy in here. That was just the way I was framing it, and years later, I can look back and learn a lot from that experience. Looking at the tapes that Gale was responsible for producing, it is clear that she had really good insights.

Also, the Pennsylvania group, because they were taking coursework with some really powerful people, opened up my eyes to the whole realm of cultural sociology. I found my own way to Diana Crane at the University of Pennsylvania, and sent a lot of the graduate students to work with her, because I wanted to rigorously become a sociologist by working with her. She then started to send students to me because she knew I was at the Graduate School of Education doing research in schools, and so I got to work with some very good people like Regina Smardon, who was doing a PhD in sociology. Regina came to work on my research squad and she had been working with Randall Collins, and that enabled me to learn about Collins' work. I came across William Sewell's work through Aiden Downey who was a doctoral student of mine at the time, and he recommended that I should read William Sewell's 1992 paper on agency and structure. It was a paper that Diana had assigned and I had not yet read it--Aiden said "I think you should read this." It was impossible to read all of the assigned readings, and we saw things in that paper that Diana never saw and as you know, it became very important to our work in science education. I think Randall Collins' work opened up the whole area of the sociology of emotions, and having sociologists working with us like Stacey Olitsky, another person who was both a sociologist and an educator, provided incredibly important insights. When Rowhea Elmesky came to work with us, I saw a different side of being Muslim, and I saw the salience of being Muslim, and female, and young. So these things became important social categories. I don't think I would have learned so much if I hadn't been working with those people in squads.

Incorporating multiple perspectives

Chris: So you made mention of coteaching with Gale as part of your research. I think that is something we haven't talked about yet, your teaching and research trajectory towards coteaching and cogenerative dialogue. Maybe you want to talk about that for a few minutes? I think is important to think of the polysemicity that we've been touching on.

Ken: I think doing research *on* became ethically problematic in the way that I talked about. So, what is the alternative? Doing research *with*. And so doing research with is one avenue, and auto-ethnography is the other. I became very convinced that doing research with was not going to be nearly as powerful as if I was also teaching, and so setting up my teaching in Philadelphia was an important thing to do. At exactly the same time that I was negotiating to teach a class at

1 *a euphemism for disadvantaged, usually oppressed by mainstream culture*

2 *an expression that means the person would support me if I encountered difficulties*

City High, we were developing coteaching as a model for learning to teach in urban high schools. It was a survival model as much as anything because there was too much going on for one teacher to be successful. So we developed coteaching; Michael Roth was working with me because he was simultaneously developing coteaching in Canada and he and I were working it out theoretically and practically.

When I negotiated my entry into the school, I did so with the suggestion that we should coteach. Legally that was an important thing too, because it allowed me to teach without having Pennsylvania certification. And so, what I did when I went in was coteaching; the focus though was on my teaching and it wasn't until I became quite unsuccessful that it became clear that I was no different from anybody else. If I was going to survive I was going to need coteachers so that we could all learn how to do this together. So when Roth and I wrote our book, Teaching at the Elbow of Another, one of the chapters we had in there was coteaching as research methodology, and another was coteaching as an evaluation methodology. We wanted to apply coteaching to both these very important activities that happen in science education. That allowed me to focus more on my own teaching while having other teachers (a) to learn from and (b) to support me as we floundered around. Then it meant that when we sat down to talk about what we learned, it was not just my voice but there was also a coteacher's voice, there were student voices, there was Roth's voice, and these voices differed from one another, thereby requiring us to figure out, what the heck are we doing? Are we doing research that converges on a truth, or on a pattern of coherence like Geertz would have us think about it, that is a thick coherence, or are we doing something different? I think that is where Sewell's theoretical framework really was the answer to a question that we had already. I had been saying for a long time that what they called residual, or error, variance in statistical research was where we needed to be focusing and figuring out what's going on in there. And to us we just needed a term for it and a way of organizing it. That is, the contradictions. These contradictions are the different robust perspectives that later on we would come to think about in terms of polysemia, meaning the different perspectives that people had, not as sources of error, or that some are right and some are wrong. These are just different ways of expressing life through different theoretical frameworks often. We wanted to argue that these differences reflected distinctive life trajectories and placements in social space.

Chris: So that brings me around then to thinking about the journal that you are the editor of, Cultural Studies of Science Education (CSSE), and how it is structured to provide a way to engage the authors, the reviewers, as well as the readers, in an open conversation around what is being written, and also provides a forum for other scholars to respond to the work that you are publishing. I think of that and I wonder how an innovation in a journal like that has changed the conversation in the field, what sorts of feedback you've gotten from people, and also what brought you to that point.

Ken: I think an increasing frustration was with where the journals were going. There are roughly seven journals in science education, not counting CSSE, and pretty much all of them were doing the same thing, and most scholars in the field knew the ranking list, the pecking order. Although it changes from time to time, basically the pecking order was the Journal of Research in Science Teaching (JRST), Science Education, the International Journal of Science Education, and Research in Science Education. They were the top four, and then there were others that some people knew about and others didn't. But the basic proposition was that you sent your paper to JRST and it got rejected. You took account of what the reviewers said, tickled up the paper and sent it either to JRST again, or you sent it to Science Education, where it got rejected again. Then, you worked it over a bit more until ultimately it got accepted somewhere. Some of our papers, because they were sociocultural, rather than slam-dunk positivism, were rejected numerous times. Some of the papers that got published in JRST went the whole cycle and ended up back at JRST and then got accepted. Now, this was very frustrating, and usually, it reflected differences in ontological and epistemological stance taking, difference in methodology, which was theoretically grounded of course, different in using sociocultural theory to conceptualize research on learning, for example, versus psychological reasoning. So, it was very safe for scholars like my good friend David Treagust to publish in any and all of the seven journals because basically he was willing to use mainstream methods and arguments and to work within educational psychology. For us (in the us I include me and my students and my colleagues like Wolff-Michael) it was sometimes unpleasant to get the reviewers' comments, because they didn't just say no, they were sometimes socially violent in what they wrote.

We were looking for a different way of treating colleagues. We felt that blind-review was a flaw; it was associated with positivism and the necessity to have some sort of ontological, authentic, one-truth world. There was one way of looking at the world and peer review was the way to maintain this way of thinking about knowledge. It was the old Newtonian way of thinking about the academy. We rejected that; we thought a more honest and ethically sound system was to have non-blind review, and have at least part of the peer review process public. We were struck by Bakhtin's ideas of dialogue and conversations. We decided we would have a peer review system that was more open, and have a forum associated with papers that were published in the journal, and the forum would always be published in conjunction with the papers. Now, how has it worked? I think the jury is out. I would say that it has been a struggle. Initially it wasn't a struggle, but it has become more of a struggle because people learn how to appropriate opportunity for their own purposes. Sometimes these purposes are hegemonic. Dealing with hegemony of superstars has been an issue where some people feel a need to publish every thought they've ever had and get it out there and to reiterate that thought over and over. This has really forced some changes, especially in the Forum where I have found that rights of reply have often been abused. Instead of opening up the conversation, rights of reply have been used to reiterate a stance, to try to convince others of your point of view

Chris: Oh, by the original author?

Ken: By the original author. I think it has been an opportunity to indoctrinate people to a point of view. That has been something of concern to me. I've been concerned too in trying to create a quick turn-around review and that's hard to do. It's easy when just two people do the reviewing, but old habits, habitus, are hard to change. So a lot of the recent additions to our editorial board are well-schooled in the old way of thinking about it. Sitting on a manuscript for three months is no problem for some people, whereas we've been trying to have two days of turn around. We've wanted the turn around to be part of this dialogue, rather than review and evaluation. So, the decision for the editors or in this case, now, since I'm the sole editor, the editor, to make the accept / reject decision, has been slow. I want the reviewers to see themselves as more in a conversation and yet they still see themselves as more of a judge and jury kind of situation. I think the long-term health of the journal and the sociocultural movement is going to be seen in the extent to which it is successful in addressing some of the really big macro structures that I've been writing about just recently. I think it is going to be important in the next two to three years to see whether we can go from a community of about 200 to a community of about 1500, and probably that is going to be the critical mass that will decide whether we continue or don't. Largely, and I hate to put it this way, but the tussle between ed psych and sociocultural views of knowledge, is going to be very important, because it is associated with a reductionist view. Educational psychology doesn't have to be this way, but it tends to be quite reductionist and is getting smaller and smaller, right down to the neuronal level, and also in doing work in terms of variables and models, this is reductionist too. So there is a reductionist way of looking at learning within individuals, and a reductionist way of doing statistics, and I think both of those are counter to the kinds of trends that we are trying to understand looking at social organizations, and looking at learning as cultural production. We'll see how it works; as always, those who want to be bricoleurs and have a bricolage are a little bit susceptible to the power of those that think there is only one way, and a right way, because you get marginalized, and sometimes we marginalize ourselves.

Moving forward

Chris: I think the one thing we really haven't spoken about also, in terms of your trajectory, is your work in New York. What do you see as the next steps of your work now? What are you working on, or thinking about, right now?

Ken: In New York, the exciting thing that happened was to come to an urban education program with a whole lot of teachers. It's like passing on to heaven or something like that. So, our squads became large in number, and we had teacher researchers who have gone on to get jobs in New York, and hopefully they will have their own squads. That part hasn't worked as well as I had hoped, but it is starting to work now, where we have individuals throughout the university system in NY each with their own research squads. Probably it's worked best at NYU where Cath Milne has her own squad and is getting her own research grants. She's working from a sociocultural model that in some ways has appropriated tools from educational psychology and statistical analysis, and Sue Kirch has also gone there too, so we have those two individuals who have started up squads. Chris Emdin, up at Teacher's College, is continuing to do his thing focusing on hip-hop and sociocultural theory and I think there are others up at Teacher's College who are starting to produce squads as well.

In the CUNY campuses there is a large group of researchers now, and we have the potential to do that. For me, as just one of those satellites now in the larger scheme of things, what I would like to do is to take on a large-scale dissemination project working with the New York City Department of Education to try to look at the transformative potential of the work that we have done on cogenerative dialogue, paying attention to the things that we know about emotions and the production of identity that is science-related, but to cast aside the neoliberal agenda. So if I can take on the neoliberal agenda, and have a system that allows students to learn science that is not so much focused on producing new forms of workers, I would much rather see the science that is focused on sustainability issues, such as the sustainability of human life in a dignified form, the sustainability of the planet, and things like that. If we could have new forms of curriculum, new forms of engagement that focused on the collective rather than competition and the promotion of individuals, then it would be a happy day for me in NYC. That is my next agenda; I have been reaching out to the Department of Education in the hope that we can get some grant money to do some of this, and I would hope that the new generation coming into the Graduate Center would be interested in participating in some of this.

Chris: Thinking about science education as a field, what do you think are the biggest challenges right now, and along those lines, what are your hopes for the future of science education?

Ken: I think the field has been characterized by this monosemic way of looking, that there is a right way to do things, and that those who don't do it right get othered and marginalized. What that gets translated to is that we end up with these little groups that tend not to communicate with one another and learn from one another. So we have this group right now that is, what I would say very much informed by Comtean positivism. A very neo-liberal type of group, and what they do essentially is fall into line and do whatever they think it is going to take to get the money to do the research. I think there is all of that, and by and large I don't respect that work much, and I have to kick myself to stay in tune with that. I think the conceptual change group has been much the same. They have dominated teaching and learning to such a degree that it is very difficult for others' views of what learning might be to get a toehold. So, I think just to cut to the chase, on the road ahead it is going to be very important that we learn to respect one another's difference and resolve to learn from differences rather than marginalizing those that are different. That would be the challenge. Will that happen, in the future, I'm not too sure. I think that by looking at the larger picture the sociocultural ways of making sense may become more prevalent in education. Within science education we have the issue of scientists and the powerful voice of science, and I think that is a challenge because educators are not respected by many scientists. I think this makes a big difference in the way that resources are allocated to do professional development and research. This complicates the road ahead, so it is going to be political Chris.

Chris: So then as a last point of question, you've talked a lot about how you have seen the field of science education changing, and your own trajectory, what would some advice be that you have for other people, for other science educators, early career scholars, students?

Ken: Not to waver. I think the key issue for people starting out is to realize that you are not starting out, you are already on a trajectory. As you create networks and listen to people, be aware of who you are listening to, and where they have been and what their trajectories are. I think a lot of the conventional wisdom is not well-based. In other words, to start out rather than to continue on; I think this is a bad way to think about building a career. Advice along these lines may be well-intended, they have an eye on what is needed for promotion and tenure, and the old idea, the modernist idea, is to show separation from your mentors. I think this is wrong. I think that you have to establish your own identity as a scholar, but it is not done by starting afresh. So, in your case, I think it would not be a good move to sever your ties with me, for example. It is better to continue on and to use that network to help and to continue to build your career. If distance is necessary, then that'll be evident and we'll both realize that distance is necessary. This cutting of ties is an old-fashioned way, and if you look at the people that are giving this advice, they are generally people that never had good ties to begin with. My experience has been in the sciences where the way that this works is maintaining ties.

CONCLUDING THOUGHTS

We would like to thank Fatih Tasar for the opportunity to publish this conversation. It is my hope that this conversation with Dr. Kenneth Tobin illuminates the various directions and trajectories that a research career can have over time, and that the points we have raised provide insights from which others can learn and gain inspiration.

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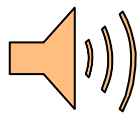
The audio recording of this conversation/interview is available from the journal web site.



Christina Siry recently completed a Ph. D. in Urban Education under the supervision of Dr. Ken Tobin. Her doctoral research explored the role that shared; supported teaching experiences can have in the production of new teacher identity and solidarity. Her interests focus on collaborative approaches in teaching and in research, and in her current position as postdoctoral researcher at the University of Luxembourg she is investigating the role of collaborative inquiring in young children's construction of science.

An interview with Richard Gunstone: Emeritus Professor of Science and Technology Education, Monash University, Australia

Dianne E. Siemon
RMIT University, Bandoora, VIC, AUSTRALIA

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The conversation between Richard (Dick) Gunstone and me took place at Monash University on June 19, 2009. The purpose of the interview was to record some of the rich and varied history of this well-known teacher, researcher, and advocate for quality science education in schools. In the course of the interview, Dick describes how circumstances conspired to lead him to science teaching, his fascination with research, and how educational thinkers and researchers influenced his own and others thinking at important times. He offers a perspective on where to from here and concludes by saying "how lucky can you be".

Keywords: Science Education, Teacher Education, Constructivism, Science Teaching and Learning, Curriculum and Pedagogy

INTRODUCTION

It was a great pleasure to be given this opportunity to interview a longstanding friend and mentor who has made such an outstanding contribution to science education and education more generally. I first met Dick during my Diploma of Education year at Monash University in 1972. He was part of a team of enthusiastic science educators whose passion and concern for quality learning modeled what it was to be a great teacher. One of the most important lessons I learnt from Dick as a beginning teacher was about the nature of learning. Of course we had been exposed to Piaget but it wasn't until Dick asked us to consider the meaning of sentences such as, 'The notes were sour because the seams were split', that I really understood the role of activity and experience in meaning making.

Correspondence to: Dianne E. Siemon, Professor of Mathematics Education,
School of Education, RMIT University,
PO Box 71, Bundoora 3083, VIC, AUSTRALIA
E-mail: *dianne.siemon@rmit.edu.au*

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Some years later, my interest in the role of metacognition in mathematical problem solving lead me back to Monash and to Dick. Many rich and insightful discussions followed, and I, like many others, are eternally grateful to him for the support and encouragement he provided as the senior supervisor of our Ph.D studies. Dick is a great teacher, scholar and advocate for experiential learning. Many have been touched by his passion, extensive knowledge, and abiding commitment to the profession. I hope you enjoy this interview with one of our national treasures.

PROFESSOR GUNSTONE'S VITA

Richard (Dick) Gunstone is Emeritus Professor of Science and Technology Education at Monash University. Dick has a Trained Secondary Teacher's Certificate (from the Secondary Teachers' College Melbourne, 1960), B.Sc. (University of Melbourne, 1963), a postgraduate B.Ed. (Monash University, 1974), and Ph.D. (Monash University, 1981 – thesis title Structural Outcomes of Physics Instruction). He is a Fellow of the Academy of the Social Sciences in Australia (one of only 4 science education researchers to have been awarded this honour), and a Life Member of

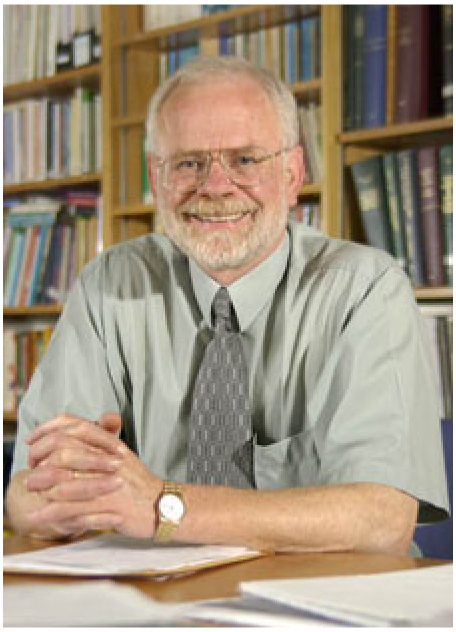

Figure1. Dick Gunstone

the Science Teachers' Association of Victoria (one of only 14 created in the 66 year life of this body).

Dick's first career was as a teacher of physics, science, and mathematics. He taught in a number of high schools in Victoria from 1962 until the end of 1973 (Lake Bolac High School, University High School, Upwey High School, Dandenong High School). In this time he became heavily involved with the Science Teachers' Association of Victoria, including being for different periods their first "Executive Officer", editor of their journal (Lab Talk), Director of their "Science Talent Search" for school students, and a number of administrative positions such as Treasurer etc. He was also seconded one day a week to University of Melbourne to teach pre-service methods programs 1968-70, and half time to Monash University to teach methods programs 1971-73. He has been at Monash University since 1974. He nominally retired at the end of 2005; after his wife died early in 2008 following a long illness he has become active again in research and development and teaching and, particularly, mentoring younger science education academics.

During his long time at Monash, Dick has had sabbaticals at the Learning Research and Development Center, University of Pittsburgh (1980-81), University of Leeds (1988) and University of British Colombia (1994). He has also spent shorter periods teaching and/or collaborating on research and development projects at the Regional Centre for Science and Mathematics Education, Penang, Malaysia (1985), University of the Philippines, Manila (1986, 1989, 1991, 1992), University of Gothenburg (1988), Seoul National University (1995, 1997), Faculty of Engineering University of Cape Town (1998, 2008), Hiroshima University (1998), King's College, London (2000, 2003, 2006), University of Waikato (2003, 2008). He has been a keynote speaker at international conferences in Korea, Spain, Germany, England, USA, Israel, Netherlands, Australia and at regional or national conferences in Singapore, New Zealand, Mexico, Japan, Australia, Bahrain, Namibia, Papua New Guinea, USA, and has conducted professional development workshops for science education academics and/or science teachers in a number of locations in Africa, North America, Europe, Asia, and in many Australian states. In 1985 he was the first science education researcher to win funding from the major Australian government research funding body (then called the Australian Research Grants Committee, now the Australian Research Council), and had a succession of large grants from this body 1985-2005. With his colleagues John Baird, Peter Fensham and Richard White he won the JRST award in 1992, for the paper "The importance of reflection in improving science teaching and learning". He is currently a member of the editorial boards of the ISI-listed International Journal of Science Education and Research in Science Education, and has previously been a member of the editorial board of Journal of Research in Science Teaching and a co-editor of the Learning section of Science Education.

His teaching in the Education Faculty at Monash has involved the spectrum of science education, at undergraduate and post graduate levels, and also more broadly issues of curriculum, assessment, learning and metacognition, and evaluation. He ahs also taught intermittently at both undergraduate and post graduate levels in the Faculty of Medicine and written materials for distance teaching of a master's degree in Family Medicine, and at undergraduate level in the Faculty of Engineering. His research student supervision has been a major part of his teaching. He has, in the "British" mode of single supervisor, supervised 35 Ph.D. theses to completion. His former students include people who now hold Chairs in Science Education, Mathematics Education and Public Health. (In 1995 and 1997 two of his PhD students separately won the "Outstanding Dissertation Award" for research on Teaching and Teacher Education given by the American Educational Research Association; these were the first two times this award had been made to theses awarded by universities outside North America.).

He has also had a wide range of involvements with science education in much broader contexts. For example, he with two Monash colleagues (Professor Richard White Education and Professor Bill Rachinger Physics) created Melbourne's first (and Australia's second) interactive science centre ("experilearn", opened Sept. 1983 within the Melbourne Museum, and closed early in 1989; this was the predecessor of the current "ScienceWorks" that is part of the Museum of Victoria organization). He was for a number of years Chair of the Management Committee of the Family Science Project of Australia, he spent a decade as Examiner of senior high school physics in Victoria, he was for several years a member of the Education sub-committee of the Committee for the Scientific Investigation of Claims of the Paranormal (USA). He has been closely involved from its begins in 2001 in the development of a high school specifically for senior students with high science interests that is being built on the campus of Monash University; the school, the John Monash Science School, takes its first students in 2010.

THE CONVERSATION

DS: Dick you have been at the forefront of science teaching and science education for many years. Three questions: What prompted your interest in science in the first place? How did you get involved with science education and thirdly what lead you to science education research?

Dick: Ok. I need a more complicated answer, in a way. The thing that attracted me to science … actually, I want to ask another question first. How come I stayed at school? Because, that is, actually quite significant. I come from rural Australia. No member of my broader family had ever stayed at school past the compulsory leaving age, which at that time for me was 14. I had a mother who was raising me as a single parent, who was desperately anxious that I should stay at school and four uncles who all told me that "people like us" didn't do what I was doing [continuing with an education]. And so the real battle for me was not what I studied at school but staying at school. And my mother and a profoundly wonderful teacher of English at this rural high school, helped me remain in schooling, which, of course, I am very grateful for. Apart from that I would have left school at 14 and have been a manual labourer all my life. That I did science, then initially, is just a reflection of the 1950's.

At that time, the assumption in [Australian] schools was absolutely that people who were seen to be bright automatically did maths and science. I have no regrets about having done that. Had I had a completely open choice at the time, without my own feelings of peer pressure and concern where my friends were going, I would probably have studied history and politics. But I have done that [history and politics] anyway, as a "side line", anyhow and probably have got more from it than from being formally taught it. So science didn't become a real passion for me until I started teaching it. I was pretty disengaged from science [at school and university]. Yes, I did it and I mostly passed exams, but not always when an undergraduate. And I had a lot of other interests then.

DS: Did you know you were going to be a teacher during University?

Dick: Yes. That also was a matter of circumstance, which was very fortunate because I found I was actually quite good at teaching and I enjoyed it enormously and I had great passion for it. But that was accidental. I had two scholarships to choose from at the end of my high school and I needed one of those to get to University because I had to be completely financially independent. One of them was a teaching studentship which paid me quite a reasonable living allowance and provided me with subsidised accommodation, so it was financially very good. The other was a scholarship given by the Commonwealth Government of Australia. Because I did not know I could work part time as a University student I assumed I could not survive on the Commonwealth scholarship so I took the teaching scholarship. Absolutely an ignorant decision and a very fortunate one, because I love teaching. So, I didn't think about teaching essentially until I began it. My first school position was in 1962 and suddenly I found teaching was fabulous stuff, I really loved it, I loved being engaged with the community I was in and all those sorts of things. So there were two really happy accidents that led me to into a wonderful career of science education.

DS: So why research?

Dick: The accidents continued to be fortunate for me. My first school was a little school in the country. When I got married I came to the city so my wife did not have to change jobs, and, quite by accident, landed in a wonderful school very well known in Victoria, University High School, where I taught with a person very heavily involved with the Science Teachers Association [of Victoria[. So, I became heavily involved with the Science Teachers Association too. I was already thinking in fairly ignorant ways about why was it with all my 'wonderful' physics teaching, people didn't get what I was saying. I then started to think a lot about professional development of teachers through my work in the Science Teachers Association. Because I was involved with them and became a reasonably prominent figure (I am very proud to, say I am one of a small number of life members of this professional body), this led Melbourne University to ask me to work part time there, teaching physics and science methods subjects in pre service teacher education - only because of the linkages that had been some what accidental did I get this opportunity. And then Monash University wanted someone to come here half time to teach physics and science methods and they poached me from Melbourne. I came here [to Monash], and really enjoyed it. A fulltime job was then advertised, which was for 3 years and to be only 3 years, to work in preservice teacher education. I applied for it because I wanted to see what it was like and I was having some difficulties with working half time at schools and half time in Monash.

Then I started a PhD and became addicted to research. There is a whole set of accidents in all of this.

DS: Very serendipitous.

Dick: Absolutely

DS: Excellent. So, we will come back to looking at science education research more specifically, but let's look back a bit earlier. How would you describe the history of science education research in Australia?

Dick: Early and strong. The serious beginning point is probably the appointment of the first professor of science education in Australia who was my wonderful friend and colleague Peter Fensham who was the first Professor of Science at Monash and the first in the country. And as far as we can tell, probably, I feel reasonable confident, the first professor of science education anywhere outside of the United States. So there was a commitment fairly early on at Monash to pursue issues of science education research. Its origins were very much as they were in the United States. The motivations were to do with curriculum concerns, curriculum change, the need to try and understand what the consequences of curriculum change were. Very early forms of evaluation. That led to the very first time, it didn't happen in America till the 1960's, for the first time there were people who called themselves science educators rather than evaluators or educational psychologists or people who were concerned about the teaching and learning and curriculum of science. And the motivation and origins were pretty much the same here.

That all coincided with the then Dean of Education at Monash convincing the Federal Government, who were responsible for these things in Australia, to allow the Faculty of Education at Monash to get heavily into post graduate work. This was very unusual; in fact until then the faculties of education trained high school teachers and just had very occasional research students. So Monash Education, in fact, got heavily into education research. Peter Fensham was an outstanding researcher in his own right, including in Chemistry. He was a senior academic of chemistry before he came here, with one of his two PhDs being in Chemistry. So he became centrally involved in the development of the research culture in this faculty, central for the development of research student numbers and research student practice. And so that led Peter into things like establishing what is now the Australasian Science Education Research Association, ASERA, which is the second oldest such body in the world, behind the US one [NARST]. So, there is this whole set of, again, interesting circumstances which Peter, a remarkable individual, ran with and used to develop a really strong culture of research in science education in Australia. I don't think there is much question Australia is over represented in the science education research forums around the world. We also had from very early on an advantage, which a lot of education research in Australia has shared - we understood that there was work going on in both North America and in Europe and we were aware of both. On the other hand the North Americans and the Europeans tended to be blissfully ignorant of each other, and even to reject each other almost, through the 60's and 70's.

DS: What major turning points do you think there were, looking back?

Dick: There was an enormous stimulus given by the very first Federal Government intervention into school curriculum in this country, which was a science curriculum project called the" Australian Science Education Project." That gave a real boost to science education research because for the very first time the Federal government was putting money into these things rather than the State government being totally responsible. That coincided with the early days of ASERA. So ASERA grew rapidly and had lots of original research to publish. My own prejudice and I am not sure I have much data for this, my own prejudice is to believe the nature of the organisation that Peter Fensham established in ASERA was really crucial to the very rapid growth of research in this country. ASERA is still a conference that has never had an invited [or keynote] speaker. It is a conference that still treats all presenters equally. Every one gets the same length of time. We still hold to a structure where it is 40 mins for every paper session and that will be 20mins presentation and 20 mins discussion, even though we are now running 6 or 7 or 8 parallel sessions. So there are a whole set of issues about ASERA which have made it a place which has fostered young researchers. For a long time the only financial assistance we gave to researchers was for people giving their first ever academic paper. But never to people who were "self proclaimed gurus", who might come and give an invited talk and so on it goes. Now that's not a turning point , but it has been central to an ethos of collaboration and sharing which has been central to the slow development of the strength of science education research in Australia.

Science educators were amongst the very early people to seriously engage with education research conferences in North America. So, science educators … I am not suggesting that this is a turning point, it is part of the same gradual evolution. A former colleague of mine, Leo West, and I began a special interest group at AREA at the US in the early 80's, which became the place where all the significant AREA constructivist presentations were made as they occurred through the 80's and to the mid 90's. It was not surprising that Australians initiated that SIG. Australians a decade before, including science educators, had been amongst the very early people to regularly go to AREA and publish in American journals and those sorts of things. This all contributed [to the growth of science education research in Australia]. The only specific turning point, I think, was the appointment of Peter Fensham, thereafter it has been a much more gradual growth and consolidation. Which is one of its strengths.

DS: And obviously this has spread through out of Australia. But what do you think the impact of this, the Australian effort has had locally, perhaps in Asia? Has there been any influence there?

Dick: Oh yes. We now have significant cohorts attending ASERA each year from Korea and Taiwan, and smaller numbers from other Asian countries. The Monash and ASERA linkage has been very strong in Korea where we worked with Seoul National University, the major public university, through the 90's to establish a doctoral program in Physics Ed and more generally science education as well. So, there have been some quite direct linkages. I have been involved in a number of collaborative research projects with Japanese science education academics. In the early days, a Monash person, Dick White, was on the board of management of RECSAM, the Regional Centre for Science and Mathematics Education in Penang - and you will recall that you and I were once in Penang at the same time teaching there. Peter Fensham, as we keep joking, but a factually based joke - Peter Fensham has been everywhere and very often. So there have been some really strong personal linkages many of us have developed.

DS: Into Asia

Dick: Into Asia.

DS: Not just Europe and America?

Dick: Yes. And they have been for the best of reasons. There has been nothing colonial about them.

DS: That's very good.

What paradigms do you think have influenced science education research?

Dick: When I first came into science education research we were still running very strongly on what I want to call, for very good reasons not belittling reasons, the agricultural paradigm. And that is an appropriate descriptor for experimental methodology such as 'brand A versus brand B'. These things were driving what I would argue were stupid research questions, like "does lab work assist student learning" – and failing to understand that student learning is a multi-faceted beast and it can be defined in many ways, so what form of learning do we focus on in such a question. And lab work is a multi-faceted beast and yada yada. And I call it agricultural because of all the statistics we used, and still use, were developed in the agricultural context. The Campbell and Stanley perspectives on experimental design were the absolutely dominant paradigm. This was experimental research in the traditional sense. This is quasi bench-top chemistry, seeing students as subjects, or teachers as subjects, as people on whom research was 'done'.

That dominant paradigm didn't advance us a lot because it led us into asking two-variable questions and that was a big weakness. Because when you try and conceptualise complex educational issues in terms of how is A relating to B this is always going to give you some difficulties. As an example, when I was editing the research section of the Australian Science Teachers Journal, I guess was probably middish to late 70's, I'm not sure, it used to have a research section. It is the major professional journal for the Australian Science Teachers' Association. I received a paper that was a teacher-audience version of something that had won a major award in a major overseas educational research journal. This was a profoundly strong study of all sorts of things to do with learning biology. Multi variant and all sorts of good stuff. The trouble was, this exploration of maybe eight or nine factors impacting on biological learning with quite sophisticated statistical approaches and really tight experimental design, had managed to arrive at an explanation for about one and a half percent of the variance in student learning. So I, of course, refused to publish the paper on the grounds that it had no relevance to teachers. Now that might have been cheeky of me, but I think it is also a really nice illustration of where we were at with research when I first came into it. This [rejected paper] was a fated and lauded study which was technically wonderful but educationally quite useless. What does 1.5% matter, when we could manage more than that by giving them all decent breakfast in the morning? And we know that.

One of the other harsh characterisations of experimental research, harsh but I would argue fair, is that individual difference was in the error column in the analysis of variance. And it is that central issue that led us off into very different directions, I believe. Some Monash people, me and Peter Fensham and Dick White, have been sufficiently self indulgent as to write a piece in the mid 80's about the ways our research approaches to the learning of science had evolved (*Gunstone, White, & Fensham, 1988*). All this was all laid out in that paper including the things which led us to go from multi-variant statistical approaches into much more intensive studies of individuals and then to oscillate backwards and forwards between the two. The experimental approach of the 1960s was based on many things, including a simple assumption – that in educational research we could use a form of science approach and operate with a simplification which said "lets pretend the world is of the simple form 'A causes B' and see what happens when we explore that". That's profoundly valuable in physics and leads to generalisations which you can't see but which are really significant. But it doesn't work in education. So the big transformations were to move to paradigms which recognised the individual as central [individual differences], which recognized the crucial importance of complexity, which saw matters such as context as major variables rather than a nuisance, and so on.

DS: And at the same time, the work of Novak?

Dick: Yes, and many others. Joe Novak and his appropriate commitment to David Ausubel's views of learning, one of life's very under recognised people, I think. David Ausubel – who died early this year, after being a recluse for a long time. Joe's commitment to those things and to meta cognition had a very different perspective in some ways but mapped strongly onto the commitments that were being worked through at Monash to understanding learning in terms of individual students, commitment to the nature of understanding and how to foster metacognition and its role, all those sorts of things. That is a nice example of how the world is pluralist and multiple perspectives will always help us understand it better. I have never been committed to a single theoretical position. Rightly or wrongly I have always been a user rather than a generator of theory because my motivations have been, at one level, pretty unchanged since the day I walked in the door.

DS: That sounds like constructivism, which has informed many educational research endeavours. What are the similarities and differences do you think across the various fields of educational research in the use of constructivism?

Dick: Quite profound. I think it is very illuminating that constructivism hit science education early and hard. And it arose from researchers actually trying to ask kids what they thought - and listening to the substance of the explanations kids had for phenomena, explanations they gave for what might happen and why. One of the overwhelmingly important messages of this huge quantity of constructivist research in science education, which must be more than in every other [curriculum] area put together I would guess. I mean one of the most well known bibliographies is up to about six and a half thousand – seven thousand entries by way of research studies. It is just huge. The single most obvious thing, for me, the message, the most significant message is, it matters what one is learning. And we tend to forget that when we look across disciplines. So, I find it very difficult to see how, for example, the learning of mathematics can be helpfully informed by the research on the learning of science and vice versa. Because the nature and knowledge that is what we call science, the way of knowing we call science, is so different from the way of knowing we call mathematics.

That raises an example for me as to why some particular variants on constructivism have arisen in one [curriculum] area but not the other. That is why, to use an example I am fond of using and I have written briefly about, that is why the notion of what is commonly known as "radical constructivism", it seems clear to me that that emerged in mathematics. This has to do with the nature of knowing that is mathematics. That it did not emerge within science, that "radical constructivists" in science have von Glasersfeld to cite rather than their own guru, is to do, for me, with the nature of knowing that is science. There are huge differences [with mathematics]. It also is no accident that science is the area in which constructivism has been most influential, most prominent, most widely practised and in some ways most abused.

DS: What, now very strongly do you associate with cultural theories, perspectives on constructivism? Has that impacted on science education research?

Dick: Yes. And indeed in other circumstances, I would have been able to say my last major funded research project was on socio cultural perspectives and science learning in the informal context of early childhood. It was that that Marilyn Freer and I had an Australian Research Council grant for. It was awarded about a month before my wife was diagnosed so Marilyn ran the project herself. And so I was little engaged with it, but Marilyn Freer, Professor of Early Childhood at Monash, is a nice example of some one who sits very clearly across both fields. Her research has been largely on early childhood learning, has been largely embedded in the context of science of learning and technology for the whole of her professional life. She is a very strong adherent to the development of and practice of socio cultural theory. This is how she seeks to understand the learning of science. Yes. It's been quite dramatic growth in the last decade.

DS: So is that moving away from individuals to perhaps a concept that scientific conceptions perhaps have been formed by groups or by students interacting in groups?

Dick: I think it is both. And I am quite happy to have someone be really in disagreement with this. Its not something I think is in the way of the "truth", but it is my interpretation of what has happened. I think the really strong commitment for a long time to individual construction within science education research led us to the point where we had a really deep understanding of what kids were almost certainly were going to be thinking, in most of the contexts you could imagine. We were still struggling with trying to understand more than logical inference for why they might be thinking that. Trying to understand the socio cultural dimensions of the evolving ideas then helps us to get a better sense of why the ideas are the way they are, how we might seek to intervene a little earlier. So the most - what will be, if I can get my head around the outrageous comments of a really strange reviewer - what will be my most recent publication within the next week, once I sort this out, with a Korean colleague who had a post doc here a little while ago. Yong Jae's work has involved the really interesting notion of "typically perceived situations", what are the situations where, in which children are more likely to apply their naïve conceptions of what ever it might be, force or energy. What we were doing was to try and understand a little of how these were culturally different. Which of course, they are. One of the things that has been a problem for science in all of this is the tendency to maintain the mythology that science is a culturally free discipline. And other lies we have lived with.

DS: Do you think there is going to be a need, or is there a need, for some sort of new paradigm, to help take the field forward?

Dick: Yes. But it won't be singular. I have a really strong commitment to the view that in any area, whether it is laboratory science, educational research, political enquiry, in any area, the most significant hallmark of good quality research is that it lets you ask better questions. Research is not something which should always lead to answers. Research should always lead to better questions. Along the way we have a better understanding of whatever the phenomenon is, but we will always be moving to new ways of conceptualising research and that will lead us to new paradigms. I think the most obvious shift over my time in research is that much more fundamental beginning acceptance of the significance of complexity. When I began research, when we were in the agricultural paradigm, the conception of significant issues as "A causes B", now seems to be really strange. Really odd. And so, the movement to recognising and embracing complexity, which is taking us forwards, the failure to address the complexity [in the past] meant we kept getting further away from what we wanted to understand. That move brings a whole raft of new paradigms that may potentially, may have positive impact, And the most obvious in that, the most obvious new paradigm is, if that is the right word, is that there a whole set of new issues contained in the perspectives of what is known as Complexity theory, which I don't really understand yet, but I will poke around a little in my retired state. But complexity theory is, at its beginning point, is a position which says, we need to understand complexity. This is a huge paradigm, shift.

DS: Looking back then, over your long years in science teaching and science education research, what do you think your major accomplishments were during that time?

Dick: I find that a really difficult question. But, don't misinterpret this, but I think my major accomplishment has been being able to work with a lot of people and develop a lot of other people in their research capabilities. And that's "with", not "on". It is working with many PhD students, learning from them and helping them learn, with research colleagues and mentoring people - and all of that doesn't answer the question, in one sense, because it doesn't answer what is it that we were researching, that is, what I see as my most significant achievement. I guess these are research outcome things that are probably to do with, a much better understanding of the complexity of physics learning, somewhat better understandings of the nature and significance of better cognition, particularly meta cognition in a classroom context, in undergraduate or school classrooms. And I have helped a little bit along the way with better understanding of teacher development - pre service and in service. So that is probably three major issues in order of whatever significance they might have.

DS: Anything that you think you might have you feel passionate about that is left undone that still needs to be done?

Dick: Oh Yes. In the last ten years I have become increasingly interested in and concerned for the intended curriculum. And, I am about to use something that is a little bit glib and simplistic in order to make a fairly fundamental point, When I was working at the University of British Columbia, so it would have been 1994, and Jim Gaskell, who was a science educator, curriculum person from the University of British Columbia for a long time, he is now retired from academia. Jim and I were playing around with some metaphorical thinking, which we didn't publish. The summary of it all was, at the beginning of the 20th century both the teaching of English literature and the teaching of science involved learning the great texts, and assessment of that learning involved reproducing the great texts, perhaps with a little bit of teacher help on some commentary to link them. By the beginning of the 21st century, literature teaching had changed. So there is a sense in which Joe Schwarb's wonderful description of science curriculum in the 1950's as a "rhetoric of conclusions" still dominates what happens in school and under graduate science education. And I have increasing passion for the need to change that, both because I feel a bit sad that so many people don't understand the extraordinarily wonderful things that there are to be understood about this way of knowing and because the world can't afford to keep producing people who are anti-science in the ways that we do. Some of that is the responsibility of our outrageously, fact-ridden, nonsensical and absurd school and university curriculum. Now my passion for that is stronger than it was 20 years ago because I have come to see that as much more significant than I did 20 years ago. In the unlikely event that I am ever an educational dictator, my first step will be to make all exams open book and that is just the beginnings to try and break this appalling focus on facts which continues to plague both science and, dare I say it, maths, education in ways in which other [curriculum areas] have grown up from. And I say grown up rather than grown away very deliberately.

DS: Sounds like a very big task indeed.

Dick: I don't have fantasies that I will achieve that. But that is where my passion is now.

DS: That links nicely to the next question. The relationship between research and practice is a perennial topic of debate in most fields of educational research. How do you see this relationship in the case of science education research?

Dick: Much healthier than it was forty years ago. As a beginning point, I'm speaking very specifically in the context in which I link with practice. It seems to me a necessary consequence of that really important question that you can't generalise, because practice in the Australian State of Victoria is not the same as practice in, well no I won't name a country, but its clearly going to be very different. I mean some countries I have worked in, the whole set of issues associated with the funding of education, the lack of education of teachers, the nature of the curriculum that teachers have to teach, mean that the practice has no relationship. The teachers in those places could not teach in Victoria and the teachers in Victoria could not teach in those places, full stop. So, I can only talk about it where I understand and have lived the practice.

It's much healthier than it used to be because it is much less hierarchical. Where it is not healthy, it is because it is still hierarchical - as a gross generalisation. It has been a very, very, very long time since people had any significant impact on school science teaching in this State through asserting what needed to be done. So that is tied up in a whole raft of things to do with the interactions that science educators have had, and others too, I know, with teacher research. They, the extent to which research is now done with teachers in real contexts, so in part it is tied up with research moving away from experimental research into the recognition of complexity. Tied up in ways in which pre service teacher education has shifted, in which professional development has shifted, most fundamentally it is tied up with changes in attitudes of the researchers, I would argue. Researchers in science education [at Monash], generally, not universally, but generally a long time ago, stopped seeing themselves as experts who told. There are some parts of the western world where that shift hasn't yet always happened, and I think the relationship between research and practice in those areas are much less healthy. The relationship is still not as good as I want and the ways in which research impacts on practice are slower than I want but I console myself by looking outside education and the ways research and practice interact elsewhere and then I am a little more sanguine about things. We tend to forget that the same practices operate in all professional areas, the same difficulties.

DS: You sort of have answered the next question, which is about the relationships between research and practice and how similar or different they are to the relationships in other professional fields?

Dick: I think it is really important to think about the similarities. We focus much too much on how we are different and not enough on how we are similar, I would argue. And the same is true of the education of professionals. I think we have a lot to learn. This is an idea so powerful that I wrote about it ten years ago and no one took any notice. I think we have a lot to learn about the commonness across professional education and the commonness across research-practice interfaces. As an anecdotal beginning point, I've off and on been doing bits and pieces of research and development in other faculties in Monash, Engineering and IT and Medicine and Science. In one of my incursions into Engineering, some years ago, I had an engineering researcher bemoaning the appalling state of events that, in his view, maybe one in 50 of the significant intellectual advances he had made in the particular area of materials engineering that was his research field impacted on practice. So I asked "what happens to the rest?" And you know, it was just like listening to someone in the Education Faculty. It was quite a singular moment for me. It was what first started me thinking about this. So, I think it is a reasonable assertion, if data free, that if we had never had drug salesmen there may still be a general practitioner practicing medicine in Australia who hadn't quite got his/her head around penicillin. Medicine tends to be the lived experience of research-practice interactions for most of us and there are change agents in medicine. These agents are driven by money, and do a lot to move some things. In other areas, like social work, like engineering, like IT, commercial structures that have set practices that are functioning well are hard to shift. Surprise, surprise. People who have learned to do things in particular ways are hard to shift. Surprise, surprise. All of these things are very familiar. The significance of that for me, is if we recognise that this is more the norm than the exception, then perhaps we will stop wailing and wringing our hands and blaming people for this and recognise that we need to be a bit more positive and function a bit more directly and look at the drivers a bit more directly. That's why I regard, quite seriously, a requirement to have all exams open book as being the single most significant educational reform we could undertake. Because assessment and the pursuit of grades is always going to be a really strong driver that is going to change both teaching practice and much more importantly, the learning approaches of kids. So let's stop sitting here, blaming teachers because 'they won't change', and accept that change is always problematic and difficult and see what can drive it. Assessment is always going to be one of the major drivers, so let's play with that.

DS: So, what do you think is the role of professional development?

Dick: Profound and deep and will only get near to recognising its really fundamental potential in the sense that any professional I want to have as my doctor, or teacher of my kids or my counsellor when I am having difficulties, is one who regards themselves as always learning. That is self evident, I think. One who regards themselves on a journey and their only commitment is that they are always moving forwards and uphill and don't expect to reach the top of the mountain. We need to find ways to value it [professional development] much more and that is both in terms of making it easier to participate in and in terms of rewarding the consequences. I haven't given huge amounts of thought as to the way we need to restructure the teaching profession, and I don't want to be committed to all of this. I don't have anything I want to say, like this is what we should do, but finding ways to reward the consequence of what is rather trendily called "life long learning" is fairly central, as they are for academics as well, I must say. So, but academics are harder than teachers. They just don't like to be reminded of that fact. But they are. I think the evidence is quite clear, across research fields again, it is not an issue just for education academics, and the history of science is littered with the inevitable consequences of reactions of senior people who have spent forty years researching a particular perspective and along comes some one who is 25 and says you are all wrong. Well of course, they don't get a favourable reaction. Researchers tend to be even more passionately committed to their world views. They are even harder to change than teachers, indeed.

DS: What do you think can be done about all of the current pleas for bringing creativity, innovation for ensuring our students have those capacities? I don't know if you heard Ken Robinson the other night? But what, how does that impact someone's education in schools? How might it impact on the sort of research that we do?

Dick: It impacts on the research we do by, well one of the shifts that we really need is this issue of complexity, which is almost an intersection of the sets of individual constructivism and the significance of complexity. We are well past more studies of how kids understand force. We need to recognise the complexity that has to be central to learning in science in the 21st Century. So, this is both terrible obvious but still not something we are pursuing enough. I think we will have made real progress with the sort of issues you are raising in Australia - all of these things are contextually culturally imbedded - when soil salination is a central part of the science curriculum. I despair when it continues to not be. There hasn't been the beginning of an attempt to understand how people's ideas about that complexity, that multi-variant thing that is soil salination evolves. So it is a nice example of how our research needs to better embrace the complexity that learning in the 21st Century must be. That also needs to take us away from factually based assessment and then curricula. It probably means playing around with another variation of the century old approach of problem based learning. I want to be careful about that because it tends to get seen as some great Nirvana which will transform the world and wasn't when it was first advocated at the beginnings of the 20th Century in undergraduate engineering and medicine. That sort of perspective is where we need to get to.

DS: And that, of course, puts very different demands on the type of science teachers we have in schools.

Dick: Absolutely.

DS: And the nature of our pre service courses, then

Dick: No. The nature of the undergraduate science those people are studying. That's where the problem is. The pre service teacher education courses, at least in this country, are at least OK. In general the sort of thing you are talking about, it is the science we teach and who teaches it and how it is valued. That's where the real changes needed. That's been true for a long time. I've had more passionate conversations than you would care to know about with people in science faculties who make the terrible mistake of telling me that teachers don't understand the science they teach very well. Because they get reminded by me very strongly and very harshly and very directly of where the teachers learnt their science. And it is from the very people that are complaining. And that is a universal phenomenon. I have had that argument with the vice chancellor of the University of Leeds; I have had it at an institution in America. Anyhow that is another story.

DS: Any conclusions or things that you feel you would like to shed some light on, in your long and lustrous career?

Dick: I have been desperately fortunate. My professional life has been a set of desperately fortunate circumstances. It's not surprising that in my nominal retired state I am working 3 or 4 days a week. Because it is not work at all. How lucky can you be.

DS: Exactly. Thank you very much Dick. That has been a good place to finish.

Dick: Thank you.

DICK GUNSTONE'S SELECTED PUBLICATIONS

Dick has published: 12 books (8 authored & 4 edited; 8 'academic' & 4 school or teacher texts; 2 more research books currently in preparation), 45 book chapters, 161 research papers (journal & conference), and many research reports, and considerable curriculum and text materials (for school and university levels, including science and medicine students). These publications include the following notable scholarly contributions.

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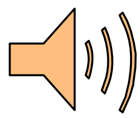
The audio recording of this conversation/interview is available from the journal web site.



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Developing Mathematics Knowledge Keepers - Issues at the Intersection of Communities of Practice

Dianne E. Siemon
RMIT University, Bandoora, VIC, AUSTRALIA

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This paper discusses some issues that arose in the context of a three-year research project on Indigenous mathematics teacher education in the Northern Territory of Australia[1]. The project was based on the premise that Indigenous student numeracy outcomes are more likely to be improved where students can work on key number ideas and strategies in first language with knowledgeable community members. The research was located at the intersection of three communities of practice involving Indigenous teacher assistants, non-Indigenous teachers, and research team members. While a range of factors variously impacted the project, tensions within and between the communities of practice emerged to challenge the initial design and pose new questions. This paper will describe the research approach and illustrate the need for analyses which accommodate the often "messy relations" between individuals, individuals and communities, and different communities of practice.

Keywords: Indigenous Teacher Education, Mathematics Education, Communities of Practice, Number Concepts, Situated Learning

BACKGROUND

The educational challenges facing remote Indigenous communities in Australia are not unique. Minority groups in many countries experience similar economic and social disadvantage and are disproportionately represented in the lower levels of educational achievement. While the provision of high quality education for increasingly diverse student populations is a challenge in many large cities around the world (Ladson-Billings, 1994), this is exacerbated in isolated Indigenous communities where English may be a fourth or fifth language and the everyday lived experience of children is very different to that of their non-Indigenous peers.

Correspondence to: Dianne E. Siemon, Professor of Mathematics Education,
School of Education, RMIT University,
PO Box 71, Bundoora 3083, VIC, AUSTRALIA
E-mail: *dianne.siemon@rmit.edu.au*

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Not surprisingly, international and system-wide data consistently point to low levels of literacy and numeracy achievement of Indigenous students. For example, although Australia's results on the 2006 *Programme for International Student Assessment* (PISA) were above the OECD average in scientific, reading and mathematical literacy, the same cannot be said of the results for Australia's Indigenous students, which were significantly lower than the results for non-Indigenous students and the OECD average overall (Thomson & De Bortoli, 2008). This discrepancy is particularly marked in the comparison of Indigenous and non-Indigenous students as they move from Year 3 to 5 in the Northern Territory. For example, results from the *Multi-level Assessment Program* (MAP) consistently show that Indigenous students are four times more likely not to satisfy the Year 5 National Numeracy Benchmarks than their non-Indigenous peers.

This is a disappointing and frustrating outcome given the many and varied attempts to find more effective ways to support the teaching and learning of mathematics in remote schools as a means of improving

Indigenous student numeracy outcomes[2]. These have taken the form of more culturally sensitive, community-based approaches to teaching mathematics (e.g., Cooke, 1990; Bucknall, 1995; Marika, 1999), evidence-based advice on 'what works' in these settings (e.g., Efthymiades, Roberts & Morony, 2000; Frigo & Simpson, 2001; Mathews, Howard & Perry, 2003; Perso, 2003; Commonwealth of Australia, 2005), considerably more and better quality pre-service and in-service teacher education (e.g., Howard, Perry, Lowe, Ziems & McKnight, 2003; Mellor & Corrigan, 2004); and increased efforts to involve more Indigenous people in community-based teacher training programs (e.g., Lamb, Arizmendi, Stewart-Dore & Danaher, 2002; York & Henderson, 2003).

While there is little doubt that the educational outcomes of Indigenous students are impacted by a complex set of socio-economic circumstances (Mellor & Corrigan, 2004; Mathews et al, 2003; Partington, 1998), it is widely recognised that teacher quality is also one of the most important factors affecting student performance more generally (Ball, 1997, Rowe, 2002; Hattie, 2003; Mellor & Corrigan, 2004). Indeed, as Darling-Hammond (2000) notes, "the effects of well-prepared teachers can be stronger than the influences of student background factors, such as poverty, language background and minority status" (p. 35).

For Indigenous students in remote communities, the issue of teacher quality is compounded by the relatively high turn-over of non-Indigenous teachers, the tendency for recently arrived teachers to revisit content that may well have been mastered previously with little regard for the connections between that knowledge and the students' lived experience, and the lack of consistent access to first language (L1) speakers who can help scaffold students' mathematics learning beyond simple modeling and rote counting. In addition, where secondary-trained teachers in remote schools are expected to teach a particular group of students across all learning areas, many find themselves teaching upper primary and/or junior secondary mathematics without any formal training in mathematics, mathematics pedagogy and/or teaching English as a second language (Commonwealth of Australia, 2005). These issues are further compounded by the increased demand for verbal reasoning and written communication skills in mathematics as a consequence of curriculum reform initiatives (Rowe, 2002). All of which point to the critical need for well-trained, Indigenous teachers who are unlikely to move from the community and have a strong vested interest in the success of their students.

Although Mellor and Corrigan (2004) question the assumption that Indigenous teachers are more likely to adopt culturally appropriate practices than their non-Indigenous colleagues, they acknowledge the critical importance qualified Indigenous teachers and/or teacher assistants in remote communities on the grounds that they are more likely to understand the cultural practices, language, and circumstances of students, and have long-standing and on-going relationships within the community. The inherent advantages in this can be seen in the following reflective journal entry of a first-year out Native American teacher (cited in Beaulieu, Figueira & Viri, 2005).

> I know what challenges the children have ... I know that these children hold the key to the success of my Tribe's future... I know that non-Indian teachers have never experienced racism for being Native, and I have. Nor have they experienced lack of effort on the part of their own teachers in encouraging the children to reach for the sky. Things like these make me different from non-Indian teachers and therefore my teaching is different ... I tell them that the language must be learned so that our ancestors aren't forgotten and our culture stays intact. Their success is my success. This is how I am different from a non-Indian teacher (p. 1)

Important and necessary as this is, cultural connectedness and commitment are not sufficient to support and sustain improved numeracy/mathematics outcomes. Sound subject-matter knowledge appropriate to the level taught and a well-developed capacity to implement effective pedagogical practices are also needed (e.g., Ma, 1999; Australian Association of Mathematics Teachers, 2002). Together with a deep understanding of students as learners of mathematics as noted by Masters (2004).

> Highly effective teaching depends on an understanding of individual learners, including their current knowledge and beliefs, misconceptions, incomplete understandings and naïve mental models ... If teachers are to function in this way, then they must have a deep understanding not only of the subject matter they are teaching, but also of the ways in which students typically learn that subject matter (p. 7).

However, given that the Indigenous community members most likely to contribute to schooling at the present time are also the ones who invariably take on a whole host of other community-based roles and responsibilities, the possibility of them being able to spend the time to acquire this sort of deep knowledge for teaching across each area of the school curriculum is increasingly unlikely. This suggests that it might be reasonable to explore the possibility of improving Indigenous student numeracy outcomes by means of an alternative, community-based approach to Indigenous teacher education exclusively focused on developing pedagogical content knowledge for teaching mathematics. Such an approach is consistent with the community-based notion of collective rather than individual knowledge, and the generally accepted view that not everyone needs to be knowledgeable about all aspects of community practice (Christie & Greatorex, 2004). This makes the task of contributing to schooling more manageable, and increases the likelihood of involving more Indigenous community members in the life and work of the school.

This discipline-specific, community-based approach to Indigenous teacher education was supported by the experience and findings of the *Supporting Indigenous Students' Achievement in Numeracy* project (SISAN) which was conducted by the author in collaboration with the Northern Territory Department of Employment, Education and Training (NT DEET) in 2003-4. The SISAN project was aimed at researching the impact of authentic (rich) assessment tasks on the numeracy outcomes of middle years' Indigenous students in a targeted group of remote schools. Although the rich tasks helped identify 'what works' in this context and highlighted important areas of learning need more generally (e.g., number sense and mathematical reasoning), the literacy demands of these tasks limited the extent to which they could be used to inform starting points for teaching. As a consequence, a small number of more focused tasks known as Probe Tasks were introduced[3] which provided a broader range of response modes and allowed teachers to identify learning needs more specifically. Participating teachers typically reported that as student responses to these tasks were more readily observed, interpreted, and matched to expected levels of performance, they felt more confident about responding to student learning needs, and as a result, more likely to positively impact student numeracy learning. This was particularly the case for the Indigenous teacher assistants and secondary-trained teachers with little/no mathematics background, suggesting that the Probe Tasks and their associated advice offered a useful means of building remote teachers' pedagogical content knowledge for teaching mathematics (Commonwealth of Australia, 2005).

Mathematics knowledge keepers

A conversation with two respected community elders at Milingimbi, an island off the coast of Arnhem Land in the Northern Territory, prompted the current research project. Both had completed their teacher training in the days when it was relatively easy to undertake periods of formal study at the Batchelor Institute for Indigenous Tertiary Education (BIITE). Now grandmothers, with considerable community responsibilities outside of school, they lamented the fact that there were very few Indigenous people to take their place, pointing to the demands on those that might be interested in teaching and the problems associated with being away from the community for extended periods of time. Given that most non-Indigenous teachers transferred or left the school after one or two years and tended to base their teaching on the age/grade level of students and/or information that might be gleaned from a written test in English, I asked them to consider what would make a difference to remote Indigenous student numeracy outcomes in the longer term. They talked about their experience in the project and their confidence in using the Probe Tasks to identify specific learning needs in first language and direct observation of student behaviour. It occurred to me during the course of this conversation that one way of addressing the issues identified was to build local capacity to support student numeracy learning and the transfer of control over 'who does what, when' to those most likely to stay in the community. I asked them how they would feel about taking on this role more formally, that is, monitoring key aspects of student learning in mathematics in L1 and providing advice to non-Indigenous teachers about what was known and possible starting points for teaching. They both expressed their interest and enthusiasm in doing this, with one responding: "Yes that would be good ... [then, after some time and with a glint in her eye] that means we could choose who to tell" (M, February, 2004). We talked about what this would mean from a community perspective where knowledge was distributed and individuals were valued on the basis of the particular knowledge and skills they maintained and nurtured on behalf of the community. This led to the notion of 'knowledge keepers for mathematics' or 'mathematics knowledge keepers' as a means of supporting sustainable improvements in Indigenous student numeracy outcomes.

The Project

Teaching informed by quality assessment data has long been recognised as an effective means of improving learning outcomes (eg, Ball, 1993; Black and Wiliam, 1998; Masters, 2004). It is also evident that where teachers are supported to identify and interpret student learning needs, they are more informed about where to start teaching, and better able to scaffold their students' mathematical learning (Clarke, 2001). However, this approach presents a challenge in remote schools where the language of instruction is not the language of the community and typical assessment tasks rarely, if ever, provide an accurate assessment of student thinking.

As indicated above, the *Building Community Capital to Support Sustainable Numeracy Education in Remote Locations* (BCC) project was established to explore an alternative, community-based model of Indigenous teacher education aimed at building local capacity to support sustainable approaches to mathematics learning in the middle years of schooling with a view to addressing the persistently low levels of remote Indigenous student achievement in mathematics beyond Year 3. It was

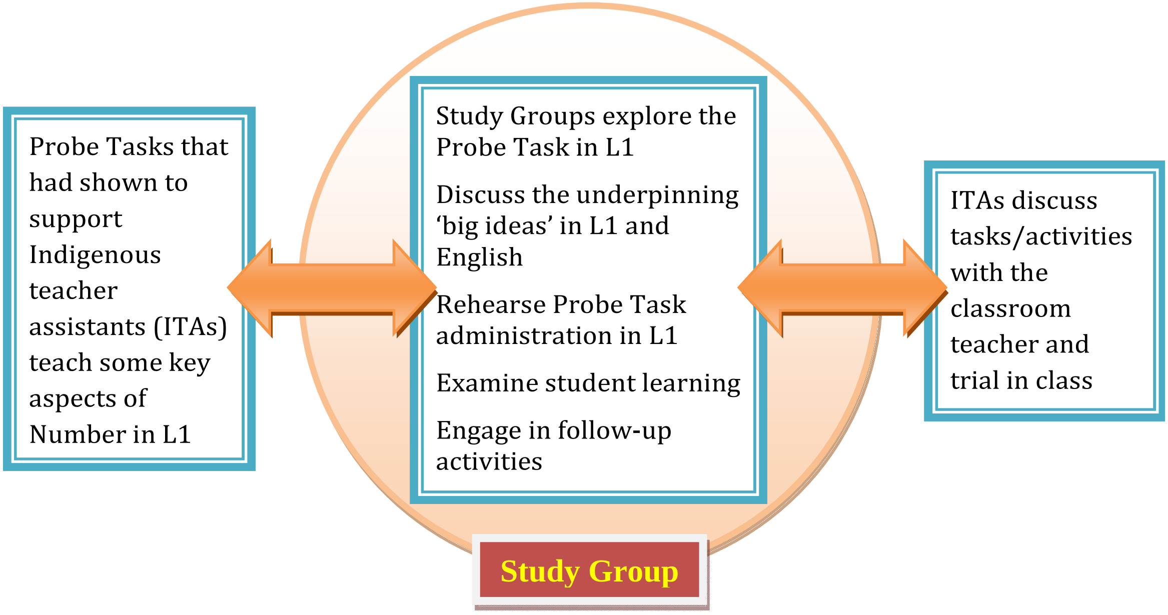

Figure 1. Schematic representation of study design

conjectured that the Probe Tasks could be used to engage volunteer Indigenous Teacher Assistants in a deeper examination of their own and their students' understanding of the 'big ideas' in Number and that by working with classroom teachers and research team members on strategies to enhance students' understanding, they would be more likely to take on the role of 'mathematics knowledge keepers'. As a consequence, the BCC project was designed to explore the following questions.

What processes are involved in building community capital to support more sustainable and better targeted approaches to the teaching and learning of mathematics in remote communities?

To what extent can deep pedagogical content knowledge for teaching mathematics be developed through the use of Probe Tasks and participation in Study Groups?

What impact, if any, does the alternative model of Indigenous teacher education have on Indigenous student numeracy achievement?

To what extent can the alternative model be documented in a form that is recognized and valued by all stakeholders, including the possibility of formal accreditation?

Two relatively recent research approaches informed the design of the study, design experiments (e.g., Brown, 1992, Cobb, Confrey, di Sessa, Lehrer & Shauble, 2003) and multi-tiered teaching experiments (Lesh & Kelly, 2000; English, 2003). Both of which accommodate a situated view of learning and acknowledge multiple elements in the process. In this instance, the design brings together a multi-disciplinary research team with expertise in mathematics education, Indigenous teacher education, the socio-cultural practices and languages of Yolngu people, and the policies and practices of the Northern Territory Department of Employment, Education and Training[4]. The project is a design experiment to the extent that it has both a "pragmatic bent … and a theoretical orientation" (Cobb, Confrey et al, 2003, p.9). The pragmatic bent is that it is focused on a particular but evolving approach to Indigenous teacher education. The theoretical orientation is evident in the intent to develop domain specific theories about the nature of the learning involved and how it came about in the context of the social settings in which it is located. The project also shares some of the features of a multi-tiered teaching experiment in that it "involves participants at different levels of development who work interdependently towards the common goal of finding meaning in, and learning from, their respective experiences" (English, 2003, p.242). The participants included volunteer Indigenous Teacher Assistants (ITAs), the classroom teachers with whom they worked, and members of the research team supported by school based linguists and/or curriculum leaders. A study group organisation was used to explore the Probe Tasks in L1, negotiate and rehearse their use with students, reflect on student thinking, and plan appropriate follow-up activities. Two Study Groups per school term were planned for the duration of the project. Figure 1 provides a schematic representation of the study design.

Theoretical underpinnings

The alternative approach to Indigenous teacher education evolved from the need to support more sustainable and better targeted approaches to the teaching and learning of mathematics in remote locations. By supporting and working with Indigenous educators and/or interested community members to become recognized 'mathematics knowledge keeper(s)' with a special regard for how best to communicate and share that knowledge with other community members, it was envisaged that the ITAs would ultimately take on a school/community leadership role in this area. For example, providing advice and direction to recently arrived non-Indigenous teachers about individual student learning and taking responsibility for decisions about where, and how to start teaching mathematics most effectively. The model has its origins in the Cognitively Guided Instruction (CGI) approach to teacher professional learning which is premised on the view that teacher's instructional decisions are shaped by their knowledge and beliefs and observations of student behaviour in response to learning opportunities (Carpenter & Fennema, 1991).

While it is acknowledged that design experiment methodology typically leaves open the issue of underpinning theory to optimize the emergence of new theory, it was felt that the particular goals and circumstances of the BCC project warranted a theoretical framing to help ensure that the very different backgrounds and perspectives of all those involved were respected in the process. As a consequence, the research was conceptually framed by a sociocultural, interactionist view of learning and development that acknowledges the importance of discourse in the shared construction of meaning both within and between different communities of practice (Clarke D, 2001; Lerman, 1998; Wenger, 1998). This approach has its origins in a situative perspective that views learning and development in terms of transformation where "the central question becomes how people participate in sociocultural activity and how their participation changes from relatively peripheral, observing and carrying out secondary roles, to sometimes being responsible for managing activities" (Rogoff, 1985, p.157).

More recently, and with specific reference to understanding student learning in classroom settings, learning has been conceptualised "as changes in participation in socially organised activities, and individuals' use of knowledge as an aspect of their participation in social practices" (Borko, 2004, p.4). The roots of this approach and indeed, the communities of practice metaphor (Lave & Wenger, 1991; Wenger, 1998) can be traced to cultural-historical activity theory (e.g., Cole & Engeström, 1993; Roth & Lee, 2007) which uses the notion of activity systems to model the complex interactions between the individual (subject) and the object of their activity as mediated within communities bound together by social rules and characterised by divisions in labour. As a consequence, Wenger (1998) views learning as social participation, where participation refers

> not just to local events of engagement in certain activities with certain people, but to a more encompassing process of being active participants in the practices of social communities and constructing identities in relation to those communities. (p.4)

A community of practice "is characterized by the shared manner in which its members act and how they interpret events" (Pawlowski, Robey, & Raven, 2000, p.331). According to Wheeler and Faris (2007), communities of practice involve people with common interest – often in a common vocation or profession – who engage in processes to share and/or acquire relevant knowledge, skills, attitudes and values, i.e., learning that informs and improves their practice. (p.1)

Wenger (1998) characterized a community of practice in terms of three dimensions of practice: a joint enterprise (what is it about), mutual engagement (how does it function), and a shared repertoire (what capability is produced). Three communities of practice are acknowledged for the purposes of the research. These will be referred to here as the Yolngu, school community, the school mathematics community, and the emergent study group community.

Three Communities of Practice

The Yolngu school community includes those members of the local Indigenous community associated with the work of the main school or homeland in some way (i.e., as assistant teachers, teachers, School Councillors and/or interested others). The joint enterprise of this community is to support Indigenous student engagement in schooling. They have shared, culturally-bound ways of engaging with each other and learned ways of acting and interacting in the school context.

The school mathematics community includes all those that by virtue of their responsibilities are concerned in some way with school mathematics (e.g., classroom teachers, the school mathematics coordinator, the assistant principal responsible for curriculum). These people may undertake different tasks, and have different levels of knowledge, confidence and commitment but they contribute in some way to the joint enterprise of ensuring students are able to demonstrate increasing levels of competence in relation to school mathematics. They share general norms of participation in the school community and have shared standards by which they justifying their decisions in relation to the teaching and learning of mathematics.

The emergent study group community involves a shifting subset of the members of the two communities described above and visiting members of the research

Table 1. The Beginning Place-Value Task

Beginning Place-Value Probe Task

You will need:

- 26 large kidney beans or counters in a suitable jar or container
- 7 bundles of ten icy-pole sticks and 22 loose icy-pole sticks
- paper and pen/pencil

Empty container of beans or counters in front of student, ask them to count the collection as quickly as possible and write down the number. Note how the count is organised.
If not 26, ask, "Are you sure about that? How could you check?"
Once student has recorded 26, circle the 6 in 26 and ask, "Does this (pointing to the 6) have anything to do with how many you have there (pointing to the collection)?" Note student's response.
Circle the 2 in 26 and repeat the question. Note student's response.

Place bundles and sticks in front of the student. Make sure student understands that they are bundles of tens and ones. Ask the student to make 34 using the materials. If they ask if they can unbundle a ten, say, "No, Is there any way you could use these (pointing to the bundles of ten) to make 34?" Note student's response.
Remove all materials.

Tip out container of 26 beans and ask student to count these again and record the number. Then ask student to place beans in groups of 4 … Once this is completed, point to the 26 that has been recorded and circle the 6. Ask: "Does this have anything to do with how many beans you have? Repeat with the 2. Note the student's responses.

team. The members of this community are engaged in the joint enterprise of supporting Indigenous participants become mathematics knowledge keepers with the knowledge, skills and dispositions to ultimately take on a specialised role within the school and the wider community. This emergent community has a developing set of shared techniques, norms, and ways of operating based on the use of the Probe Tasks to identify and better understand student learning and targeted teaching activities to address those needs.

The use of study groups both as a space where different communities of practice can meet to negotiate shared meaning around mutually accessible cultural objects, and as a research tool to explore the processes involved in building community capital, builds on the work of Wenger (1998), Borko (2004), and Cobb, McClain et al (2003). The idea of using the Probe Tasks for this purpose was prompted by their demonstrated accessibility to Indigenous education workers in the context of the SISAN project (Commonwealth of Australia, 2005). Their conceptualisation as *boundary objects* (Wenger, 1998), around which shared understandings of key ideas in western mathematics might be negotiated and explored from different perspectives, including community numeracy practices and languages, was suggested by the experience of Christie and Greatorex (2004) in working with the notion of social capital at the interface of two communities of practice. The nature and role of the Probe Tasks as boundary objects are discussed in more detail below.

The Probe Tasks

In addition to their hypothesized role as boundary objects, the Probe Tasks were chosen as the focal point of the study group deliberations on the grounds that learning is enhanced when teachers pay attention to the knowledge and beliefs that learners bring to the learning tasks, use this knowledge as a starting point for new instruction, and monitor students' changing conceptions as instruction proceeds (Bransford, Brown & Cocking, 2000, p.11)

The tasks were drawn from the research literature and/or our experience in working with 'at risk' middle years' students (e.g., Siemon & Virgona, 2002). They were specifically chosen or designed to examine Year K to 6 student's understanding of key number-related ideas and/or strategies on the grounds that differences in students capacity to work with number accounts for most of the difference in mathematics achievement in the middle years of schooling. The tasks support a range of student responses and generally require students to manipulate concrete materials and/or provide non-written responses to visual prompts (i.e., they are performance-based). They are also relatively short and easy to administer individually within the context of the classroom (i.e., they do not require withdrawal).

The original Probe Tasks focussed on subitising (recognising numbers to 5 and beyond without counting), counting (including part-part-whole understanding), place-value, partitioning, addition, and multiplication. They were prepared at three different

Table 2. An excerpt from the Beginning Place-Value Task Advice

Beginning Place-Value Advice
Kidney Beans:
Student responses to this task indicate the meanings they attach to 2-digit numerals. A version of this task was originally employed by Ross (1989) who identified five stages in the development of a sound understanding of place-value, each of which appears in some form in the advice below.

Observed Response:	**Interpretation/suggested teaching response**
Little/no response	*May not understand task* • Check part-part-whole knowledge for numbers to 10 and capacity to recognise and use 2, 5 and 10 as composite units to count large collections
Response given but not indicative of strong place-value knowledge, eg, refers to 6 ones or physical arrangement such as "2 groups of 3" for circled 6, and "twenty" for circled 2.	*Suggests 26 is understood in terms of ones, or 20 (ones) and 6 ones, may not trust the count of 10 or see 2 as a count of tens* • Check extent to which child trusts the count for 10 by counting large collections (see Consolidating Counting Probe Task Advice above), play Trading Games • Practice making, naming and recording tens and ones, emphasising the count of tens in the tens place and the count of ones in the ones place.
Says 6 ones and 2 tens fairly quickly	*Appears to understand the basis on which 2-digit numbers are recorded* • Consolidate 2-digit place-value by comparing 2 numbers (materials, words and symbols), ordering/sequencing (by ordering 5 or more 2-digit numbers or placing in sequence on a rope from 0 to 100), counting forwards and backwards in place-value parts starting anywhere (eg, 27, 37, 47 (clap), 46, 45, 44, 43, …), and by renaming (eg, 45 is 4 tens and 5 ones or 45 ones) • Consider introducing 3-digit place-value (see Booker, 2003 for further details)

Bundling Sticks:
Student responses to this task indicate their understanding of place-value and the extent to which they trust the count of 10, that is, can treat 10 as a countable unit. ...

levels of understanding to support the identification of learning needs across Years K to 6. An example of one of these tasks is presented in table 2. The levels were referred to as beginning, consolidating, and establishing to avoid Year level identification. The task shown in Figure 2 was adapted from a task reported by Ross (1989) and an item in the *Early Numeracy Interview* (Victorian Department of Education, Employment and Training, 2001) which was very similar to the one used by Ross originally.

Given the positive response to the use of the Probe Tasks in the context of the SISAN Project, a Probe Task Manual[5] was prepared to document the advice provided in the field. The advice was organized in the form of a table that matched an observed response (left hand column) to a possible interpretation (in italics) and one or more suggested teaching responses (dot points) in the right hand column. The advice was prepared on the basis of the relevant research literature and student responses derived from mainstream classrooms and a small sample of Indigenous students from remote communities who were observed or interviewed for this purpose. An excerpt of the advice associated with the Beginning Place-Value Task is shown in table 2 below.

The Probe Task Manual that was prepared after the SISAN project was completed was aimed at supporting classroom teachers in remote schools more generally to use the tasks to identify specific learning needs and choose developmentally appropriate activities to address those needs. Given that this form of the advice had not been 'road-tested', it was decided that relevant aspects would be provided on a task-by-task basis for use in the study groups with the classroom teachers. This was done on the basis of the reported efficacy of using hypothetical learning trajectories to support teacher learning (Simon, 1995) and Fennema, Carpenter, Franke, Levi, Jacobs and Empson's (1996) observation that

There may be many ways in which teachers can come to create their own psychological models of children's thinking that are useful … However, starting with an explicit, robust, research-based model of children's thinking, … enabled almost all teachers to gain knowledge, change their beliefs about teaching and learning and improve their mathematics teaching and their students' mathematical learning (p.433).

Where possible it was also decided to video student responses to the Probe Tasks to further support the work of the study groups.

To date, the tasks have proved useful as boundary objects in that the two established communities of practice can engage with the tasks and what they reveal about student learning at some level and they have undoubtedly been responsible for motivating and establishing the emergent community of practice. For instance, there was evidence early on of an ITA confidently demonstrating the Subitisation and Sequencing Probe Tasks to participating classroom teachers (Study Group video, 28 August 2006) and the study group initiated and organized a Community Maths Day in November 2006. However, a number of quite challenging issues have emerged as a result of using the tasks in this way. These include the relationship of key underpinning ideas (e.g., place-value) to Yolngu ways of representing value and order in the world (e.g., the kinship system), the assumptions inherent in mandated school mathematics curriculum about learning sequences and pedagogical practices; and classroom teachers' views about their role in relation to the ITAs with whom they work. These will be discussed in more detail below along with a number of other issues that served to challenge the original design.

Participants and study group organisation

Expressions of interest in participating in the project were elicited from remote schools by NT DEET in March 2006. Initially it was thought that we would work in two remote schools but given the logistics of this (difficulties and expense of travel in remote locations, particularly in the wet season), a decision was made to work with a relatively large school site and one of its associated homeland schools. Briefing meetings were held with the leadership and teaching staff of the main school in June and plans were made for implementing the project in the second half of 2006. Given the complexities involved in setting up the study group at the main site and negotiating ways of working, it was agreed that work would not start in the homeland school until the beginning of the school year in February 2007.

In recognition of the fact that English is a second language for the vast majority of students in remote schools, NT DEET supports a trained teacher and an Indigenous assistant teacher for each K-7 classroom. Schools may vary in the extent to which they adopt a 'both ways' approach to curriculum and/or a bilingual program. In this case, both schools are recognised as bilingual schools and provide regular (usually daily) opportunities for students to engage with Yolngu language and community-based cultural practices. Qualified Indigenous teachers and ITAs take on this role, negotiating the curriculum and contributing to the preparation of appropriate resources.

As the project was aimed at exploring an alternative approach to Indigenous teacher education, expressions of interest in project participation were invited from all those Yolngu associated with the school in whatever capacity. Indigenous School Council members were also approached with a view to securing the participation of interested community members. In the event, six of the ITAs, who were also undertaking an Indigenous Education Worker's Certificate Course offered on-site by a staff member supported in part by BIITE, agreed to participate in the project. This had an unforeseen consequence in that it 'locked in' those classroom teachers who were working with the ITAs at the time into the study group meetings. This ultimately led to some issues within the study group community itself which will be elaborated below. A comparable but smaller number of participants are involved in another Study Group at the associated homeland site.

At the outset, the study groups were designed to meet in school time for approximately 6 hours (3 sessions) every 3 to 4 weeks per term over 8 to10 school terms (2 to 2.5 school years). The initial two and half hour session involves the Yolngu teacher assistants and at least two members of the research team, one of whom is a fluent Yolngu speaker. Whenever possible the school linguist also participates in this session. This is followed by a second session involving everyone in the first session together with the respective classroom teachers and at least one other member of the school mathematics community (usually the mathematics coordinator and/or the assistant principal in charge of curriculum). The third session, generally held on the following day, involves those who participated in the first session.

The purpose of the first session is to provide a supportive environment in which the Indigenous participants can reflect on their experiences of using the Probe Tasks and/or the targeted teaching activities in L1 (Yolngu Matha) using video and/or reports of student responses. The second session is designed as a sharing phase in which student responses and/or teaching experiences are shared in English and discussed with a view to building a shared understanding of what is involved (e.g., key ideas, strategies, implied learning need) and what might be done next (e.g., appropriate follow-up activities, questions). New Probe Tasks and/or targeted teaching activities may also be modelled and discussed at this time. The final session is designed as a planning phase in which participants 'unpack' any new Probe Tasks /activities using L1 to explore meanings and representations, engage in suggested targeted teaching activities, and discuss/explore alternatives with a view to deciding on an agreed course of action and how it might be supported.

Discussion of Issues

At the time of writing this paper, we are still in the final stages of translating the videotapes and collating the records associated with the operation of the Study Groups so my intent here is not to report findings but to outline, from my perspective, a number of issues that emerged to challenge the initial design and question our original assumptions. As observed by Cobb, McClain et al (2003), it was some time before the issues within and at the edges of the communities of practice emerged. In the initial stages, we also experienced the phenomenon noted by Grossman, Wineburg, and Woolworth (cited in Cobb, McClain et al, 2003) of "pseudo agreements that serve to mask differences in viewpoints" (p.17). While this had the effect of lulling us into a false sense of security at the time, in retrospect it was understandable given the time needed to establish agreed ways of operating and build a sufficient level of trust and confidence to support more robust forms of interaction. In what follows, I will briefly describe the issues as they emerged from my perspective. In doing this, it needs to be recognized that this is a work in progress and that many of issues described are issues because they simultaneously both afford and constrain how we organise, advance, and make sense of the work of the project. The issues are highly interrelated and their presentation as a list (not in any order) is purely a device to help clarify my thinking[6]. Apart from my purposes here (contributing to an emerging group of researcher's understandings of the communities of practice metaphor and how this might be used to advance our separate fields and build bridges between them), the primary motivation for preparing this paper is to support the on-going work of the research team and study groups. Subsequent retrospective analyses from the different standpoints of all those involved may well challenge this tentative, personal, and preliminary view to offer a more informed and considered account of what we are doing and seeing.

Tension between 'starting small' and 'thinking big'

In teasing out aspects of the initial design with school leadership and NT DEET representatives at the beginning of the project, a decision was made to 'start small'. That is, after an orientation session to inform all those about the nature of the project and negotiate ways of working, it was agreed that rather than 'roll out' all the Probe Tasks at once and dip into these as relevant for particular classroom contexts, we would all start with the same Probe Task (in this case, the Subitizing task) as our priority was to generate a shared understanding of purpose and to maximize interaction by focusing on a common object. This was embraced by the members of the school mathematics community, accepted by the Yolngu school community, and clearly afforded the practices of the study group community at the time. However, once this community was more comfortable with what we were doing and why, the pseudo agreement to proceed in this way that existed at the outset was challenged. The members of the school mathematics community, particularly those charged with responsibility for mathematics more generally, were keen to explore how the Probe Tasks related to the NT Mathematics Curriculum Framework and the work that had been done locally on translating a widely used interview tool into Yolngu Matha (L1). They were also focussed on preparing/sourcing an extended range of 'activities'. At more or less the same time, and after we had started to make connections with the Indigenous community more generally, the members of the Yolngu school community were keen to explore the 'big ideas of Western mathematics' in relation to 'Yolngu mathematics' (e.g., see Cooke, 1990; Bucknall, 1995; and Marika, 1999).

This has resulted in a change to the design in that we are now working towards a 'big picture' and a form of representation that links the ideas implicit in the Probe Tasks to the learning sequences of the NT Curriculum Framework and, where possible, to Yolngu knowledge systems. For example, the relationship between place-value and the *rulu* system[7] used to 'count' turtle eggs (Marika, 1999). This decision will support the on-going work of the study group but it may also operate as a constraint if it reduces and reifies the ideas to the point where the meanings and representations become taken for granted and thereby less likely to be critically examined. One of the theoretical considerations that has arisen out of these deliberations concerns the 'fiveness of five' (Christie, 2007), an on-going and developing conversation about the relationship between individual and collective knowing and the nature of mathematics as a cultural practice.

Passive resistance

At the outset, as a consequence of the formation of the study groups, some of the classroom teachers felt 'dragooned' into the enterprise. With little shared experience to build on, and the expectations associated with assessment and reporting at the time (last term of the school year, 2006), it was inevitable that some of the classroom teachers involved displayed little interest in participating in the study group at the main school.

Interestingly, although the same method of participation is still being used and there has been a considerable turn-over of non-Indigenous staff in the intervening time, it appears that this is much less of an issue than it was. There are some plausible explanations for this. With time the study groups have become an established part of the 'school furniture', two senior members of staff are actively and visibly involved in the project, visiting research team members, particularly the two doctoral students, are well known and warmly welcomed in the school, and the school community as a whole is arguably more aware of the aims of the project and the benefits that it brings (increased resources, a greater awareness and increased focus on the 'big ideas' in number). However, it could also be argued that this shift has come about as a result of a change in the design which re-assigned the project officer support provided by NT DEET to a school-based, support team who work one-on-one with individual classroom teachers and their teacher assistants to plan the use of the Probes and the follow-up activities.

Level of support

This is a related but more general issue to the one described above. While we recognised the diversity in the school mathematics community, we underestimated the level of support that was (and is) needed to enlist classroom teachers' participation in the study group community both as reflective practitioners and as mentors for the ITA with whom they work. For instance, when non-Indigenous classroom teachers apply and are appointed to a remote school, little is said in the process about their role in relation to the ITAs that they are expected to work with in their classroom. As a consequence, perceptions of the assistant teachers' role may vary from someone who is simply there to translate, maintain class control, and mediate disputes, to someone who is recognised as a valued colleague whose knowledge of local language and culture can be drawn upon to add value and relevance to classroom learning activities.

In addition, a number of the classroom teachers were at different places in their own knowledge and confidence for teaching mathematics compared to the mathematics coordinator and the assistant principal who had many more years experience at the school and were charged with the responsibility of supporting mathematics teaching and learning more generally. Understandably, given the manner in which the classroom teachers came to be involved in the study group at the host school, their understanding of the 'joint enterprise' and their levels of commitment to the work of the project also varied. This contributed to the decision to provide the one-on-one support to classroom teachers and assistant teachers referred to above. But it also prompted new questions that might be addressed in the context of the project. For example, the pragmatic: Is there a role for more rigorous and selective process for recruiting remote classroom teachers as advocated by Haberman (cited in Sleeter, 2001) who identified seven main attributes that enable teachers to teach effectively in culturally diverse urban schools:

persistence, willingness to work with authority on behalf of children or youth, ability to see practical application of principles and research, willingness to take responsibility for the learning of at-risk children, a professional orientation to teaching, ability to persist within an irrational bureaucracy, and expectation of making mistakes and learning from them. (p.215)

A number of theoretical questions are also prompted by these considerations: How do complex, personal histories interact to mediate the participation of individuals in social practices? How might the communities of practice metaphor account for the "complex and often messy relationships between individuals and between individuals and communities, which contribute to shaping the very social practices in which learning is situated in these models" (Linehan & McCarthy, 2001, p.129)? Does confidence have a role in mathematics teacher learning within a community of practice as suggested by Graven (2004)?

Confusion between the Probe Tasks and follow-up activities

As the study group has evolved, and as it became clear that we needed to provide additional support for the classroom teachers, some confusion arose in relation to the distinction between the Probe Tasks and the targeted follow-up activities that were aimed at addressing the specific learning needs identified by the Probe Tasks. In part, this arose as a result of the extra activities provided by some members of the school mathematics community to support the classroom teachers (referred to above). In some instances, the relationship between these and the learning needs identified by the Probe Tasks was unclear. In other instances, the literacy demands of the activities limited their potential to address the learning needs.

Another source of confusion was that Probe Task advice advocated the use of similar materials in many of the follow-up activities. For example, the advice associated with the Subitising Probe Task advocated the use of an expanded range of subitisation cards. Although these were printed, laminated and made available to classroom teachers, there have been instances where either the teacher or the ITA have used the subitisation cards from the Probe Task kit for the purposes of a whole class activity (Classroom Video, November 2006). This is not particularly important, but it has the potential to diminish the value of the Probe Tasks as an assessment tool in the longer term. On the other hand, the fact that classroom teachers and assistant teachers have appropriated certain aspects of the Probe Tasks as teaching activities (e.g., the subitisation cards, open number lines, and ordering number activities using rope, pegs, and cards) can also be viewed as evidence of the affordances offered by the Probe Tasks and their efficacy as boundary objects in stimulating discussion and building a shared repertoire of teaching strategies. It is interesting that, in the first instance, this issue was identified and responded to by those members of the study group community charged with responsibility for mathematics more generally (the mathematics coordinator and the project officer from NT DEET). Their individual representations of the relationship of the Probe Tasks to the activities and the NT Mathematics Curriculum in the form of two quite different tables (Project artefacts, February 2007) reflected their different roles within the study group at the time and their respective understanding of the joint enterprise, but it also afforded a productive discussion among the study group community more widely which led to the decision to prepare a poster that would connect the Probe Tasks and activities to the 'big ideas' referred to earlier.

Division of Labor

Role diversity is to be expected in communities of practice but a tension arises when, with the very best of intentions (e.g., increasing tool accessibility, elaborate the 'big ideas'), the activity of one or more individuals in a community of practice serves to 'fill the participatory space' leaving little or no room for more marginalized members of the community to transform the nature of their participation. An example of this is when those members who justifiably view themselves as participants in a broader community of mathematics educators, prepared a number of tools, resources aimed at 'making the task of maintaining student responses easier' for the Indigenous participants (Project artefacts, March 2007). Another example is when, in the context of a interactive discussion of the 'big ideas', I failed to leave sufficient silences for others to grapple with the ideas and offer their suggestions (Study Group Video, July 2007).

Acting with the best of intentions but in a way which limits participation, is also evident among Indigenous members of the study group community who have been observed in the context of conducting a Probe Task interview to shift from a focus on probing students' understanding to directly telling and/or modelling to ensure that the student is not shamed and experiences a measure of success (Classroom videos, June, 2007, February 2008).

This points to the need to engage more openly and reflectively on how and why we act in certain ways and the impact of this on other members of the community. While this prompts the same sort of questions that were raised under the issue of level of support above, it also raises the more general question of how identity and agency operate within activity systems to marginalise and/or position community members in ways which restrict or enhance their participation in the social practices of the community?

CONCLUSION

Various attempts have and are being made to improve the educational outcomes of remote Indigenous Australians. There are many reasons for the relative lack of success of these initiatives and programs but two of the most significant are that we fail to recognise the enormous complexity involved in working across cultural and linguistic divides, and we grossly underestimate the resources required to bring together the sort of multi-disciplinary teams that might work collaboratively and interactively over whatever time it takes to address the inherent issues involved.

While very few of the issues referred to here are entirely unexpected, what they point to is the value of conceptualising complex learning sites as activity systems involving multiple communities of practice. Although this represents a tentative and incomplete account of the work of the BCC project, I believe it demonstrates the power of sociocultural theory (e.g., Wenger, 1998; Roth & Lee, 2007) and the value of design experiments (e.g., Lesh, & Kelly, 2000; Cobb, Confrey et al, 2003) in accommodating significant shifts in circumstances and modifying design elements. It also demonstrates the need for analytical approaches which enable us to disentangle the complex relations and interactions involved and reconsider underpinning theories. For example, framing cultural objects at the intersection of the communities of practice as boundary objects is helpful but it is the reframing of issues at the intersection of communities of practice as *boundary encounters*, and *people* at the intersection of communities of practice as brokers (Cobb, McClain et al, 2003, p. 13) that might ultimately prove to be the most valuable shift in our understanding of our collective experience.

In this contribution, I have outlined the design and methodological approach that is being used in the BCC Research Project, which is aimed at investigating an alternative, community-based model of Indigenous teacher education in remote Australia. A range of issues within and between communities of practice have been identified which illustrate the advantages of a design research approach to this type of research. In doing this, both the strengths and some of the limitations of a communities of practice approach have been highlighted.

Notes:

1. The Building Community Capital to Support Sustainable Numeracy Education in Remote Locations Project (BCC Project) is funded by the Australian Research Council and the Northern Territory Department of Employment, Education and Training. The views expressed are the author's and not necessarily those of the funding bodies.

2. The relationship between school mathematics and numeracy remains unresolved. However, for most practical purposes (e.g., the implementation of centrally funded programs to improve numeracy outcomes), the primary responsibility for numeracy education is seen to reside with school mathematics. For the purposes of the BCC project, numeracy education was seen to be best served by focusing on a small number of underpinning mathematical concepts and skills that could be considered in L1. This supports the view that numeracy is a "fundamental component of learning, performance, discourse and critique across all areas of the curriculum. It involves the disposition to use, in context, a combination of underpinning mathematical concepts and skills, ... mathematical thinking and strategies; general thinking skills; and a grounded appreciation of context" (Department of Education Training & Youth Affairs, 1997, p. 15, emphasis added).

3. The Probe Tasks were originally developed for the purposes of primary pre-service teacher education at RMIT University (Siemon, 2003). In particular, they were designed to meet the learning needs of graduate entry students who could not be expected to be familiar with the extended numeracy interview protocols used in schools at the beginning of the year.

4. Respectively, Professor Dianne Siemon (Project Director), Mr Tom Evison (Deputy Director, Batchelor Institute for Indigenous Tertiary Education), Associate Professor Michael Christie (Charles Darwin University), Ms Debbie Efthymiades (Manager, Curriculum Services, NT DEET), and for the first year of the project Ms Jan McCarthy (Numeracy Project Officer, NT DEET). In addition the project is supporting two full-time doctoral students, Ms Christine Walta whose interest is the identity and agency of the adult Indigenous participants in relation to school mathematics and Ms Kathryn McMahon, an experienced teacher of Indigenous students and Yolngu speaker, who is interested in the role of language and culture in the joint enterprise. I acknowledge their contributions and conversations in the preparation of this paper, although the views expressed are not necessarily representative of the views of the team.

5. See Commonwealth of Australia (2005, Appendices)

6. I am aware that in labeling the issues in this way, there is a danger in misrepresenting or masking their inherent complexity. The labels serve as markers of a particular impression/viewpoint at the time of writing. The reader is invited to ignore these if they feel they are getting in the way.

7. A rulu is the Yolngu word for five turtle eggs arranged in the sand so that four eggs are on the bottom and one is on the top. The use of 'rulu' with the number names for one to four, represented here within the limitations of the Times Roman font (e.g., 'wanggany rulu' meaning 1 five, 'marrma rulu' meaning 2 fives, and so on), suggest a quinary number system, where numbers such as 23 are referred to in terms of the number of fives and the number of ones (e.g., 'dambumiriw rulu ga lurrkan' meaning 4 fives and 3).

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Barriers to the Successful Integration of ICT in Teaching and Learning Environments: A Review of the Literature

Khalid Abdullah Bingimlas
RMIT University, Bandoora, VIC, AUSTRALIA

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The use of ICT in the classroom is very important for providing opportunities for students to learn to operate in an information age. Studying the obstacles to the use of ICT in education may assist educators to overcome these barriers and become successful technology adopters in the future. This paper provides a meta-analysis of the relevant literature that aims to present the perceived barriers to technology integration in science education. The findings indicate that teachers had a strong desire for to integrate ICT into education; but that, they encountered many barriers. The major barriers were lack of confidence, lack of competence, and lack of access to resources. Since confidence, competence and accessibility have been found to be the critical components of technology integration in schools, ICT resources including software and hardware, effective professional development, sufficient time, and technical support need to be provided to teachers. No one component in itself is sufficient to provide good teaching. However, the presence of all components increases the possibility of excellent integration of ICT in learning and teaching opportunities. Generally, this paper provides information and recommendation to those responsible for the integration of new technologies into science education.

Keywords: Science Teaching, ICT, Integration, Barriers, Professional Development, Review

INTRODUCTION

Information and communication technology (ICT) has become an important part of most organisations and businesses these days (Zhang & Aikman, 2007). Computers began to be placed in schools in the early 1980s, and several researchers suggest that ICT will be an important part of education for the next generation too (Bransford, Brown, &Cocking, 2000; Grimus, 2000; Yelland, 2001). Modern technology offers many means of improving teaching and learning in the classroom (Lefebvre, Deaudelin & Loiselle, 2006). Dawes (2001) is of the view that new technologies have the potential to support education across the curriculum and provide opportunities for effective communication between teachers and students in ways that have not been possible before. ICT in education has the potential to be influential in bringing about changes in ways of teaching. However, this potential may not easily be realised, as Dawes (2001) underlined when he stated that "problems arise when teachers are expected to implement changes in what may well be adverse circumstances" (p. 61).

Due to ICT's importance in society and possibly in the future of education, identifying the possible obstacles to the integration of these technologies in schools would be an important step in improving the quality of teaching and learning. Balanskat, Blamire, and Kefala (2006) argue that although educators appear to acknowledge the value of ICT in schools, difficulties

Correspondence to: Khalid Abdullah Bingimlas,
PhD Student in Science Education
School of Education, RMIT University
PO Box 71, Bundoora, 3083, VIC, AUSTRALIA
E-mail: *khalid.bingimlas@student.rmit.edu.au*

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continue to be encountered during the processes of adopting these technologies.

Many studies have been conducted to investigate barriers to the integration of technology in education and in particular in science education (e. g. Al-Alwani, 2005; Gomes, 2005; Osborne & Hennessy, 2003; Özden, 2007). This paper provides a meta-analysis of this literature that aims to present the perceived barriers to technology integration in science education highlighted in these studies.

The purpose of this paper

This analysis aims to bring together the findings and key points from a review of a significant part of the available literature associated with teachers' integration of ICT into their teaching. Studying the obstacles to the use of ICT in learning and teaching environments is crucial because this knowledge could provide "guidance for ways to enhance technology integration" (Schoepp, 2005, p. 2) and encourage greater use of ICT. Identifying the fundamental barriers may assist teachers and educators to overcome these barriers and become successful technology adopters (Al-Alwani, 2005).

Based on this analysis, the paper provides recommendations on improving ICT integration in classrooms.

According to Becta (2004), although there is a reasonable amount of research literature on the barriers to ICT in general, there are few studies that look at barriers which exist in specific subject areas. Becta (2004) asserts that focusing on the barriers that particularly affect practitioners in specific roles may be helpful. In response to this suggestion, after briefly reviewing the literature on the place of ICT in education more generally, the paper then provides a general discussion of the relationship between ICT and science education.

The importance of ICT in education in the future

Several studies argue that the use of new technologies in the classroom is essential for providing opportunities for students to learn to operate in an information age. It is evident, as Yelland (2001) argued, that traditional educational environments do not seem to be suitable for preparing learners to function or be productive in the workplaces of today's society. She claimed that organisations that do not incorporate the use of new technologies in schools cannot seriously claim to prepare their students for life in the twenty-first century. This argument is supported by Grimus (2000), who pointed out that "by teaching ICT skills in primary schools the pupils are prepared to face future developments based on proper understanding" (p. 362). Similarly, Bransford et al. (2000) reported that "what is now known about learning provides important guidelines for uses of technology that can help students and teachers develop the competencies needed for the twenty-first century" (p. 206).

ICT can play various roles in learning and teaching processes. According to Bransford et al. (2000), several studies have reviewed the literature on ICT and learning and have concluded that it has great potential to enhance student achievement and teacher learning. Wong et al. (2006) point out that technology can play a part in supporting face-to-face teaching and learning in the classroom. Many researchers and theorists assert that the use of computers can help students to become knowledgeable, reduce the amount of direct instruction given to them, and give teachers an opportunity to help those students with particular needs (Iding, Crosby, & Speitel, 2002; Shamatha, Peressini, & Meymaris 2004; Romeo, 2006).

While new technologies can help teachers enhance their pedagogical practice, they can also assist students in their learning. According to Grabe and Grabe (2007), technologies can play a role in student skills, motivation, and knowledge. They claim that ICT can be used to present information to students and help them complete learning tasks.

According to Becta (2003, p. 10), five factors influence the likelihood that good ICT learning opportunities will develop in schools: ICT resourcing, ICT leadership, ICT teaching, school leadership, and general teaching. Becta (2003) also indicated that the success of the integration of new technology into education varies from curriculum to curriculum, place to place, and class to class, depending on the ways in which it is applied. In science education, there are some areas where ICT has been shown to have a positive impact. The next section discusses this in more detail.

Science education and ICT

In the past few decades, science curriculum has changed to match the new aims of science education and it will continue to change (Osborne & Hennessy, 2003). Osborne and Hennessy (2003) state that the latest move towards "teaching about science rather than teaching its content will require a significant change in its mode of teaching and an improved knowledge and understanding in teachers" (p. 4). They emphasise that along with the changes in views on the nature of science and the role of science education, the increase in the number of ICTs offers a challenge to science teaching and learning.

Potential benefits from the use of ICT for science learning have been reported in several research studies. One of these potential benefits is the encouragement of communication and collaboration in science research activities. According to Gillespie (2006), new technologies can be used in primary science education to enable students to collect science information and interact with resources, such as images and videos, and to encourage communication and collaboration. Murphy (2006) reviewed the impact of ICT on the teaching and learning of science in primary schools. She indicated that "the Internet is used in primary science both as a reference source and as a means of communication" (p. 24). New technologies may also help to increase student motivation (Osborne & Collins, 2000), facilitate clearer thinking, and develop interpretation skills with data (Newton & Rogers, 2003).

Another benefit from using ICT in science education is that it expands the pedagogical resources available to science teachers (Al-Alwani, 2005). Pickersgill (2003) explored effective ways of utilising the Internet when teaching science. He found that the ease of Internet access allows teachers to help students to become experts in searching for information rather than receiving facts. He claimed it could "increase their [students'] awareness of the importance of the world around them, of citizenship and of a scientifically literate community" (p. 86). Kelleher (2000) reviewed recent developments in the use of ICT in science classrooms. While he wrote that ICT cannot replace normal classroom teaching, the review indicated that ICTs could be positive forces in science classrooms for a deeper understanding of the principles and concepts of science and could be used to provide new, authentic, interesting, motivating, and successful educational activities.

The new ICTs have other potential benefits as tools for enhancing science teaching and learning in schools (Skinner & Preece, 2003). These tools include those for data capture, multimedia software for simulation, publishing and presentation tools, digital recording equipment, computer projection technology, and computer-controlled microscopes (Osborne & Hennessy, 2003).

However, although the use of educational technologies in the classroom has many advantages, current research would suggest that it is not appropriate to simply assume that the use of ICT will necessarily transform science education (Osborne & Hennessy, 2003). As suggested above, there are several barriers that confront teachers when integrating ICT into education.

BARRIERS TO INTEGRATION OF ICT INTO EDUCATION

The act of integrating ICT into teaching and learning is a complex process and one that may encounter a number of difficulties. These difficulties are known as "barriers" (Schoepp, 2005). A barrier is defined as "any condition that makes it difficult to make progress or to achieve an objective" (WordNet, 1997, as cited in Schoepp, 2005, p. 2). The objective being analysed in this paper is successful ICT integration in science education.

Classification of the barriers. Different categories have been used by researchers and educators to classify barriers to teacher use of ICT in science classrooms.

Several studies have divided the barriers into two categories: extrinsic and intrinsic barriers. However, what they meant by extrinsic and intrinsic differed. In one study, Ertmer (1999) referred to extrinsic barriers as first-order and cited access, time, support, resources and training and intrinsic barriers as second-order and cited attitudes, beliefs, practices and resistance; whereas, Hendren (2000, as cited in Al-Alwani, 2005) saw extrinsic barriers as pertaining to organisations rather than individuals and intrinsic barriers as pertaining to teachers, administrators, and individuals.

Another classification found in the literature is teacher-level barriers versus school-level barriers. Becta (2004) grouped the barriers according to whether they relate to the individual (teacher-level barriers), such as lack of time, lack of confidence, and resistance to change, or to the institution (school-level barriers), such as lack of effective training in solving technical problems and lack of access to resources. Similarly, Balanskat et al. (2006) divided them into micro level barriers, including those related to teachers' attitudes and approach to ICT, and meso level barriers, including those related to the institutional context. The latter added a third category called macro level (system-level barriers), including those related to the wider educational framework.

Another perspective presents the obstacles as pertaining to two kinds of conditions: material and non-material (Pelgrum, 2001). The material conditions may be the insufficient number of computers or copies of software. The non-material obstacles include teachers' insufficient ICT knowledge and skills, the difficulty of integrating ICT in instruction, and insufficient teacher time.

Some of these studies look at the barriers at teacher, institution, or system level. However, since the purpose of this paper is to determine the present and future barriers that face science teachers in their schools, this analysis focuses on the teacher-level and school-level barriers only as discussed in the following sections.

Teacher-level barriers

Lack of teacher confidence. Several researchers indicate that one barrier that prevents teachers from using ICT in their teaching is lack of confidence. Dawes (2001) sees this as a contextual factor which can act as a barrier. According to Becta (2004), much of the research proposes that this is a major barrier to the uptake of

ICT by teachers in the classroom. In Becta's survey of practitioners (2004), the issue of lack of confidence was the area that attracted most responses from those that took part.

Some studies have investigated the reasons for teachers' lack of confidence with the use of ICT. For example, Beggs (2000) asserted that teachers' "fear of failure" caused a lack of confidence. On the other hand, Balanskat et al. (2006) found that limitations in teachers' ICT knowledge makes them feel anxious about using ICT in the classroom and thus not confident to use it in their teaching. Similarly, Becta (2004) concluded their study with the statement: "many teachers who do not consider themselves to be well skilled in using ICT feel anxious about using it in front of a class of children who perhaps know more than they do" (p. 7). In Becta's survey (2004), many of the teacher respondents who identified their lack of confidence as a barrier reported being particularly afraid of entering the classroom with limited knowledge in the area of ICT with their students knowing that this was the case. It was argued that lack of confidence and experience with technology influence teachers' motivation to use ICT in the classroom (Cox, Preston, and Cox, 1999b; Osborne & Hennessy, 2003; Balanskat et al., 2006).

On the other hand, teachers who confidently use technologies in their classrooms understand the usefulness of ICT. Cox, Preston, and Cox (1999a) found that teachers who have confidence in using ICT identify that technologies are helpful in their teaching and personal work and they need to extend their use further in the future.

Lack of teacher competence. Another barrier, which is directly related to teacher confidence, is teachers' competence in integrating ICT into pedagogical practice (Becta, 2004). In Australian research, Newhouse (2002) found that many teachers lacked the knowledge and skills to use computers and were not enthusiastic about the changes and integration of supplementary learning associated with bringing computers into their teaching practices.

Current research has shown that the level of this barrier differs from country to country. In the developing countries, research reported that teachers' lack of technological competence is a main barrier to their acceptance and adoption of ICT (Pelgrum, 2001; Al-Oteawi, 2002). In Syria, for example, teachers' lack of technological competence has been cited as the main barrier (Albirini, 2006). Likewise, in Saudi Arabia, a lack of ICT skills is a serious obstacle to the integration of technologies into science education (Al-Alwani, 2005; Almohaissin, 2006). Empirica (2006) produced a report on the use of ICT in European schools. The data used for the report came from the Head Teachers and Classroom Teachers Survey carried out in 27 European countries. The findings show that teachers who do not use computers in classrooms claim that "lack of skills" are a constraining factor preventing teachers from using ICT for teaching. Another worldwide survey conducted by Pelgrum (2001), of nationally representative samples of schools from 26 countries, found that teachers' lack of knowledge and skills is a serious obstacle to using ICT in primary and secondary schools. The results of a study conducted by Balanskat et al. (2006) have shown that "in Denmark ... many teachers still chose not to use ICT and media in teaching situations because of their lack of ICT skills rather than for pedagogical/didactics reasons" while "in the Netherlands ... teachers' ICT knowledge and skills is [sic] not regarded any more as the main barrier to ICT use" (p. 50). Hence, lack of teacher competence may be one of the strong barriers to the integration of technologies into education. It may also be one of the factors involved in resistance to change.

Resistance to change & negative attitudes. Much research into the barriers to the integration of ICT into education found that teachers' attitudes and an inherent resistance to change were a significant barrier (Cox et al., 1999a; Watson, 1999; Earle, 2002; Becta, 2004; Gomes, 2005; Schoepp, 2005). From his/her analysis of the questionnaires, Gomes (2005) found that science teachers' resistance to change concerning the use of new strategies is an obstacle to ICT integration in science teaching. At a broader level, Becta (2004) argued that resistance to change is an important barrier to teachers' use of new technologies in education.

Watson, an Australian researcher, (1999) argued that integrating the new technologies into educational settings requires change and different teachers will handle this change differently. According to him, considering different teachers' attitudes to change is important because teachers' beliefs influence what they do in classrooms. Becta (2004) claims that one key area of teachers' attitudes towards the use of technologies is their understanding of how these technologies will benefit their teaching and their students' learning. Schoepp's study (2005) found that, although teachers felt that there was more than enough technology available, they did not believe that they were being supported, guided, or rewarded in the integration of technology into their teaching. According to Empirica (2006), teachers who are not using new technology such as computers in the classroom are still of the opinion that the use of ICT has no benefits or unclear benefits.

Resistance to change seems not to be a barrier itself; instead, it is an indication that something is wrong. In other words, there are reasons why resistance to change occurs. According to Earle (2002), the change from a present level to a desired level of performance is facilitated by driving (encouraging) forces such as the power of new developments, rapid availability, creativity, Internet access, or ease of communication, while it is delayed by resisting (discouraging) forces such as lack of technical support, teacher expertise, or time for planning. In their study, Cox et al. (1999a) found that teachers are unlikely to use new technologies in their teaching if they see no need to change their professional practice. They showed that teachers who resist change are not rejecting the need for change but lack the necessary education in accepting the changes and are given insufficient long-term opportunities to make sense of the new technologies for themselves.

Obviously, not all communities have this barrier. In Europe, for example, Korte and Hüsing (2007) state that only very few teachers can be regarded as fundamentally opposing the use of ICT in the classroom. Only a fifth of European teachers believe that using computers in class does not have significant learning benefits for pupils (Korte & Hüsing, 2007).

School-level barriers

Lack of time. Several recent studies indicate that many teachers have competence and confidence in using computers in the classroom, but they still make little use of technologies because they do not have enough time. A significant number of researchers identified time limitations and the difficulty in scheduling enough computer time for classes as a barrier to teachers' use of ICT in their teaching (Al-Alwani, 2005; Becta, 2004; Beggs, 2000; Schoepp, 2005; Sicilia, 2005). According to Sicilia (2005), the most common challenge reported by all the teachers was the lack of time they had to plan technology lessons, explore the different Internet sites, or look at various aspects of educational software.

Becta's study (2004) found that the problem of lack of time exists for teachers in many aspects of their work as it affects their ability to complete tasks, with some of the participant teachers specifically stating which aspects of ICT require more time. These include the time needed to locate Internet advice, prepare lessons, explore and practise using the technology, deal with technical problems, and receive adequate training.

Recent studies show that lack of time is an important factor affecting the application of new technologies in science education (Al-Alwani, 2005). According to Al-Alwani (2005), lack of time is a barrier affecting the application of ICT in Saudi Arabia because of busy schedules. He indicated that because Saudi teachers work from about 7.00 a.m. until 2.00 p.m. and the average number of class sessions taught by science teachers is 18 per week, both teachers and students have a limited number of hours during the day to work on integrating ICT into science education. Similarly, in Canada, Sicilia (2005) concluded that teachers take much more time to design projects that include the use of new ICT than to prepare traditional lessons. Teachers interviewed by Sicilia (2005) commented that "the constraints of different class schedule [sic] contributed to the lack of time they spent together to work on planning classroom activities" (p. 41). Supporting this finding, the most significant constraint on use quoted by 86–88% of primary and secondary science teachers surveyed by Dillon, Osborne, Fairbrother, and Kurina (2000) was lack of time (as cited in Osborne & Hennessy, 2003, p. 37). Gomes (2005) concluded that one of the main reasons that science teachers do not use ICT in the classroom is lack of the time necessary to accomplish plans.

Lack of effective training. The barrier most frequently referred to in the literature is lack of effective training (Albirini, 2006; Balanskat et al., 2006; Beggs, 2000; Özden, 2007; Schoepp, 2005; Sicilia, 2005; Toprakci, 2006). One finding of Pelgrum's (2001) study was that there were not enough training opportunities for teachers in the use of ICTs in a classroom environment. Similarly, Beggs (2000) found that one of the top three barriers to teachers' use of ICT in teaching students was the lack of training. Recent research in Turkey found that the main problem with the implementation of new ICT in science was the insufficient amount of in-service training programs for science teachers (Özden, 2007), and Toprakci (2006) concluded that limited teacher training in the use of ICT in Turkish schools is an obstacle.

According to Becta (2004), the issue of training is certainly complex because it is important to consider several components to ensure the effectiveness of the training. These were time for training, pedagogical training, skills training, and an ICT use in initial teacher training. Correspondingly, recent research by Gomes (2005) relating to science education concluded that lack of training in digital literacy, lack of pedagogic and didactic training in how to use ICT in the classroom, and lack of training concerning the use of technologies in science specific areas were obstacles to using new technologies in classroom practice. Some of the Saudi Arabian studies reported similar reasons for failures in using educational technologies: the weakness of teacher training in the use of computers, the use of a "delivery" teaching style instead of investment in modern technology (Alhamd, Alotaibi, Motwaly, & Zyadah, 2004), as well as the shortage of teachers who are qualified to use the technology confidently (Sager, 2002).

Providing pedagogical training for teachers, rather than simply training them to use ICT tools, is an important issue (Becta, 2004). Cox et al. (1999a) argue that if teachers are to be convinced of the value of using ICT in their teaching, their training should focus on the pedagogical issues. The results of the research by Cox et al. (1999a) showed that after teachers had attended professional development courses in ICT they still did not know how to use ICT in their classrooms; instead they just knew how to run a computer and set up a printer. They explained that this is because the courses only focused on teachers acquiring basic ICT skills and did not often teach teachers how to develop the pedagogical aspects of ICT. In line with the research by Cox et al. (1999a), Balanskat et al. (2006) indicated that inappropriate teacher training is not helping teachers to use ICT in their classrooms and in preparing lessons. They assert that this is because training programmes do not focus on teachers' pedagogical practices in relation to ICT but on the development of ICT skills.

However, beside the need for pedagogical training, according to Becta (2004), it is still necessary to train teachers in specific ICT skills. Schoepp (2005) claims that when new technologies need to be integrated in the classroom, teachers have to be trained in the use of these particular ICTs. According to Newhouse (2002), some initial training is needed for teachers to develop appropriate skills, knowledge, and attitudes regarding the effective use of computers to support learning by their students. He argued that this also requires continuing provision of professional development to maintain appropriate skills and knowledge.

Fundamentally, when there are new tools and approaches to teaching, teacher training is essential (Osborne & Hennessy, 2003) if they are to integrate these into their teaching. However, according to Balanskat et al. (2006), inadequate or inappropriate training leads to teachers being neither sufficiently prepared nor sufficiently confident to carry out full integration of ICT in the classroom. Newhouse (2002) states that "teachers need to not only be computer literate but they also need to develop skills in integrating computer use into their teaching/learning programmes" (p. 45).

According to Newhouse (2002), teachers need training in technology education (focusing on the study of technologies themselves) and educational technology (support for teaching in the classroom). Similarity, Sicilia (2005) found that teachers want to learn how to use new technologies in their classrooms but the lack of opportunities for professional development obstructed them from integrating technology in certain subjects such as science or maths. Other problematic issues related to professional development in ICT are that training courses are not differentiated to meet the specific learning needs of teachers and the sessions are not regularly updated (Balanskat et al. 2006).

Pre-service teacher education can also play a significant role in providing opportunities for experimentation with ICT before using it in classroom teaching (Albirini, 2006). Lack of on ICT focus in initial teacher education is a barrier to teachers' use of what is available in the classroom during teaching practice (Becta, 2004). Where training is ineffective, teachers may not be able access to ICT resources.

Lack of accessibility. Several research studies indicate that lack of access to resources, including home access, is another complex barrier that discourages teachers from integrating new technologies into education and particularly into science education as the following discussion illustrates.

The various research studies indicated several reasons for the lack of access to technologies occurred. In Sicilia's study (2005), teachers complained about how difficult it was to always have access to computers. The author gave reasons like "computers had to be booked in advance and the teachers would forget to do so, or they could not book them for several periods in a row when they wanted to work on several projects with the students" (p. 50). In other words, a teacher would have no access to ICT materials because most of these were shared with other teachers. According to Becta (2004), the inaccessibility of ICT resources is not always merely due to the non-availability of the hardware and software or other ICT materials within the school. It may be the result of one of a number of factors such as poor organisation of resources, poor quality hardware, inappropriate software, or lack of personal access for teachers (Becta, 2004).

The barriers related to the accessibility of new technologies for teachers are widespread and differ from country to country. Empirica's (2006) European study found that lack of access is the largest barrier and that different barriers to using ICT in teaching were reported by teachers, for example a lack of computers and a lack of adequate material. Similarly, Korte and Hüsing (2007, p.4) found that in European schools there are some infrastructure barriers such as broadband access not yet being available. They concluded that one third of European schools still do not have broadband Internet access. Pelgrum (2001) explored practitioners' views from 26 countries on what were the main obstacles to the implementation of ICT in schools. He concluded that four of the top ten barriers were related to the accessibility of ICT. These barriers were insufficient numbers of computers, insufficient peripherals, insufficient numbers of copies of software, and insufficient simultaneous Internet access. Toprakci (2006) found that low numbers of computers, oldness or slowness of ICT systems, and scarcity of educational software in the school were barriers to the successful implementation of ICT into science education in Turkish schools. Similarly, Al-Alwani (2005) found that having no access to the Internet during the school day and lack of hardware were impeding technology integration in Saudi schools. Recent research on Syrian schools indicated that insufficient computer resources were one of the greatest impediments to technology integration in the classroom (Albirini, 2006).

Basically, there are several barriers associated with the lack of access to ICT. In his research, Gomes (2005) found a lack of appropriate infrastructure and a lack of appropriate material resources to be barriers. However, overcoming such hardware barriers does not, in itself, ensure ICT will be used successfully. According to Balanskat et al. (2006), the accessibility of ICT resources does not guarantee its successful implementation in teaching, and this is not merely because of the lack of ICT infrastructure but also because of other barriers such as lack of high quality hardware, suitable educational software, and access to ICT resources.

Newhouse (2002) asserts that poor choices of hardware and software and a lack of consideration of what is suitable for classroom teaching are problems facing many teachers. Similarly, Cox et al. (1999a) found that the majority of teachers agreed that insufficient ICT resources in the school and insufficient time to review software prevent teachers using ICT. According to Osborne and Hennessy (2003), the limitations on access to hardware and software resources influenced teachers' motivation to use ICT in the classroom.

Lack of technical support. Without both good technical support in the classroom and whole-school resources, teachers cannot be expected to overcome the barriers preventing them from using ICT (Lewis, 2003). Pelgrum (2001) found that in the view of primary and secondary teachers, one of the top barriers to ICT use in education was lack of technical assistance.

In Sicilia's study (2005), technical problems were found to be a major barrier for teachers. These technical barriers included waiting for websites to open, failing to connect to the Internet, printers not printing, malfunctioning computers, and teachers having to work on old computers. "Technical barriers impeded the smooth delivery of the lesson or the natural flow of the classroom activity" (Sicilia, 2005, p. 43).

Korte and Hüsing (2007) argued that ICT support or maintenance contracts in schools help teachers to use ICT in teaching without losing time through having to fix software and hardware problems. The Becta (2004) report stated that "if there is a lack of technical support available in a school, then it is likely that technical maintenance will not be carried out regularly, resulting in a higher risk of technical breakdowns" (p. 16). Many of the respondents to Becta's survey (2004) indicated that technical faults might discourage them from using ICT in their teaching because of the fear of equipment breaking down during a lesson.

In science teaching, several studies indicated that lack of technical support is a main barrier to using technologies. According to Gomes (2005), ICT integration in science teaching needs a technician and if one is not available the lack of technical support can be an obstacle. In Turkey, Toprakci (2006) found that the lack of technical support was one of two significant barriers to the integration of ICT into science education in schools and might be considered "serious". In Saudi Arabia, science teachers would agree to introduce computers into science teaching, except that they believe they will encounter problems such as technical service or hardware problems (Almohaissin, 2006). Sicilia (2005) argued that whatever kind of technical support and access teaching staff have and whether they have twenty years of experience or are novices to the profession, technical problems generate barriers to the smooth delivery of science lessons by teachers.

Although lack of technical support can prevent teachers from successfully integrating ICT into education, recent research indicates that in some countries (such as the United Kingdom, the Netherlands, Latvia, Malta and the Czech Republic), schools have recognised the importance of technical support to assist teachers to use ICT in the classroom (Korte and Hüsing, 2007).

In general, several studies have identified a range of the following or similar factors as widespread barriers: lack of computers, lack of quality software, lack of time, technical problems, teachers' attitudes towards computers, poor funding, lack of teacher confidence, resistance to change, poor administrative support, lack of computer skills, poor fit with the curriculum, lack of incentives, scheduling difficulties, poor training opportunities, and lack of skills in how to integrate ICT in education. There are complicated relationships among these barriers as discussed in the following section.

DISCUSSION

This section is divided into three parts. First, the relationship between the barriers will be discussed, then some implications for teachers and for schools will be suggested, followed by a discussion on the limitations of this study.

The relationship between the barriers. As previously mentioned, there are multifaceted relationships between the barriers. Some barriers such as lack of teacher competence and lack of accessibility seem to be closely related to others. Some barriers such as lack of teacher confidence and resistance to change seem to be more significant than others. The following discussion focuses on the relationships between lack of accessibility and lack of competence and other factors such as time, training, and technical support.

The lack of accessibility to resources as a barrier is closely related to several other key issues which can themselves be considered barriers to teachers' use of ICT. Although the resources are available in schools, the lack of time does not allow teachers to access these resources. There may be technical equipment available but there is no time for the teacher to operate and review those techniques. This may be because the number of lessons in one day is too many or because the time available during the class lesson is insufficient.

Another example related to the accessibility barrier, as found by previous studies, is that lack of teacher training reduces the integration of technology into education. Educational technological materials may be available in schools but teachers cannot use them because of a lack of pedagogical or skills-related (practical) training in how to use these ICT resources. On the other hand, it may be that the lack of access to resources leads to a reduction in training opportunities. It is important to remember that not only is access to resources used in the classroom for students' learning important, but also access at home will help with self-training.

Access to resources might be available, but teachers cannot use ICT in the classroom because it may be difficult for them to operate ICT tools. Thus teachers always need technical assistance because this assistance may provide them with up-to-date equipment in the new world of technology. Technical support helps in training and training takes time. Together they allow access to ICT resources and thus help the successful integration of technology in the teaching process.

Lack of competence is one of the most important obstacles to teachers' use of technology in education. It is linked to other issues such as training, time and technical support. The first problem linked to the competence barrier is the lack of effective training. Teacher training in the use of modern technology in the classroom helps to increase the teachers' efficiency in using ICT in education effectively. Training includes training in basic skills in using technology as well as training in the integration of those technologies into interactive and effective teaching. Self-training is also important to increase competence and improve ICT use. It can happen through providing teachers with opportunities to use resources such as user guides, CDs, and IT equipment for self-training at home.

The improvement of ICT skills also requires that teachers have time available. Teachers whose schools give them time to develop their skills can be more creative than teachers who do not have sufficient time. In order to achieve sufficient competence in using ICT effectively in education, a teacher also needs professional technical support.

As discussed above, the relationship between access to modern technological resources and the competence of teachers to use them is complicated. This relationship links those factors with other issues such as time, training, and technical support. Also, there is a relationship between the barriers of lack of accessibility and lack of competence. In other words, teachers may not be able to access ICT resources unless they have skills in the use of technology and can work with it efficiently in their teaching. On the other hand, access to ICT resources can help teachers increase their competence whether by self-training through the Internet or by communication with experts. The opportunities for development of teachers' skills and their access to ICT resources can be increased by providing them with technical support and sufficient time.

Another issue that has to be raised, according to previous studies, is the teachers' confidence in using ICT to help them teach effectively. The lack of confidence is a problem linked to the previous two issues: the lack of access to resources and the lack of teacher competence. Regarding the availability of ICT resources, perceived ability to use ICT and having the basic skills to operate it may increase teachers' satisfaction with modern technologies, which may motivate teachers to integrate ICT in education. However, we should not overlook the provision of training, enough time, and technical support.

In general, it is difficult to classify the barriers into groups and think about the barriers in entirely separate categories because, as mentioned above, there are complex relationships among the barriers. For example, lack of technical support, time, and training can lead to technical problems, which can in turn lead to a lack of access to ICT resources and a lack of teachers' competence. This can lead to teachers lacking confidence and influence their motivation.

Understanding the levels in this study at which these barriers prevent teachers from using ICT may help educators to decide how the barriers can be tackled. In other words, teachers should be convinced of the importance of using ICT in the classroom. Then, they should be provided with access to resources. After that, teachers need to be able to use these resources successfully. Access to ICT and the ability to use it cannot be possible without sufficient time, effective training, and technical support.

Implementation. One can see that it is much easier to remove barriers by resolving and reducing the reasons for the occurrence of these barriers. Educators, teachers, and school principals need to collaborate to overcome any of the obstacles and break down the above mentioned barriers to the meaningful integration of ICT into teaching and learning.

There are some implications for teachers and schools for successful integration of ICT into education arising from this. Table 1 aims to illustrate these implications.

Schools need to provide training courses for teachers to gain experience in dealing with the new devices, modern technologies, and new pedagogical approaches. Technical support needs to be provided in schools. Additionally, schools must provide teachers with the necessary ICT resources including hardware and software. It is important for schools to cooperate with

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Table 1. Possible implications for schools and teachers for the integration of ICT into education

Barriers	Implementation	
	For schools	**For teachers**
Lack of access	- Providing ICT resources including hardware and software	- Taking advantage of resources offered at schools - Access to ICT resources at home
Resistance to change	- Training in new pedagogical approaches	- Being open minded towards new ways of teaching
Lack of time	- Providing sufficient time: reducing the number of teacher lessons or increasing the daily lesson time	- Acquiring skills of self-organisation and time managements
Lack of training	- Providing training courses in dealing with the new devices, modern technologies, and new pedagogical approaches	- Preparing themselves (pre-service) by self-training - Taking up opportunities for training offered at schools - Knowing how to access to resources
Lack of technical support	- Providing continued technical support	- Relying on themselves to be able to solve problems in their use of ICT - Accessing available support

teachers by providing sufficient time to implement new technologies in the classroom. For example, a school can reduce the teacher's number of lessons or increase the daily lesson length.

Teachers also need to engage with this implementation. Teachers should take advantage of ICT resources offered at schools. They need to be prepared well before joining the teaching profession. Where training is absent, teachers can prepare themselves by enrolling in private sessions or by self-training. They should be open minded towards new approaches of teaching. Where support is lacking, they need to find ways to be able to solve problems involving their use of ICT in schools. Finally, teachers should acquire skills of self-organisation which will help them a great deal in conducting their classes when using ICT.

Limitation. The purpose of this paper was to determine the present and future barriers that face science teachers in integrating ICT in their schools. Thus this study has focused on the teacher-level barriers and school-level barriers only.

It should also be noted that although this study focuses on significant barriers revealed by the research literature, there are less direct barriers to the use of ICT in the classroom. Some of these barriers, which are mentioned in the literature are lack of classroom management skills, poor administrative support, poor school funding, and poor fit with the curriculum (Al-Alwani, 2005; Balanskat et al. 2006; Becta, 2004; Beggs, 2000; Gomes, 2005; Lazaros & Rogers, 2006; Schoepp, 2005). While these barriers were not addressed here, they are still important and need to be investigated.

CONCLUSION

The aim of this paper was to provide information on encouraging the desired improvement in the future teaching situation to those responsible for the integration of ICT into science education. The findings of this study indicate that teachers have a strong desire for the integration of ICT into education but that they encountered many barriers to it. The major barriers were lack of confidence, lack of competence, and lack of access to resources. Since confidence, competence and accessibility have been found to be critical components for technology integration in schools, ICT resources including software and hardware, effective professional development, sufficient time, and technical support need to be provided for teachers. No one component in itself is sufficient to produce good teaching. However, the presence of all components increases the likelihood of excellent integration of ICT in learning and teaching opportunities.

Note

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Developing a Rural and Regional Science Challenge to Utilise Community and Industry-Based Partnerships

Damian Blake & Coral Campbell
Deakin University, Geelong, VIC, Australia

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Interest and participation in science in schools has been declining for many years and there is a genuine need to rejuvenate interest in science at the high school level. One possible solution is the completion of challenging science projects which fulfil an authentic purpose in the community. This paper discusses the results of ongoing research into the establishment of a rural and regional Science Challenge which makes use of partnerships with local industries and community groups to encourage the development of authentic science projects. In the development of the Science Challenge, many issues are emerging in relation to teachers' work, resources, administration and school cultures. This paper reports on the preliminary findings and indicates directions for the future.

Keywords: Community, Engagement, Learning, Partnerships, Science Education

INTRODUCTION

Interest and participation in school-based science has been declining for many years and there is now an established need to rejuvenate the appeal of science for students at the secondary level (Lyons 2006; Tytler, Osborne et al. 2008). Contributing to the image problem that science has in our schools is a perception commonly held by students that learning science simply involves the transmission of rather abstract scientific knowledge, from the text book or teacher, into the minds of the students. Unfortunately, the scientific knowledge being learned is too frequently considered to be irrelevant by school students (Aikenhead, 2006; Sjøberg & Schreiner, 2005; Thomson & Fleming, 2002).

Yet there exists some shining examples of innovative teaching in science education that encourage students to understand science as a process of meaningful inquiry (Tytler, Symington, Smith & Rodrigues, 2008). Such innovative practices in science education typically involve:

- *Project based or problem based learning;*
- *A strong skills focus involving scientific knowledge and related processes;*
- *More open pedagogies where students are given increased agency;*
- *The creation rather than absorption of knowledge by students;*
- *A wider set of knowledges including knowledge processes, interdisciplinary links, knowledge about the contemporary and local use of Science Technology and Mathematics (STM), and knowledge of people using STM in employment;*
- *School programs providing significant in situ learning experiences for teachers;*
- *A 'real' audience for students' work;*
- *Field trips and projects in the local environment;* and
- *Working with scientists and with local community members, as well as involvement of parents and the wider community (Tytler, Symington, Smith & Ridrigues, 2008 p. 11).*

Fensham (2006) emphasises the need to make stronger links between science education practices and the real world beyond the classroom as a strategy to achieve more meaningful and relevant learning

Correspondence to: Damian Blake, Senior Lecturer in Applied Learning
Faculty of Arts and Education, School of Education, Deakin University, Geelong 3220, VIC, AUSTRALIA
E-mail: *damian.blake@deakin.edu.au*

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experiences for students. This is a theme also represented in place-based education (Sobel, 2004), which highlights the need for teachers to re-connect classrooms with communities and for students to experience 'hands-on' learning in real world contexts. Sobel suggests that:

> *Place-based education is the process of using the local community and environment as a starting point to teach concepts in language arts, mathematics, social studies, science and other subjects across the curriculum. Emphasising hands-on, real-world experiences, this approach to education increases academic achievement, helps students develop stronger ties to their community, enhances students' appreciation for the natural world, and creates a heightened commitment to serving as active, contributing citizens. Community vitality and quality are improved through the active engagement of local citizens, community organisations and environmental resources in the life of the school (Sobel, 2004, P.7).*

In extending the idea of community-embedded and project-based approach to learning science, the researchers have investigated the possibility of students completing extended science projects linked with local industry or community groups, and which fulfil a valuable purpose within the community. It is the researchers' intention to eventually create a network of support and community of practice (Wenger, 2002) around similar pedagogical innovations in rural and regional areas of South West Victoria. Based on this idea, the researchers have developed a Science Challenge that involves students in secondary science working alongside scientists or community groups to solve real problems within the local community.

Students participating in the Science Challenge are expected to work closely with their teacher and a community partner to develop a significant scientific question that has relevance to the local community. They then go about designing an appropriate investigative approach to answering the question through the collection of empirical data. At the end of a project (that may run for six to twelve months) the students present their work at a small conference with fellow students and teachers in the region and members of the local community. This process involves the students producing a research report, giving a presentation to their peers and teachers, and being involved in a brief interview with a panel of judges.

Approach

In developing the Science Challenge the researchers initially investigated the type of science fairs that currently exist in Australia and internationally. We were particularly interested in what was currently available, where fairs were being held and what sort of 'scientific challenge' was being presented to students. It was found that, while there were many examples of challenges that required students to solve a singularly-focused scientific problem formulated by an external organisation such as a university, there were very few science challenges that focused on solving real-life problems originating from the students' local community. Similarly, while we discovered there are many excellent examples of partnerships being formed between schools and their local communities, there is significant potential for the development of a *network of partnerships* approach to research and develop the resources and innovative pedagogical practices that are currently tending to occur in isolated instances.

To research the development of a rural and regional Science Challenge the researchers decided to start by advertising the idea of a challenge to schools and members of the wider community in the region. Participants interested in developing the challenge were then asked to attend a workshop meeting where the idea would be further developed in collaboration with science teachers and potential community/industry partners. Here the researchers presented some examples of international science challenges and then there was discussion loosely based around the following questions:

- *What are current examples of innovation in the local region that provide instances of how science can be taught by solving real-life problems in the community?*
- *What value could be found in the introduction of a regional 'Science Challenge' that emphasises students solving local community problems by using science?*
- *What is the nature of the partnerships that will need to be formed between the schools and their local community to achieve the 'hands-on' approach to teaching science required by the introduction of the Science Challenge?*
- *What challenges are likely to be confronted by teachers and community partners when they undertake 'hands-on' scientific investigations with community partners?*
- *What are the future possibilities for the development of community-embedded science projects in the local region?*

Each of the workshops was video recorded so the researchers could analyse the participants' responses to the questions and the discussions that followed. Four schools and three community partner organisations eventually committed to undertake a trial of a Science Challenge in 2008. An additional two schools had expressed interest in participation in the challenge and attended the first workshop, but were unable to continue because of staffing changes at their schools and a concern that participation would require them to undertake too much additional work. The researchers visited each of the four participant schools to investigate how the process was unfolding in the eyes of the teachers and community partners.

FINDINGS

Support for the challenge

The schools who committed to participate in the Science Challenge were all represented by teachers who anticipated using the Science Challenge as a part of their Year 9 and 10 Science programs. The reasons for their interest have been summarised in Table 1 below:

Although the idea of the Science Challenge was offered to high school science teachers generally, it is interesting to note that all of the teachers who responded to the invitation intended to use it as a strategy for engagement for their Year 9 or 10 classes. When this point was discussed at the workshop the teachers' responses emphasised the significant potential they saw for the 'hands-on' dimension of the Science Challenge to engage their Year 9 and 10 students in learning science.

> *They [Year 9] respond much better when they can do something 'hands-on' for our science classes…I think this would be a great opportunity for the students to undertake a real science project that gets them thinking about what they are learning [Year 9 Science Teacher].*

Several of teachers noted that while they would have liked to participate in such a challenge with their senior Biology or Chemistry students, they felt that the "*pressure of the VCE curriculum meant they had too much content to get through and could not afford the time out of the classroom*". On this point the teachers noted that the time constraint of the senior curriculum was one of the most significant factors stopping them from engaging their senior students in more hands-on activities outside the classroom.

As shown in Table 2, each of the community groups represented at the workshops expressed an interest in the challenge that related to their core business in the community as well as providing authentic opportunities for students to learn science within the realm of their area. The Regional Water Authority, for example, understood that there was a need to develop better understanding in community about water conservation and management and thought the "*Science Challenge could provide the potential to develop deep understandings in the next generation by their 'hands-on' involvement in a local issue*" related to water management.

In the course of the discussion there was general agreement between the teachers and the community groups that the Challenge could provide a good strategy to link theory and practice for young people learning about science. They also expressed concern that a lack of *connection to the real world* meant *many students' were turned-off learning science by the time they get to Year 10* and that the challenge would potentially address this issue by *making science more real* for students.

Factors potentially inhibiting participation

The teachers and community partners identified a number of significant factors that could potentially inhibit their sustained participation in the Science Challenge. These have been summarised in Table 3.

During the workshops, two of the three key factors identified to be potential inhibitors to participation in the challenge were able to be overcome by developing new 'partnership arrangements' between schools and community partners. In the case of access to resources it was decided during the workshops that the schools would be able to utilise some resources available in industry to support students undertaking investigations in the challenge. Such resources included instruments that were likely to be useful for undertaking scientific measurements and the discussion eventually lead to a consideration of other potential community/industry partners.

The idea of forming partnerships between schools and community/industry organisations also enabled the issue of teachers' concern for their knowledge of current scientific practices to be addressed. To support the Challenge it was decided that schools would be able to access the knowledge and expertise of industry staff. This would allow teachers the opportunity to up-date their knowledge of science.

The issue of time was more difficult to resolve as it was a factor over which teachers and the community/industry organisations had limited control. The four schools that were able to overcome the concern for accessing suitable amounts of time needed to participate in the Challenge were schools that had already committed to making available blocks of time in the timetable as a strategy to support 'hands-on' learning throughout the middle years curriculum in particular. The Challenge therefore represented an opportunity to support what the schools were already attempting to do. For Schools 5 and 6 the issue of time represented a serious inhibitor to their participation in the Challenge.

The Projects

The projects proposed and developed by the students and their teachers from the four schools were all related to themes that were understood to be relevant to each individual school's community context. All of the projects adopted an environmental focus and involved accessing local contexts, such as creeks and parks. The projects have been summarised in Table 4.

The following case study provides a more detailed account of one school's challenge project in action. The nature of the students' scientific investigations must be understood in the context of their local community to reveal the significance and meaning of their local application of science.

Table 1. School Participants' interest in the Science Challenge

School Participants	Interest expressed in the Science Challenge
Schools 1 to 4 were all represented by Year 9 and 10 Science Teachers.	• Interested in the potential for the challenge to engage Year 9 and 10 students in learning science by using 'hands-on' projects. • Professional learning benefits from the development of a wider network of like-minded science teachers. • Benefits to be gained from purposeful links to community resources that will support 'hands-on' teaching of science. • Excellent strategy to connect theory and practice for students and to make science more meaningful. • An opportunity to encourage and extend students displaying a high aptitude for science. • The idea would work well with each of the four schools' commitment to applied learning in the middle years. This meant the schools each had timetabled extended periods of time for applied learning activities where students would be able to undertake the challenge. • Significant potential for the Science Challenge to achieve several outcomes within the Victorian Essential Learning Standards (VELS) (Victorian Curriculum Assessment Authority, 2008) if an integrated approach across the disciplines was to be adopted by schools.
Schools 5 and 6 were also Year 9 and 10 teachers who were interested in the Challenge but unable to continue involvement past the first workshop.	• Expressed an expectation that there would be benefits for their Year 9 and 10 Science students. • Noted that the challenge did not fit into any allocated time for this type of 'hands-on' learning. • Did not continue because the challenge would require additional time over and above the existing science curriculum which was timetabled as single periods of contact.

Table 2. Community Participants' interest in the Science Challenge

Community Participants	Interest expressed in the Science Challenge
Regional Water Authority, including Water Watch	• Understood there was significant potential for the challenge to assist with students learning about contemporary issues of water conservation and management. • Had experienced success with accessing Primary schools with the Water Watch program but had very limited success with high schools. The challenge provided an opportunity to connect to science education in high schools. • Understood there was an opportunity to extend their scientific data on the local water ways with the help of high school students. • The theme of water conservation and management provided an excellent source of authentic challenges for the students.
Parks Victoria, Weed Warriors and Weed Busters	• Noted there were several authentic problems related to conservation and management of land in the region suited to the challenge. • An opportunity for students to experience first-hand some the issues that are affecting the local area.
Biotechnology Industry	• Identified the significance of increasing students' awareness of science in the real world. • An opportunity for students to become involved in a science-based industry that is increasingly important in terms of the region's economy. • Potential for students to see the region's growing Biotechnology Industry as a career path at a time when interest in science-related careers is waning.

Table 3. Factors potentially inhibiting participation in the challenge

Factors expected to inhibit participation	Comment
Time	✓ All of the teachers involved noted the school's timetable ultimately controlled their access to time to participate in the challenge. However, four of the schools were able to synchronise their participation in the challenge with periods of extended time allocated in the timetable for applied learning activities. The remaining two schools did not have access to these larger periods of time in the timetable and concluded they were likely to struggle to sustain their involvement in the challenge. ✓ The issue of time was also raised by the community/industry organisations who were concerned that because their core business was not education, their involvement in the challenge could potentially be expensive if too much time was required of their staff.
Accessing resources	✓ Two of the teachers were concerned that they may not have access to the appropriate scientific equipment required for the students to participate in the challenge. Examples of the equipment that might be required for participation in a water-related investigation included pH meters, Dissolved Oxygen (DO) meters and other similar instruments. On this point the participants from the Water Authority noted they were willing to assist with access to such equipment. ✓ Further discussion revealed many opportunities for schools to access scientific equipment they normally had limited access to, including Atomic Absorption Spectrophotometers (AAS) and other very sensitive analytic instruments that would be helpful.
Teachers' Knowledge	✓ In the course of the discussion about potential investigations several teachers expressed concern that their own scientific knowledge might not be sufficient to support their students undertaking an investigation. Teachers who were specialists in Biology, for example, expressed concern about their need for detailed knowledge of physics if an open-ended investigation was predominately in this area. ✓ Both the teachers and community organisations noted the challenge would provide a good opportunity for teachers to up-date their knowledge of science in different areas as they could be exposed to current industry practice.

Case Study: Year 9 Science Challenge Students Investigating Water Quality in their Local Creek

The Context: *The school is located in a large rural township in Victoria which is currently experiencing the full effects of sustained drought in the region. The town has a large, centrally located lake that forms a prominent feature of the town and which is in close proximity to the school. The dwindling water levels in the lake and its connecting water ways and creeks have been a source of major concern in the community, particularly because of the apparent impact on water quality and the local fauna and flora. The poor condition of the lake is commonly discussed in the local newspaper and on the radio, although there has been very limited reference to scientific investigations describing the changing water quality.*

The Challenge for Students and their Teacher: *The science teacher and students in Year 9 decided to investigate precisely how water quality in the local creek was changing as a result of the diminishing levels of water in the town's lake. The students and their teacher decided to approach the local council and the regional Water Catchment Authority to discuss how they could design and carry out their investigation. The Water Authority was able to assist with the provision of suitable equipment for testing water quality and provided training for both the students and their teacher to assist with their use of scientific instruments. The Council and Water Authority decided they would publish the students' results on their website as they did not currently have access to that level of data about changing water in the region's creeks.*

The Students and Teacher in Action: *As the school bell rings to signify the end of lunch, Ms Smith moves swiftly through the staffroom to meet her Year 9 Science students at the front of school where she has arranged their transport to the nearby creek. The fifteen students are already gathered at the entrance of the school with their water analysis equipment stacked neatly for their imminent departure in the mini-bus. The equipment is loaded into the bus carefully, followed by the students eager to begin collecting data at the creek. They know they have a limited time and the routine has been well-rehearsed for the past few weeks.*

The students arrive at the creek and, without being prompted by Ms Smith, they unpack the testing equipment and prepare to collect data about the quality of the creek water passing through their town. Each of the students has a particular role in the process which they carry out with confidence and without delay.

The first pair of students to alight from the bus move swiftly towards the creek to sweep for macro-invertebrates using the special net supplied by the Regional Water Authority. After each sweep

Table 4. Summary of Challenge Projects

School	Brief Description of Challenge Projects in Context
1	Year 9 students and their science teacher undertaking an investigation into water quality changes in the local creek caused by the rural town's diminishing supply of water in the lake. The students and teacher worked with the Regional Water Authority and Local Council.
2	Year 10 students and their teacher investigating biodiversity in the large local flora and fauna reserve located close to the school. The students and teachers consulted with staff from Parks Victoria and were interested to understand how rapid population growth in region may be impacting on biodiversity.
3	Year 9 students and their teacher decided to investigate the distribution of weeds and land management in their rural location. The students were able to utilise expertise from the local Landcare group.
4	Year 9 students and their teacher investigated fluctuations in fish populations in the local creek. The students consulted with staff at a fish hatchery to examine the possibility of replenishing diminishing fish numbers.

they carefully place the contents of the net into a tray where two other students identify and investigate the diversity of invertebrate life in the creek. The students' excitement levels are high as they find another specimen of a small fish they had found previously in the creek, much to the surprise of the Regional Water Authority. According to their consultations with staff at the Authority this specimen is an unusual find for the creek and indicates all is not normal with the water quality. Word of their discovery has passed around the school and the town and one student comments 'now we're famous scientists'.

Another pair of students commences measuring the temperature and pH of the water at various points along the creek. They work beside a pair of students who are analysing the level of Dissolved Oxygen in the creek water. These students are also using equipment supplied by the Regional Authority and they exercise care as they know their data is contributing to a local understanding about the health of the water systems. Their confidence in using the equipment has been gained by their work with staff from the Regional Water Authority who, several weeks earlier, had provided some 'hands-on' instructions for the students and Ms Smith on how to perform the tests using the equipment provided. Later, when the students return to school, their data is promptly recorded in spread sheets and they commence analysing it for trends over the previous weeks.

As these Year 9 Science students go about their investigation of their local creek to determine its health as an aquatic system their industrious efforts demonstrate a genuine engagement with learning science. The data they have collected is also used by the Regional Water Authority and eventually posted on the Regional Council's website for public access.

DISCUSSION

Discussions with students and teachers participating in the Science Challenge demonstrate there are clear benefits to be gained for Middle Years students' and teachers participating in the 'hands-on' investigations associated with the Science Challenge. The levels of Year 9 student engagement with scientific concepts such as pH, Dissolved Oxygen and biodiversity, reinforced the teachers' initial beliefs that students at this level would respond very positively to the Challenge. Further discussions with the students also indicated that they perceived the science they were learning as a part of the Challenge to be meaningful because of its capacity to contribute knowledge that was also valued by the wider community. The students perceived they were 'doing science rather than just learning facts from a text book' and that 'this way of learning was much more fun'.

It is also clear that the partnerships formed between science teachers and organisations such as the Water Management Authority are essential for supporting the Challenge with specific knowledge and resources that otherwise may inhibit schools from participating in such authentic hands-on investigations. The community organisations also serve a very important role in assisting students to understand the value attributed to the knowledge they are producing as a part of their investigation. On this point the researchers believe there is potential for the students to differentiate between the objectivity required in order to undertake scientific investigations, and the subjective meaning that is then attributed to the knowledge produced by their science.

Although there is evidence of some success being experienced in the individual schools by encouraging students to undertake meaningful, 'hands-on' investigations in partnership with community partners, the full potential of the Science Challenge is yet to be realised through the establishment of a wider network of school-community partnerships and a community of practice to support it on a regional level. However, a new network has now emerged in the region specifically to support Science and Maths Education by facilitating better partnerships between schools and community organisations. The network includes science educators from schools, the local Technical and Further

Education (TAFE) institution and the University sector, as well as representatives from the wider community, such as the Biotechnology Industry, whose core-business involves an application of science.

It is also clear that while increased levels of Year 9 students' engagement in science is a positive consequence of the Science Challenge, there is also a need to further investigate other important issues such as: effective strategies for assessment to support the authentic nature of their learning; exploring possibilities for better integration of the Challenge across the different components of the Victorian Essential Learning Standards (Victorian Curriculum and Assessment Authority, 2008), including:

- *the processes of physical, personal and social development and growth;*
- *the branches of learning reflected in the traditional disciplines; and*
- *the interdisciplinary capacities needed for effective functioning within and beyond school.*

There is also a need to further examine strategies that maximise the partnership arrangements between schools and community partners on a regional level. The partnerships that appeared to form most easily were those related to environmental science applications, such as a school working with the local Regional Water Authority to investigate water quality. Although the teachers were very interested in potential projects involving the local biotechnology industry, they were less confident with the science involved with this industry and struggled to establish a clear project their students could realistically investigate.

CONCLUSION

The researchers' intention of creating a rural and regional Science Challenge in South West Victoria has stirred the interest of community organisations and middle years science teachers in the region. The teachers, in particular, see value in using the Challenge to engage middle years students in science through 'hands-on' learning projects that focus on real-life issues. Staff from the community organisations also see the Challenge as an opportunity to address important issues related to their core business in the community. The Challenge has worked most effectively when teachers have been able to align the Challenge to curriculum time allocated for 'hands-on' learning projects in a school. Additionally, when teachers have worked closely with community partners to support the Science Challenge, there is significant potential for scientific resources and expert knowledge to be shared and teachers' professional learning to be enhanced.

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Towards a Theory of Identity and Agency in Coming to Learn Mathematics

Peter Grootenboer and Robyn Jorgensen (Zevenbergen)
Griffith University, Gold Coast, Qld, AUSTRALIA

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In writing this paper we draw considerably on the work of Jo Boaler and Leone Burton. Boaler's studies of classrooms have been particularly poignant in alerting the mathematics education community to a number of key features of successful classrooms, and how such features can turn around the successes for students who traditionally perform poorly in school mathematics. This is supplemented by the recent work of Leone Burton who worked extensively with research mathematicians in order to understand their communities and ways of working. Collectively these two seminal works provide valuable insights into potential ways to move the field of school mathematics forward. In times when there is international recognition of the plight of school mathematics, there is a need for new teaching practices that overcome the hiatus of contemporary school mathematics.

Keywords: Learning Theory, Identity, Agency, Working As A Mathematician.

INTRODUCTION

For a long time now we have known that there have been serious problems with mathematics participation and engagement. The situation facing mathematics has been highlighted recently in Australia by two significant reviews into the mathematical sciences:

Statistics at Australian universities (Statistical Society of Australia, 2005)

Mathematics and statistics: Critical skills for Australia's future (Australian Academy of Science, 2006).

Although these reviews were conducted in Australia, a similar story has emerged around the world. In these reviews, particular attention has rightly been given to school mathematics and the problems of non-engagement with an increasing number of students in higher level courses of mathematical study. That said, it has been known for a long time, through the many descriptive studies that have been undertaken since the 1970s, that mathematics has been unpopular and disliked, and yet the problems appear to grow unabated and little progress has been made to arrest the decline.

In this paper we draw on the work of two researchers - Jo Boaler and Leone Burton - who collectively create a new space for theorizing a way out of the potential teacher blame. Drawing on these works, we seek to illustrate the power of agency in working mathematically. For too long, the pedagogy of school mathematics has focused on procedural knowledge rather than depth of understanding. Combining the work of Boaler and Burton, we draw on an illustrative example of teachers working to solve a task. They draw on many of the concepts identified in the works of Boaler and Burton. Our contention is that the combining of Boaler's 'dance of agency' with Burton's 'working as a mathematician' enables a rich way forward in the teaching of school mathematics.

Mathematics and Teaching: A Link?

Recently there have been reviews of the preparation, qualities and qualifications of mathematics teachers (e.g., "The Preparation of Mathematics Teachers in Australia" (Harris & Jensz, 2006) for the Australian Council of Deans of Science). There have been reports highlighting

Correspondence to: Peter Grootenboer, Senior Lecturer in Mathematics Education
Griffith Institute for Education Research, Griffith University, Gold Coast 4222, Qld, AUSTRALIA
E-mail: *p.grootenboer@griffith.edu.au*

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the poor mathematical content knowledge of teachers, particularly primary teachers and non-specialist teachers who are placed in front of secondary classes. Primary preservice teachers often are not confident with the study of mathematics and generally have low levels of understanding of many mathematical concepts (Kanes & Nisbet, 1996). Many preservice teachers enter their teacher education courses with low levels of mathematics knowledge as well as considerable anxiety towards the subject (Brown, McNamara, Hanley, & Jones, 1999; Cooney, Shealy, & Arvold, 1998; Grootenboer, 2003). In many cases, preservice primary teachers have opted for studies in areas other than mathematics so when they enter their courses they have low levels of mathematics content knowledge and frequently have an anxiety towards involvement in the discipline (Goulding, Rowland, & Barber, 2002). The development of a strong content knowledge is central to the development of quality mathematics teachers. For example, Mandeville and Lui (1997) concluded that the level of teacher knowledge impacted significantly on the learning of the students, whereby teachers with high levels of mathematical understandings provided higher quality learning opportunities for their students than did their peers with limited understandings of mathematics. Thus, the role of teacher education is to scaffold teachers into confident and competent developers and users of mathematics so that they are better able to teach mathematics.

Simon (1993) has raised concerns about primary preservice teachers' weak conceptual knowledge and Cooney et al. (1998) have noted similar difficulties with secondary teachers' content knowledge. In their study of preservice teachers in the UK, Goulding et al. (2002) found that there was a significant link between "poor subject knowledge [being] associated with weaknesses in planning and teaching primary mathematics" (p. 699). Recognizing that such a correlation does not imply causation, the authors elaborated further that the positive links were potentially due to the connection that preservice teachers were making between content knowledge and pedagogic knowledge. Goulding, et al contended that the link was due to both cognitive and affective dimensions of the students. Being strong in content knowledge offered a sense of confidence, which in turn was realized through teacher actions. Offering a strengthened program in content knowledge gave students resources upon which they could draw as they planned their teaching. The authors concluded that where students had secure mathematical foundations, they had greater confidence in their own knowledge as a teacher.

Preservice teachers often enter their initial training courses with self doubt about their capacity to learn mathematics (Cooney et al., 1998; Philippou & Christou, 1998). These conceptions come to frame how they will organize learning environments once they begin to plan for teaching (Sánchez & García, 2008). This extends to practicing teachers: Bibby (2002) showed that the belief that mathematics is about 'right answers' brings about feelings of shame amongst practicing teachers if they do not know the answers. This produces teaching practices that are governed by teachers ensuring they have correct answers, thereby offering a restricted repertoire of learning experiences for students. Ball (1990) argued strongly that the focus in teacher preparation needed to be one that encouraged students to relearn the content knowledge in order to develop new understandings of pedagogic knowledge. In attempting to break the distinction between content knowledge and how it is taught, Ball (1990) argued that preservice teachers needed to develop connections between mathematical knowledge and teaching knowledge. Strength in content knowledge can be transferred to pedagogical knowledge. This possibility was made evident by Mandeville and Lui (1997), who reported that teachers with a strong knowledge were "[able to provide] greater depth in dealing with concepts, better equipped to lead students to use their knowledge and use more higher-order content than teachers less knowledgeable about the content" (p. 406).

At this critical point we want to suggest that it is time to move on from studies that repetitively show that mathematics is suffering from poor teacher knowledge and attitudes towards mathematics—either with teachers or students—and to try and look forward by offering some positive directions. To advance this agenda we need more than good ideas that seemed to have worked in a particular context; we need to begin developing a theoretical, robust framework that will address these concerns in a coherent and holistic fashion. In this paper we have drawn on the seminal works of Burton and Boaler to consider mathematical learning from both the discipline knowledge and the mathematical activity perspectives. After reviewing Burton's findings from her study with research mathematicians we briefly highlight some relevant points from Boaler's classroom studies. After presenting an example from teacher education we finish by employing the metaphor of a 'dance of agency' (Pickering, 1995) to discuss mathematics learning, particularly in the light of the current crisis.

The Practice of Mathematicians

The two recent reviews of mathematical sciences in Australia mentioned previously both made significant comment on and recommendations for school mathematics education. Interestingly, the authors of these reports were mathematical scientists and there appeared to be little input from mathematics educators and mathematics teachers. Although this is problematic, it does perhaps highlight the gap that seems to exist between mathematicians and statisticians, and teachers and teacher educators. This is unhealthy and if the current decline in participation and interest in mathematics is to be arrested these groups need to engage in dialogue and mutual projects. To this end, the work of Burton (1999a, 1999b, 2001, 2002) is helpful because her research explored the practices of research mathematicians and their implications for the learning of mathematics.

In 1997 Burton studied the practices of 70 research mathematicians in Great Britain and one of the key features she identified was the collaborative nature of their practice. The benefits for collaborating included practical (e.g., sharing the work), quality (e.g., greater range of ideas on problems), educational (e.g., learning from one another) and emotional (e.g., feeling less isolated) reasons. Clearly, working together with other mathematicians was seen as important, but there appeared to be a distinction between the public perception of mathematics as a lonely enterprise and the reality of mathematicians' practice, in which collaboration is highly valued.

Perhaps another anomaly from public perception was Burton's finding that mathematicians have emotional, aesthetic and personal responses to mathematics.

> … although knowing when you know is extremely important, you have to live with uncertainty. You gain pleasure and satisfaction from the feelings that are associated with knowing. These feelings are exceptionally important since, often despite being unsure about the best path to take to reach your objective, because of your feelings you remain convinced that a path is there. … This is particularly poignant in the light of the picture painted of mathematics as being emotion-free … (Burton, 1999a, p. 134)

The mathematicians in her study highlighted the power of the "aha!" moment and the joy of mathematical discovery, revealing the clear link between mathematics and those who produce it. Allied to their emotional responses to their mathematical practice were aesthetic reactions. They described mathematics in terms such as "wonder", "beauty" and "delight" and these personal responses provided motivation for continued engagement and fuelled a passion for the discipline of mathematics. Davis and Hersh (1998, p. 169) lamented that "blindness to the aesthetic element in mathematics is widespread and can account for the feeling that mathematics is dry as dust, as exciting as a telephone book …".

Another feature of research mathematicians' practice was the importance of intuition or insight. While the mathematicians were less than clear in describing what intuition and/or insight were, they were unambiguous in highlighting the importance of these factors in their mathematical practice. The suggestion was that intuition can be developed through the application of knowledge and experience in mathematical discovery and reflection upon such investigations.

Burton highlighted other features of the practice of mathematicians including the desire to seek and see rich connections between the various branches of mathematics and between mathematics and other disciplines, but her other main agenda was to highlight the pedagogical implications of her findings. Throughout her reports Burton highlighted the distinction that is evident between the work and learning practices of research mathematicians, and the learning experiences of mathematics students at almost all other levels from preschool to undergraduate degree programs. This led her to assert that "we have a responsibility to make the learning of mathematics more akin to how mathematicians learn and to be less obsessed with the necessity to teach 'the basics' in the absence of any student's need to know" (Burton, 2001, p. 598). Even at a very general level, this would require mathematical pedagogy to be characterized by collaboration and group work with attention paid to the emotional, aesthetic and intuitive dimensions of the discipline. This encompasses the 'doing' of mathematics that has been under-emphasized in education as it has focused on the 'knowing' of mathematics. Indeed, perhaps an issue with the educational recommendations in the Australian review of mathematical sciences was the emphasis on mathematical content knowledge that can be taught largely through a transmission model. On this point Boaler (2003) commented:

> There is a widespread public perception that good teachers simply need to know a lot. But teaching is not a knowledge base, it is an action, and teacher knowledge is only useful to the extent that it interacts productively with all the different variables in teaching. Knowledge of subject, curriculum, or even teaching methods, need to combine with teachers' own thoughts and ideas as they too engage in something of a conceptual dance. (p. 12)

In her seminal work in England and the United States, Boaler (1997, 2008) explored the mathematical practices of teachers and students in two different sorts of mathematics classrooms. In one group of classes, the mathematical pedagogy was 'traditional' and the students learned standard algorithms through worked examples and textbook exercises. The other classrooms were characterized by open-ended projects, group work and discussion (Boaler & Staples, 2008). Not surprisingly, Boaler found that generally students learned a form of mathematics that was consistent with the mathematical epistemology and pedagogy of their classroom experiences. In addition the students in the 'non-traditional' classes performed better in a range of assessment tasks and overall they developed more positive attitudes towards the subject and a stronger sense of their own mathematical identity. While the detail is light here, it seemed in short that the experiences of the students in the non-traditional classrooms were akin to the mathematical practices of research mathematicians outlined above.

The studies undertaken by Boaler and Burton were substantially different in terms of their participants - school students and research mathematicians - but offer poignant insights into the ways in which working as a mathematician enhances the potential for learning school mathematics. The characteristics identified by Burton as being the ways of working as a research mathematician encouraged her to plead for schools to adopt such practices in school mathematics classrooms. She hoped that this would improve the learning outcomes for students. Boaler's study indicates that when teachers embrace the characteristics mentioned above there is enhanced performance of students. But, as we noted at the outset of this paper, there is a strong sense that many of the teachers entering school mathematics classrooms may have weak content knowledge, weak pedagogic content knowledge and/or a fear of mathematics. If school mathematics is to be reformed, then we propose that there should be some sense of agency among teachers that will enable them to move forward with their existing knowledge. To this end, we draw on Boaler's notion of agency which she expands from the work of Pickering (1995).

The Dance of Agency

The claims of Burton regarding the working practices of mathematicians and the classroom evidence of Boaler (2003) together seem to make a strong case for considering the learning of mathematics to be like 'working as a mathematician'. Conceptually, this requires engaging in what Pickering (1995) calls a 'dance of agency'. In studying the practices of research scientists and mathematicians he noted that they choreographed a complex routine by which, at times, they drew on their own agency as scientists or mathematicians, and yet at other times they would concede authority to the agency of their discipline and associated community of practice. This is like the interplay between the activity of mathematics and the content knowledge of mathematics that was highlighted above. Rather than seeing the practice or knowledge-base being supreme, it reveals a dialectic interdependence where the mathematician (at any level) requires both to meaningfully and successfully engage in the mathematical enterprise. Likewise, teachers also need to engage in a dance of agency where they appraise and decide when to encourage and support the students' own agency as mathematicians and when to defer to the authority of the discipline (e.g., the requirement to follow a standard procedure or form of presentation). It is worth noting that mathematicians do defer to the agency of the discipline in their practice and it is this authority that is credible in a mathematics classroom. However, in traditional mathematics classrooms the authority usually resides with the textbook and the teacher, both of which are temporal aspects of students' mathematical development and they do not endure as the discipline itself does.

Boaler's (2003) use of the dance of agency in her work illustrates the importance of the learner having a robust and empowering identity in relation to mathematics. Knowing how and when to draw on mathematical ideas to solve problems is a critical part of the dance of agency. Boaler used examples of learners who could not solve tasks but drew on a range of skills, knowledge and collective wisdom in order to solve those problems. This process is akin to that identified in Burton's work with research mathematicians. The practices offered by Boaler and Burton may offer a way forward and out of the quagmire of contemporary school mathematics that is being identified by many external forces.

In the remainder of this paper, we draw on an example taken from a professional development activity that one of us undertook with a group of primary school teachers. We argue that the level of the learners is not the feature of the analysis as we contend this example can be used across all sectors of learning—primary, secondary and preservice/inservice education. Rather, the analysis focuses on the ways of working, which is the significant aspect of the example. These provide an illustration of how learners, in this case teachers, can draw on previous knowledge to work collectively to achieve a common goal. That is, they drew on their sense of agency around particular mathematical ideas and their collective wisdom as a group to solve the task. Collectively the goal is attained but not without considerable input from the learners. The input varies in form and timing, and helps to illustrate the powerful learning made possible when working in ways similar to mathematicians but also having a sense of agency that allows for the legitimate use of learners' understandings that enable the building of deeper understandings. However, as Boaler's work has highlighted, such success is dependent on the learners' sense of identity with mathematics and their sense of agency through which they can 'dance' between the known and the unknown in order to build deeper understandings. It is for this reason we have used this example. After describing and illustrating the mathematical practices of these teachers we will draw on their example to discuss the features of mathematical classrooms that promote the development of robust mathematical identities through an authentic 'dance of agency'. We use this illustrative example to show how the mathematical identity of learners may be constituted through particular practices of mathematics.

The data provided in the following example are drawn from field notes from the professional development activity. The quotes and drawings are those written by the observer and are representative of the discussion made by the participants as no formal recording tools (tape recorders) were used. The data were triangulated with participants so that they are an accurate summation of the interactions in the workshop.

Sum of the Interior Angles of an Octagon: A Working Example

A group of primary school teachers had been working on mathematical problems as part of a professional development day. The participating teachers were engaged in the mathematical tasks in order to better understand their own teaching of mathematics. A standard geometry task was provided that required the teachers to work out the sum of the interior angles of an octagon. There was some discussion as to what an octagon is, and how many sides it has. Once this was clarified, the teachers worked in small groups. In the example we have used here, there were four teachers in the group and they were all relatively experienced teachers.

I have no idea on how to work this out.

Well if you look at it you can divide it into triangles. [T divides octagon into 8 triangles; see Figure 1]. See, there are 8 triangles. Each triangle has got 180º so to work out what the angles are on the bottom of the triangle, you have to work out how many degrees are in the top angle there [draws an arrow to the centre].

Ah, so that is 360° divided by 8

Huh? [unsure of where the figures are coming from]

Well you know that there are 360° in a circle [draws a circle around the centre where the apexes of the triangles meet] and you can see there are 8 triangles making up that circle.

So, 360 ÷ 8 is [some talk on how to work this out, two teachers use pencil and paper for the division] … 45.

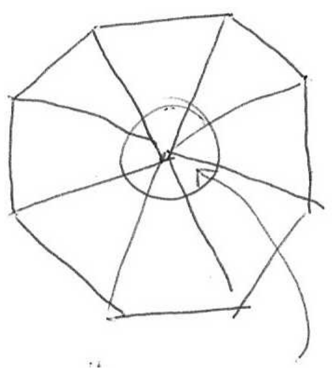

Figure 1. Participant's diagram

OK now what we have to do is work out how big the other angles are. They are the same size so you take 45 from 180 and then divide by 2.

Why?

Well there are two angles [points to the two angles at the bottom of one triangle] and we need to see how big one is.

The discussion continues so that the group identifies the size of one of the interior angles of the constructed triangles as being 67.5º. There is some discussion that it cannot be correct. One teacher commented that she thought it must be incorrect as the leader would not have given them an angle with a half in it. Calculations are checked and the answer is seen to be correct. Someone then suggested that they have to multiply it by 8 so it will not be a "half number" any more.

To this point, the teachers have been drawing on their shared knowledge of the properties of a triangle, in particular, the internal angles of the triangle. There has been considerable sharing of intellectual resources that have enabled the group to move forward. At this point, one of the teachers noticed incongruence between what had been calculated and her knowledge of angle types.

Another teacher in the group comments that it cannot be right as the number they have calculated is less than 90° which would make for a less than 'straight angle' [assumed to mean a 'right angle']. There is some discussion and movement of the shape and then agreement that they have done something wrong.

I know what it is… that is only half of the angle. See look, we have worked out half of the angle; the other part is in the triangle next door.

You're right, so the size of one angle is really double what we found so that makes it 135. And that is bigger than 90 so we must be right now.

Ok, then we multiply by 8 and find out what the total size is.

Someone in the group then multiplied 135 by 8 using pencil-and-paper to come to an answer of 1080.

At this point the group has successfully completed the task of finding the internal angles of an octagon. This is often the end of a mathematics exercise. However, such an approach leads to shallow thinking and not what we would see as working as a mathematician. Much like the task of the scientist, the task of the mathematician is to find generalizations and to prove their results. In this case, all that has been achieved is the answer to a routine problem. To facilitate the moving into the 'working as a mathematician' the leader of the session then asked the group to find patterns.

Once the group has finished, the leader then asks them to find out what it might be for a hexagon and some other shapes. The group goes through a similar process, this time drawing the hexagon, finding the magnitude of the central angle and then the size of each interior base angle. This is then doubled and multiplied by 6. At this point, a woman who had not contributed too much of the discussion interrupts and poses the following:

You know what we are doing… making more work for ourselves. Look at this. You divided the 120 by 2 and got the size of the angle inside the triangle and then you doubled it. We halved and then doubled so we have just done the same thing twice.

The teachers then go on to do two more shapes of their own choosing. The leader then posed the problem to see if they could make a prediction for any shape and how would they do it. The response was that this means they needed to make a formula for the problem.

For us, it is this step that makes this activity more akin to Burton's proposition that schools adopt the practices of working as mathematicians. By seeking ways to make generalizations, the teachers were being asked to think as mathematicians do. As the following section of the field notes suggest, the two groups of teachers being observed used different strategies, one of which was more effective in resolving the generalization task.

Group one made a table for their results. Aside from the triangle which they knew had 180°, they had only made shapes with even numbers of sides so that the table looked like that shown in Figure 2.

Hey, look at that you can see a pattern there. Each time we go up by 2 sides, it gets bigger by 360. That is a square so if we only increased by one side it would be getter bigger by 180° – that is a triangle.

However, this group was unable to move beyond this observation to make a more generalizable statement.

Group two used a similar method and when it came to the discussion at the end of the session during which groups shared their findings, this group explained that they found that the pattern was "increasing by 180° each

sides	o°	△s
3	180	1
4	360	2
5		
6	720	4
7		
8	1080	6
9		
10	1440	8

Figure 2. Participant's table

time a side was added to a shape" but you could not go below one triangle as this was the lowest point. One teacher explained their generalization as follows:

We found that what the pattern is- is that each shape is the number of sides take away 2 and then you multiply by 180°. So if you use a hexagon as the example, you can see that it has 6 sides but if you takeaway 2, you have 4 and then if you multiply it by 180 you get the sum of the interior angles. We thought you could say it like (number of sides minus 2) and then multiply by 180 so that is (n-2) x 180. We checked it out with the others and it worked. So if you use the triangle. It has 3 sides, so that is 3-1 and then times 180 so that is 180 and that is right.

This final part of the activity we see as critical in enabling participants to justify and explain their working processes. Again, as Burton's work indicated, this justification strategy is used by working mathematicians. It made the teachers use metacognitive processes to think through and then articulate their working and thinking strategies.

In the next section we draw on this example to theorize the aspects of 'working as a mathematician' from the combined works of Boaler and Burton. In this section, we identify three key elements to working as a mathematician which are evident in the example cited.

Coming to Understand "Working as a Mathematician"

In drawing on Burton's and Boaler's work, we propose that there are three elements to developing a sense of working as a mathematician. There are the cognitive aspects of knowing mathematics and thinking like a mathematician. Burton draws considerably on the cognitive features of working mathematically. Both Boaler and Burton recognize the importance of the social context within which learning occurs. The pedagogy employed at Railside was strongly influenced by Complex Instruction (Cohen & Latan, 1997; Cohen, Latan, Scarloss, & Arellano, 1999) in terms of organizing the learning environment. Burton draws more closely on the literature regarding communities of practice (Wenger, 1998) to theorize her position, and in doing so, sees that "knowledge and the knower are mutually constituted within these dialogic communities" (1999a, p.132). Collectively the two positions provide a more comprehensive picture of the potential for classroom practice. Finally, the focus of both authors, and this paper, is that of mathematics. This tripartite model – social/cultural, cognitive/affective and mathematics – is represented diagrammatically in Figure 3.

What can be seen in this example are a number of features about working as a mathematician. We use the example presented above to illustrate the notion of

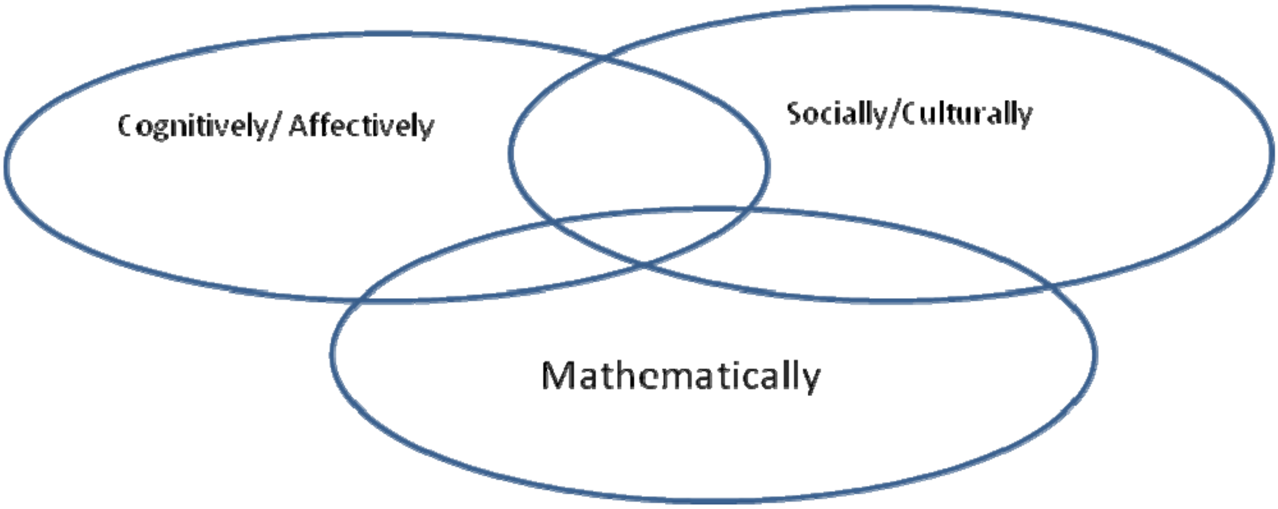

Figure 3. Aspects of working as a mathematician

working as a mathematician and the importance of agency in this process. In so doing, we link this to classroom practice as a means of moving forward the debates on mathematical thinking and learning.

Socially

We define the context within which learning and working is occurring as the social dimension. This includes the ways in which the learning environment is organized along with the social and cultural dispositions that learners bring to that environment. Indeed, the social context of mathematical learning has been widely discussed in the literature and many of the concepts that emerged (e.g., agency) have been dealt with in greater depth elsewhere, but here we want to particularly highlight aspects of the example through which we can see features that enabled the learners to work as mathematicians.

Group Work: Being part of a group and working as a collective enabled the teachers to share their knowledge which is often tacit and not well understood. The sharing and discussion of mathematical knowledge can also be generative and leads to more complete understandings. Furthermore, it can reduce the pressure that individual students can experience in mathematics to memorize and readily recall mathematical rules and formulae and hence, they can devote more attention to mathematical thinking and problem solving. In this example, the teachers did not know the formulae and so they relied on their collective wisdom, which enabled them to fill in gaps in each other's knowledge. Without the input from various members of the group it is unlikely that the collective would have advanced as far with their thinking as was evident in the observations. It is also important to note that this form of collaborative group work is consistent with the practices of mathematicians highlighted by Burton in the studies we reviewed earlier. It seems that when individuals are released from the pressure of having to carry the complete package of relevant knowledge to work on a particular mathematical problem, they are free to engage more fully in the generative mathematical thinking and conceptualizing, and more significant outcomes are possible. This sort of community activity is based on constructive discussion.

Collaborative Talk: The interactions between the participants were focused on the task, and thus enabled them to talk through their observations. When working alone the individual has to undertake the roles of worker and observer either simultaneously or by flipping between the two (or some combination), but in the group context there are opportunities for learners to negotiate, either overtly or tacitly, times of activity and times of reflection and observation. In the example above, having some participants working on the task and others observing enabled the observers to gain insights into the actions and base their discussion on shared and recent experiences. In this case, one of the teachers was able to 'see' that her colleagues were halving and then doubling. Being able to provide this input in a non-threatening way to colleagues enabled the group to move forward in a productive way.

Ethos: The environment established in this session was non-threatening and supportive so that learners could actively engage in the task at levels that met their current needs and understandings. Issues relating to student affect in learning mathematics have received a lot of attention in recent years, and it is clear that there have been real problems for many students when they are stressed and anxious about mathematical activity. The benefits of developing and sustaining a supportive ethos have been documented in Boaler's studies (Boaler, 2002a, 2002b) as enabling learners to participate without threat and hence open opportunities for participation and learning. While teachers have a significant role in developing this sort of learning environment, there is a sense of camaraderie and shared mission when the students can provide this mutual support through operating in a collaborative group.

Agency: In the example presented, the participants seemed to have a sense of agency because they were able to draw on their own understandings of the situation and use these to develop richer understandings that were strongly mathematical. Given their ages and teaching background, it would not have been unreasonable to expect that they recalled the formulae for internal angles of a polygon. However, none of them could remember this formula (which is what we had hoped in planning the activity). Instead, they drew on their preexisting knowledge in ways that enabled them to move forward with the problem, and to ultimately solve it—and to generate their own formula. Being able to draw on existing knowledge to solve the problem in non-traditional ways ensured task completion and also allowed the participants to gain a strong sense of achievement. Their sense of agency was not based on their knowledge, attitude, aptitude or ability to single-handedly complete the investigation, but rather on being able to contribute something to the shared dynamic that emerged as they engaged with the task collaboratively.

Task: A critical dimension to the successful mathematical work of the participants was the task. The design of the task may be seen as quite traditional but the leader deviated from those practices often found in classrooms where rote procedures are applied to a range of questions and little opportunity is provided to develop richer understandings. Extending the task to find the generalization enabled the teachers to develop ways of thinking mathematically and to construct their own formula/generalization. It is important to note that the task was inherently mathematical in both content and process and, as such, it was consistent with the practices of mathematicians (as highlighted by Burton and summarized previously). Moving away from tasks that can be solved through the application of formula that are applied in a rote, lock-step manner is critical in fostering learning environments that encourage deep learning.

Working as a Mathematician

This aspect of the learning environment is very different from the format of the traditional classroom where the learner is often situated as a 'consumer' or user of mathematics rather than a creator of mathematics. The practices of research mathematicians are creative in that their work is to 'create new knowledge' by drawing on their own sense of agency and by working with others in ways consistent with their discipline. While the knowledge developed by the participants in the example was not unknown, it was new to them and, as such, it involved a creative process. Furthermore, the participants drew on their collective mathematical knowledge and developed their thinking within a mathematical framework.

Mathematically

This aspect of working as a mathematician draws on features that can be considered as part of the mathematical content knowledge or the pedagogical content knowledge identified by Shulman (1986). These features are often distinctly mathematical and are what can be seen to differentiate mathematics from other curriculum areas. The features involve mathematical knowledge, but also mathematical practices. Unlike traditional classrooms where rote-and-drill learning, textbook-based exercises and strong teacher direction dominate, mathematicians employ practices that are quite different from school mathematics practices. Indeed, this difference does raise concerns about the 'mathematics-ness' of what occurs in classrooms as we would argue students' contemporary mathematical experiences are not necessarily based on mathematical behaviour. Below we highlight some of the key mathematical practices that were identified in the example.

Identifying Patterns: Creating the table enabled the participants to observe a pattern. Some participants were able to describe the pattern but not the generalization. For others, seeing the pattern through representing the information on the table enabled them to construct the generalization. It is important to note that although most students can be taught to draw a table (and they are in most classrooms), the drawing of the table was not an end in itself, but rather it was a technology to help the participants engage in the mathematical task of identifying a pattern. Of course, teaching mathematical learners to identify a pattern is a much more difficult task than to teaching them to simply draw a table or memorize a set algorithm to see prescribed patterns - it involves less tangible aspects of mathematicians' practices such as insight and perception. But it is these very aspects that make it a rich mathematical experience rather than the dehydrated pseudo-mathematical task that most students experience - the clear and easily defined mathematics that has been carefully programmed, pre-processed and homogenized so all can get the right answer. Perhaps in our attempts to make mathematical knowledge more accessible to students we have kept the knowledge but lost the mathematical behaviours, and in the process the mathematical experiences of the classroom can no longer be regarded as 'mathematical'.

Constructing Generalizations: Another integral part of working as a mathematician is about making the generalizable statement. The insight to see and construct the generalizable statement, and to be able to state it clearly, is an important mathematical practice. In this case, the development of a formula for the interior angles of a polygon was part of the task. Unlike traditional mathematics classrooms where the generalization (i.e., the rule) is often the starting point and learners are encouraged to practise on examples, this learning enabled the participants to generate their own generalization. At this point it is worth noting that the participants in our example did not perhaps take the final mathematical step of proving their result. Indeed, they were not far away from it and if they could have drawn the construction lines shown in Figure 4, they may have been able to complete their 'proof'.

We do acknowledge that it is also an important activity to apply and use known mathematical rules, but this is relatively straight-forward and simple, and perhaps inherently less mathematical, than the engaging and creative task of constructing generalizations. Boaler's research suggests that mathematical knowledge developed in this way is more robust and accessible for learners than prepackaged formulas that are memorized as preordained facts.

Using a Simple Example to Test the Hypothesis: Once a potential generalization had been developed, the participants applied this to a simple example (the triangle) to check its validity. In this case it worked so the generalization appeared valid to the participants. They also applied the generalization to the examples that they had worked out (and recorded in the table) to check that the generalization was valid in other examples. It seems that in a traditional classroom there is little scope for conjecturing and hypothesizing, as the route to the answer is known and the task of the student is to travel the prescribed and clearly structured route to the known answer. Dead-ends and time-wasting side tracks are thus avoided and the journey is quick and efficient. However, this is not consistent with mathematical practice (as outlined previously) and hence its place in the mathematics classroom deserves consideration.

Identifying Limits: Finally, part of working on a mathematical task is being able to determine parameters. Of course, it is not a necessary mathematical action if all the mathematical tasks faced are bounded and clearly defined. As noted by one group, the limit in this activity was that the shape had to have three or more sides if the generalization was to work. Again, this was a relatively innocuous observation, but an integral mathematical process that can easily be lost in the process of sanitizing authentic mathematical tasks for the classroom, thus diminishing the true mathematical thinking required by students.

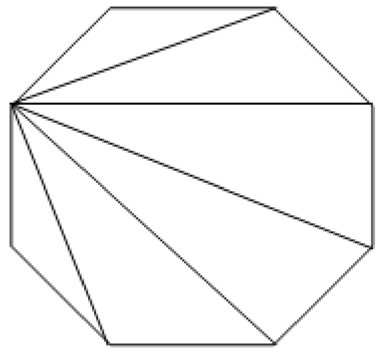

Figure 4. Octagon with construction lines

Cognitively

Drawn from Burton's work are aspects of cognition, affect and other constructs of the internal features of working as a mathematician. Rather than trying to delineate these various dimensions, we have accepted their inter-connectivity and tried to note them as they arose in the example. This approach is similar to that undertaken by Burton and means we do not apply a pre-determined theoretical framework. Historically, affect and cognition have largely been studied independently, or at least as separate concepts, but here we have not made that distinction. What we have done is identify particular features of cognition and dispositions that are part of the learners' ways of approaching the tasks, particularly as exemplified in the account above.

Thinking Styles: As shown in the example used, the learners engaged a range of thinking styles that included verbalization, drawing illustrations, and the use of tables to arrive at insights about the problem, the mathematics, and ways to solve the problem. These various thinking styles enabled the group to gain insight into the problem, and whether they would have been successful with a uni-dimensional approach is debatable. Indeed, drawing on a range of thinking styles– visual, analytic and conceptual - was identified by Burton (2001) in her study of mathematicians, and we can see how most of the participants in our example used a composite of these styles. The use of a variety of cognitive approaches is valued in the mathematics community because it is integral to, and enhances, the mathematical endeavour.

Insight/Intuition: Burton's (2001) mathematicians referred to the 'light being switched on' which enabled them to see what works and what does not work without being overtly aware of how they gained such insights. Barnes (2000) also studied 'aha moments' in school students' mathematical experiences. While these sorts of expressions seem to be common in general conversations about mathematics learning, they are relatively absent in the research literature, and yet both Burton and Barnes saw them as critical affective/cognitive components of doing mathematics. We cannot do justice to this topic in this example, but we do want to flag *insight* and *intuition* as aspects that require further research.

Making Connections: It can be seen from the example that various elements of mathematics have been linked together to form a coherent whole. Burton (2001) argues that it is akin to fitting the pieces of the jigsaw together. What can be seen in this example is how the teachers have drawn on various aspects of mathematical knowledge, in particular their knowledge of triangles, and have pooled this knowledge in order to come up with a deeper appreciation of mathematical understanding. This making of connections leads to a more robust and inter-connected mathematical knowledge by which mathematics is not seen as a collection of isolated procedures and concepts. In general, it seems that a more holistic and related mathematical understanding is not developed in mathematics classrooms because experiences are based around learning small, bite-sized conceptual chunks that are rarely stitched together into a broader conceptual framework. This is often exacerbated by the teach-test-and-forget program mentality that discourages applying a range of mathematical concepts to the solution of a problem. Thus, for mathematics learners to engage in the critical cognitive activity of making connections, they need problems and tasks that inherently demand more than one mathematical idea to solve.

In this section we have discussed the example presented earlier vis-à-vis the activity of working as a mathematician. To do this, we briefly explored the activities of the participants under quite a few themes. In the next section we look at the example at a more macro level, in particular noting the choreography of agency between their mathematical identities and the discipline of mathematics.

Identity and the Dance of Agency

What becomes possible to see through this example is that the learning situation draws considerably on those aspects of working as a mathematician as identified by Burton's work and on the aspects of classrooms and teaching identified by Boaler's work. Boaler's work has been particularly powerful in illustrating the importance of agency and identity. When we consider the activity identified in this paper, we recognize that the three features – social, mathematical and cognition – are critical variables in the provision of quality learning opportunities. If we are to emerge from the current demise in mathematics education identified at the start of this paper, then reforms are needed to enable change from the current, traditional practices to ones which are more empowering for learners. This requires a shift not only in pedagogy and curriculum but also in the dispositions of learners. As noted by Zevenbergen (2005) many of the current practices in school mathematics create particular mathematical habitus which are far from empowering for learners and indeed encourage disengagement with the discipline.

This example and our analysis of that practice highlight some of the features that foster the characteristics of working as a mathematician that have been identified through the combined work of Burton and Boaler. However, in this final section, we want to draw more constructively on Boaler's use of Pickering's (1995) notion of a 'dance of agency'. For Boaler this construct is critical, as it enables learners to draw on their mathematical understandings, to build on what they know, and to construct deeper understandings. This is one of the fundamental premises of much mathematical learning but it is improbable in many of mainstream classrooms due to the pedagogies being implemented. As shown in the Queensland School Longitudinal Reform Study (Education Queensland, 2001), the teaching of mathematics in schools is the most poorly taught area of school curriculum and dominated by shallow teaching approaches with little scope for students to engage substantially with ideas and deep learning. The example here provides some insights into the ways in which a commonly used activity can be adjusted to allow for depth of learning. However, as Boaler's work highlights, learners must feel some sense of agency to be confident to draw on other forms of knowing in order to solve problems.

In the example provided, we note that the first comment provided by a participant was "I have no idea of how to work this out". Such a comment is not a surprise for many mathematics educators and has been well documented as an outcome of the teaching of school mathematics. Yet, as the activity unravelled, the engagement and success of the participants illustrated the importance of a number of characteristics Burton identified among the practices of research mathematicians who strongly identify with mathematics. We suggest that the activity, including the way it was organized and presented to participants, enabled them to engage with the problem in order to solve it. It seems that allowing the participants/learners to engage in a collaborative group and to draw on pre-existing concepts, which they knew were robust, enabled them to engage successfully with the task. Further, it was critical to the dance of agency that the participants felt confident to draw on their existing knowledge to build deeper mathematical understandings. The participants appeared to be confident in their knowledge and they identified strongly with the concepts encountered in their teaching of primary mathematics, including the properties of triangles in particular, and polygons in general, along with the types of angles. They then drew on this knowledge to solve a more complex problem -

something that they did not encounter in their teaching in the primary school, and hence was unfamiliar to them.

We contend that traditional classrooms would have fostered learning activities around the application of a formula for calculating the sum of interior angles. In this example, the participants could not remember this formula (and it was not provided) so they needed to rely on their existing knowledge, the collective wisdom of the group and a sense that they could solve the problem. This sense of agency - where not only could they rely on their own knowledge in a legitimate sense, but also the collective knowledge across the group – enabled them to gain a sense of learning and achievement through the completion of the task. We contend that such practice is far more enabling and develops a strong sense of agency and identity with mathematics.

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Socially Response-able Mathematics Education: Implications of an Ethical Approach

Bill Atweh and Kate Brady
Curtin University of Technology, Perth, WA, AUSTRALIA

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This paper discusses an approach to mathematics education based on the concept of ethical responsibility. It argues that an ethical approach to mathematics teaching lays the theoretical foundations for social justice concerns in the discipline. The paper develops a particular understanding of ethical responsibility based on the writings of Emanuel Levinas and discusses its implication for decision making on the curriculum and pedagogy in mathematics education. The paper argues that such an approach is consistent with a critical mathematics approach; however, it highlights the need to balance the concern about equity with that of quality. The paper concludes that this ethical stance, rather than being a normative criteria which dictates a particular line of action in different situations, it establishes a means to reflect on action and policy towards the achievement of more equitable access to high quality mathematics education.

Keywords: Mathematics Education, Social Perspective, Social Justice, Ethics, Pedagogy, Curriculum

INTRODUCTION

The "social turn" in mathematics education (Lerman, 2000) is well illustrated by the intensification and diversity of research issues in the discipline during the past five decades that adopted social and critical perspectives. These include concerns about equity, participation and social justice (Burton, 2003; Secada, 1989); consideration of the political dimension of mathematics education (Mellin-Olson, 1987); sociology and mathematics education (Dowling, 1997); cultural perspectives (Bishop, 1988); critical mathematics education (Frankenstein, 1983; Skovsmose, 1994;); ethnomathematics (D'Ambrosio, 1985; Powell& Frankenstein, 1997); philosophical analysis (Ernest, 1994); and the history of mathematics movement (Furinghetti, Kaisjer, & Vretblad, 2004). While these agendas have different foci, and often are at variance in their conclusions and implications, they share a few common foci. There is a strong rejection of the dominant view that mathematics is a singular, objective and value free discipline that is isolated from human interest. They also discuss the relationship of mathematics to the social and cultural context in which it arose and in which it is applied – hence they raise concerns about the privilege that certain groups and cultures have as they access this mathematics. Similarly, on the teaching of mathematics, they challenge the dominance of the traditional mathematics curriculum outlined in many syllabus documents and the traditional teaching practices in mainstream classes around the world. Further, they question the assumption that the teaching of mathematics should follow set procedures and pedagogies that, once supported by rigorous research findings, are generalisable to *all* contexts and for the teaching of *all* students.

In particular, concerns about social justice, or its variants of equity, and diversity (Atweh, 2007), are often

Correspondence to: Bill Atweh, PhD in Mathematics Education,
Science and Mathematics Education Centre
Curtin University of Technology
PO Box U1987, Perth 6845, WA, AUSTRALIA
E-mail: *b.atweh@curtin.edu.au*

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raised in writings from these social perspectives. However, the discourse of *ethics* is raised very infrequently in mathematics education. This is not to say that there has been no concern about ethical conduct or ethical implications in the design of curricula and the teaching of mathematics. Nor do we mean to imply that ethics and social justice are two divergent discourses. Here we posit two reasons why thinking about ethics in mathematics education supports, and lays the foundation for, concerns about social justice. First, social justice issues are often constructed as concerns related to the participation of social groups in social activity and their enjoyment of their fair share of social benefits[1]. Such a construction has less to do with the outcomes achieved by a particular individual - unless the outcomes are due to their belonging to a social group; it is often silent on issues related to the interaction between two people – say of the same social group. Ethics, on the other hand, is concerned with a face to face encounter and interaction between people. Secondly, ethical considerations highlight moral responsibility of one to, and for the other. This focus on responsibility establishes social justice concerns as a moral obligation, rather than charity, good will or convenient politics. In other words, adopting a social justice approach places knowledge as a servant to justice, whereas an ethical approach places justice at the service of the moral (Cohen, 2001).

Arguably, this absence of ethics discourse in mathematics education is paralleled by its absence from general discourses in education and humanities in Western culture. With the rise of scientific rationality, ethics has often been associated with questions of morality, dogma, codes of behaviour and legal imperatives and often seen as belonging to the domain of metaphysics rather than philosophy proper. Cohen (2005) explains this avoidance of ethical discussion in philosophy as a fear of moralising, preaching and questions of values by philosophical discourses mainly focused on ontology rather than meaning. Similarly, in Western thinking there is a movement away from essentialist thinking represented in the universality of ethical principles (Christie, 2005) and their foundation on rationality as established by philosophers such as Kant. Going back to the philosophical and ethical discourses of Socrates, who argued for the primacy of the knowledge of the *good* over the knowledge of the *truth*, Cohen raises the question "has the philosopher abdicated responsibilities" by only dealing with questions of knowledge rather than values (p. 39). However, this avoidance of ethical discourse is slowly dissolving. As Critchley (2002) indicates, it was only in the 1980s that the word ethics came back to intellectual discourse after the "antihumanism of the 1970s" (p. 2). Further, the post-ontological philosophical writings of Levinas (1969, 1997) have been influential in the re-introduction of ethics within philosophy by establishing ethics as the First Philosophy. As Christie (2005) argues, when it comes to ethics, it is possible to "work with and work against" (p. 240) the construct at the same time. In other words, we adopt a critical stance on the concept by discussing both its usefulness and limitation.

This paper invites a discussion of the social aspects of mathematics education framed by the construct of ethical *responsibility*, with one particular interpretation of the term as *response-ability*. It attempts to argue for the need to raise ethical concerns as a basis for principles of politics, critique and social justice in the discipline. It bases this understanding on one approach to ethics as the 'first philosophy' principles espoused by Levinas. Secondly, it discusses the implication of such an approach to two areas of mathematics education; namely, for supporting the social response-ability of the student through the curriculum and for supporting the social response-ability of the teacher through pedagogy.

We will commence with a discussion of ethics and the concept of responsibility.

Ethical Response-ability

The demand for responsibility, or more often in its related term accountability, is an increasing concern in educational discourse, policy and practice. However the term is used with a variety of meanings. Responsibility is often presented as a requirement or duty that restricts (as in, it is the teachers responsibility to cover the curriculum) as well as enables (as in, evaluating students' learning is the teachers' responsibility) or sometimes in the placement of blame (as in, who is responsible for the students' lack of achievement?). It often posits a conflict between self-interest and the interests of the other, or the collective - giving a priority to the latter. Ethical codes are constructed under the assumption that norms and regulations need to be set and agreed upon otherwise our "natural instincts" would find some teachers lazy or dishonest, and leave students under the threat of marginalisation or exploitation. In other words, while ethical codes may be drafted to guard the students' interest from malpractice, they may not be as useful in a positive sense for promoting fruitful and effective relationships between students and teachers. Taylor (1989), using an ontological approach to ethics, draws attention to the limitation of contemporary moral philosophy, by pointing out the narrow focus on morality as a guide to action rather than ethics being concerned with what it is good to be.

[1] *Feminist critique has constructed social justice as having two main agendas - distribution and of recognition (e.g. Fraser & Honneth, 2003; Young, 1990). Equity concerns in mathematics education literature have often been constructed in re-distribution terms (Atweh, 2007) – hence only this aspect of social justice is referred to here.*

If the law or the system does not form a valid foundation of ethical responsibility, what does? Philosophy? As discussed above, Western philosophy has often avoided the consideration of ethics. Further, as Levinas argues, philosophy is mainly concerned with questions of being (ontology) and knowledge (epistemology). The discussions of being and knowledge are achieved by reducing the other to the same (Critchley, 1992) and by dealing with consciousness (Bergo, 1999). For Levinas, ethics is before any philosophy and is the basis of all philosophical exchanges. It precedes ontology "which is a relation to otherness that is reducible to comprehension or understanding" (Critchley, 2002, p.11). This relation to the other that precedes understanding he calls "original relation". Chritchley goes on to point out that the powerful contribution of Levinas is that he "does not posit, *a priori*, a conception of ethics that then instantiates itself (or does not) in certain concrete experiences. Rather, the ethical is an adjective that describes, *a posteriori,* as it were, a certain event of being in a relation to the other irreducible to comprehension. It is the relation which is ethical, not an ethics that is instantiated in relations" (p. 12). Using a phenomenological approach, Levinas argues that to be human is to be in a relationship to the other, or more accurately, in a relation *for the other*. This relation is even prior to mutual obligation or reciprocity. Roth (2007) argues that this original ethical relationship discussed by Levinas consists of an "unlimited, measureless responsibility toward each other that is in continuous excess over any formalization of responsibility in the law and stated ethical principles".

In his later work, Levinas (1997) introduced the distinction between *saying* and the *said* in the face to face encounters with the other. The *said*, for example, philosophical dialogue, is propositional while the *saying* is the ethical. Neyland (2004, p. 517) explains the distinction in this way:

When I speak to another person, I *acknowledge* him or her as another person. Thus, [Levinas] puts it, before every 'said" there is a "saying". When I acknowledge another person, when I focus on his or her "face" I do more than just gaze, I actually *encounter* him or her. This encounter, Levinas argues, is, at its deepest level, an awareness of the other as one who in some way needs me. This … is the source of the social bond. He emphasises that there is compulsion involved. I am not obliged to respond to the other. I can choose to break the encounter. But in doing so, I weaken the social bond. Further, because my selfhood my self concept and self identity – depends on my responding to the need I recognise in another, when I break the social bond, I impair my selfhood.

Neyland uses Keman's specifications on how this 'original relation' can be eroded to specify three conditions "(i) particular procedures are *authorised*, (ii) actions are *routinised*, and (iii) people are *dehumanised*" (2004, p. 817, italics in original).

The construction of ethics based on the "original relation" with the other is not apolitical. Critchley (2002) points out that many of Levinas's writings present ethics as a critique of politics. He adds that Levinas "wants to criticise the belief that political rationality can answer political problems" (p. 24). Rather, ethics inevitably leads into political concerns of social justice (Caygill, 2002). In a chapter on *Politicizing the Mathematics Classroom*, Noddings (1993) discusses the role of the mathematics classroom in hindering the development of students as responsible persons. She highlights the need to involve students with shared responsibility for content assessment, the level of mathematics they engage in, and assessment. The challenge is not only to produce competent mathematicians and mathematics users but ultimately to promote "the growth of students as competent, caring, loving and loveable people" (p. 159). She calls for an increasing need for mathematics educators to "consider the ethical and political dimensions of learning mathematics as well as the cognitive aspects" (p. 159).

Puka (2005) argues that the distinction some feminists1 make between responsibility and "response-ability" is a significant contribution to ethical thinking. Response-ability highlights the ability to respond to the demands of our own wellbeing and the ability to respond to the demands of the other. This is similar to what Roth (2007) points out, that responsibility "etymologically derives from a conjunction of the particles *re-*, doing again, *spondere*, to pledge, and *–ble*, a suffix meaning "to be able to." Responsibility therefore denotes the ability to pledge again, a form of re-engagement with the *Other* who, in his or her utterances, pledges the production of sense. Each one, on his or her own and together, is responsible for the *praxis* of sense, which we expose and are exposed to in transacting with others" (p. 5).

Puka goes on to state that A "response-ability" viewpoint makes better sense of our responsibilities toward ourselves as well, including our growth or development and our personal integrity. The standard picture of self-responsibility, where we force ourselves to do things, cannot represent the self-discipline or self-determination involved as true freedom--except through sleight of hand abetted by self-delusion. And ethics must be free; it must organize voluntary cooperation, not cooperation-or-else. By contrast, self-response-ability focuses us on our own worth and the value of our talents or potentials. It enhances our self-appreciation and rests on our predictable response to what we really are and can become.

Towards a Socially Response-able Mathematics Education

Undoubtedly, mathematics is an important subject in the curriculum and in the current and future lives of students. In the minds of many, such importance is given to the subject due to the increasing importance of technology and science, two essential areas in problem solving and raising living standards. Mathematics, like science, is often associated with the economic development of a nation (Kuku, 1995). At the personal level of the student, mathematics is often justified as opening doors to many careers and courses of further study.

However, these assumptions about the value of mathematics education for the student and society should not be accepted uncritically. First, the relationship of mathematics to general economic development is far more complex than is often assumed. For example, Woodrow (2003), citing the example of the development of the Asian economies and the high achievement by their students in international testing, argues that increases in mathematics education standards have occurred after their economic development, and arguably as a result of it, rather than the other way around. Further, Ortiz-Franco and Flores (2001) demonstrate that during the period between 1972 and 1992, the mathematics achievement of Latino students in the USA have increased in comparison with other students, although their socioeconomic status has decreased.

Similarly, the assumption that mathematics is needed to increase access of students to jobs as a justification of its place in the curriculum should be regarded with care. The dominance in school mathematics of content needed for careers that are seen as mathematically based – mainly science and engineering, is unwarranted and, perhaps, is a residue of times when few students finished high school and went to university. Notwithstanding the importance of jobs in science and engineering for social technological development, only a few students end up in such careers. Further, with advances in technology, the demand for most calculations and algorithms that still dominate the majority of school teaching are increasingly becoming obsolete. Indeed, Jablonka and Gellert (2007) point out that, in certain areas, mathematics has become mostly invisible due to the wide spread of technology. Arguably, the nature of mathematics used in society has changed more rapidly than school curricula. This leads to our argument that all students need a considerable amount of mathematical knowledge for effective citizenship in the increasingly mathematised world of today – albeit different type of mathematics. Not only is a significant amount of mathematical thinking behind most day-to-day decisions that people make, but also as Skovsmose (1998) asserts, mathematics plays a role in "formatting" the world. In other words it creates a social and physical world after its own image. This power of mathematics is, of course, double edged. While many great achievements in science and technology were facilitated by mathematics, mathematics is also implicated in technologically caused catastrophes such as wars and mass destruction (D'Ambrosio, 1998). Hence, a *utilitarian* approach to mathematics falls short of developing a response-able student. As Ernest (2002) argues a critical approach to mathematics and citizenship is needed. This ethical response-ability discussion applied to mathematics education posits the primary aim of mathematics education to enable the response-ability of students in their current and future lives as citizens.

Developing mathematical knowledge and capacity helps the students to not only, using Freire's (in Gutstein, 2006) terminology, 'read the world', i.e. understand it, but it should lay the foundation for their capacity to 'write the world', i.e. change it. In the traditional wisdom of school mathematics, reading the world (at least some aspects of it) is the function of the school, whereas writing the world is often constructed as a possible capacity that might arise later when the students enter the workforce and civil society. Borrowing the terminology from Down, Ditchburn and Lee (2007), the role of mathematics education as it relates to citizenship can be at three levels. Mathematics education can contribute to the ability of students to function as effective citizens in the world. The authors call this a *conforming* ideal. This is consistent with the dominant justification of mathematics as developing skills and knowledge useful for preparation for work. However, mathematics can also be used to enable students to understand how the world works (or does not work) in order to change some aspects of their world. This, the authors refer to as *reforming*. However, mathematics has an additional capacity. It can be used to create the world in a new way. The authors call this the transforming capacity. This focus on mathematics education is consistent with the critical mathematics movement.

Similarly, an ethical responsibility approach to mathematics education changes the focus of interactions between teachers and students. Increasingly, schools and classrooms are controlled from outside (Fullan, 2000) by increasing demands of the system. Teachers increasingly feel deprofessionalised when faced with continuous changes imposed from above (Hargreaves, 1994). Perhaps relevant here is the discussion by Habermas of his theory of communicative action in which he makes the distinction between the *lifeworld* and the *system* world (Habermas, 1987). While the lifeworld is the taken for granted, pre-interpreted, everyday life existence, communicative action in this world is saturated by tradition and routine. Through the lifeworld, individuals construct their own identities, create social solidarity, participate in, and create culture. On the other hand, the social world consists of social organisations dominated by technical goals and outcomes. The function of the systems level of society is to coordinate and control natural and social forces, as well as the resources and organisations required to administer them through bureaucratic structures. Seidman (1998) explains that whereas in the lifeworld "action is oriented to mutual understanding", the emphasis is on "instrumental control and efficiency" at the systems level (p. 197).

Habermas goes on to argue that these two life spheres are highly differentiated into subsystems and that their interactions are complex. In analysing late modernity, Habermas makes two key observations about this interaction. The first he terms the *uncoupling of the system from the lifeworld*. This refers to the fact that systems have become increasingly autonomous from the concerns of the lifeworld. Systems seem to have developed a rationality of their own and act according to their own imperatives even at times when they contradict the processes of the lifeworld that sustain them. The second observation that Habermas makes about late modernity relates to the *colonisation of the lifeworld by the system imperatives*. This is seen, for example, in the dominance of the systems language of efficiency, productivity, goals and roles on the lifeworld on people. For instance, our roles in social systems functioning contribute to our notions of our own personal identity, for example as clients and consumers.

For example, Neyland (2004) argues that in mathematics education the demand for accountability or responsibility as portrayed in the world-wide push towards standards and testing reflects a 'scientific management' rationality that posits institutions and norms as the cause of ethical behaviour. Using Levinas's writings, he goes on to argue that such institutions externalise and mechanise ethical behaviour and thus "sometimes erodes a primordial ethical relation between people" (p. 517). In this context, we argue that a focus on ethical responsibility shifts the focus of interactions between students and teachers to an encounter between two human beings, and although it is not totally free from system demands, it allows for teachers' decision making based on the interest of the student. At the same time, it re-establishes the professional status of teachers and frees the lifeworld of the school from some of the colonization of the system. It implies a collaborative and mutually respectful classroom environment where the participants are constructed as co-learners, an environment to which Vygotsky and Freier aspire.

In the following two sections we will examine both implications of an ethical stance for the curriculum and the pedagogy respectively in mathematics education.

Supporting the Students' Response-ability through the Curriculum

In the dominant mathematics education discourse, intellectual quality is often understood as mathematical abstraction and the rigor of academic mathematics (e.g. Juter, 2006). This includes formalized symbolic language, axiomatic thinking, standard efficient algorithms and proofs. It also includes sophisticated modelling of mathematically-based problems - usually from areas such as physical reality, engineering, and the economy, in which there is a unique or best fit solution. This is often contrasted with practical mathematics that focuses on real world applications, routine problem solving – on personalised (often called student-invented) algorithms, solutions and presentations of mathematical arguments. In many Australian curricula these two types of mathematics are contained in separate alternative streams that students chose between depending on their previous mathematics performance (often taken as a sign of ability) and post school aspirations. This construction of intellectual quality of mathematics as a dichotomy between formal and practical mathematics is presented as a *common sense* argument for providing a greater choice (a valuable endeavour in neo-liberal politics) for students and to cater for the needs of a larger number of students. However, this binary might be counter productive by denying the majority of students (that is, those taking the so called social or practical mathematics), the opportunity and the ability to develop their generalised abstractions of mathematical concepts and procedures. Further, in spite of the rhetoric of curriculum documents, and the assurances of many teachers that the two streams deal with equally valuable mathematics – albeit for different needs - for many students a hierarchy of values exists (resulting in a higher status for the formal academic mathematics).

Seen in this way, the intellectual quality of mathematics is measured primarily from within the discipline itself rather than the usefulness of that knowledge for the current and future everyday life of the student. In other words, intellectual quality is measured by the level of decontextualisation and abstraction of the discipline and in isolation from social questions and issues into which it can be applied. In particular there is a resistance by many mathematics teachers and curricula developers to deal with controversial social issues as a source of examples of mathematical problems. Perhaps because of the common belief that mathematics provides objective tools to deal with reality (Bishop, 1988), less often does school mathematics deal with issues of socio-political aspects in society such as distribution of wealth, disadvantage and demographical changes. These social issues are often seen by mathematic teachers and curriculum designers as belonging to other subjects in the curriculum. This demarcation is consistent with the separation of the realm of the *know-how* of science and technology and questions of values and morality dealt with in the social sciences and philosophy.

Undoubtedly, developing the capacity of students to master the language and findings of mathematics, and even its formality, is a contribution to students' response-ability as active citizens. As Ernest (2002) argues, empowerment of students in and through mathematics necessarily includes *mathematical empowerment* which consists of the ability to critically read and produce mathematical texts as well as pose their own problems and solve problems. With the *transforming the world* aim of mathematics education, perhaps a different type of mathematics and different ways of teaching may be necessary. First, the development of mathematics in isolation from the capacities developed in other areas of school curriculum limits the role of mathematics in achieving its transformative potential. A more interdisciplinary approach is essential. Further, the privileging of abstract knowledge over contextualised knowledge becomes problematic. As Christie (2005) argues, "current times require the consideration of both universalistic, abstract knowledges and particularistic, contextualised knowledges" (p. 244). Seen from this perspective, intellectual quality looks different from the above construction. Quality in mathematic education is measured not as, or not only as, formal abstraction and generalisation, but by its capacity to transform aspects of the life of the students both as current and future citizens.

Mathematics can only contribute effectively to student response-ability if it engages with the world of the students. Perhaps every teacher of mathematics at one time or another has faced the question from a distressed student "but why are we studying this". Perhaps not surprisingly the usual answer, that you need this for future jobs, leaves many students unsatisfied, if not unconvinced. Here we argue that the usefulness of mathematics should not only be demonstrated by using examples from the real world of the student as applications of mathematics, but also that mathematical knowledge should be developed through such activities. The development of mathematical knowledge through real world activities demonstrates the usefulness of mathematics at the same time as engaging students. Further, this engagement of mathematics with the life of the student should be an engagement not only with the physical world and the economic world, but also with the social world; not only with the world as the student will experience as an adult, but their current world; it should aim at developing an understanding not only of mathematics but also an understanding of the world. Finally, such engagement should aim at not only *reading the world* but also, whenever possible, at *transforming the world* – even to a small degree.

Interrogation of the concept of connectedness of mathematics to the life of the student is consistent with many of the writings in the discipline from critical mathematics and social justice discourses. What does the focus on ethical response-ability add to the discussion? The focusing of critical mathematics on social issues and data is in harmony with the principles argued here. Arguably, the focus on supporting the response-ability of the student highlights the need for activities that are designed to change the world rather than merely to read the world – albeit critically. Response-ability for transforming the world has two implications for mathematics education. First, the isolation of mathematics from other discipline areas may hinder the development of the ability to deal with social transformation. Issues of values, politics and social action have to be joined with mathematical knowledge in order to identify factors that need changing as well as to implement them. The call here is for a more interdisciplinary approach to mathematics education and the willingness to deal with controversial topics in which debate and difference of opinion and interests are part of the equation rather than nuisance variables. The challenge for the mathematics teacher is to identify areas for activities that are not only of interest to students, but also that are important for students to know and engage with. The implication here is that students can learn about their social world while they are learning mathematics and, at the same time, learn about mathematics as they are engaging with real world activities. Second, in working towards social transformation, the teachers and students develop a new relationship of co-inquirers or co-learners in contrast to the traditional construction of expert and novice. In such real life activities, while the teacher is not the source of knowledge about what needs to be changed, the students need support in identifying these needs and in negotiating change. As Atweh and Bland (2005) point out in their evaluation of one such project, there needs to be a balance between the teachers abdicating their duty of care by minimizing the risk of student failure, the silencing of student voice, and their willingness to take risks when needed.

Supporting the Teachers' Response-ability through Pedagogy

The above section discussed the type of mathematics curriculum that enhances students' social response-ability. It posited the meaning of *quality* mathematics education not as measured by the discipline itself, but by the power of that mathematics to enable students become more active participants in their current and future lives. In this section, we deal with another important challenge to mathematics teaching, namely that of *equity* (Burton, 2003; Secada, 1989). Atweh and Keitel (2007) note that social justice concerns with regards to participation in mathematics study by different social and cultural groups are no longer seen at the margins of mathematics education policy, research and practice. Issues relating to gender, multiculturalism, ethnomathematics, and the effects of ethnicity, Indigeneity, socio-economic and cultural backgrounds of students on their participation and performance in mathematics are regularly discussed in the literature. Many of these have found their way into policies in educational systems around the world.

Whereas concerns about quality are about what type of mathematics is worthwhile and valuable and about how students can best develop this mathematics, concerns about equity are about who is excluded from the opportunity to develop quality mathematics within our current practices and systems, and about how to alleviate their disadvantage. It is important first to note that there is no intrinsic theoretical contradiction between the two sets of concerns. In another context, Gough (2006) pointed out that in many policies "equality (or equity) is understood to be a *necessary condition* of quality" (p. 12). However, in practice, a focus on one without the other is problematic. In the above article, Gough refers to several South African writers who argue that the quality agenda in that country is often used as means to justify the continual exclusion of black students from further education. Hence, a concern about quality with no concern about equity may lead to "elitism". Conversely, a concern about equity with no consideration about quality runs the risk of sacrificing it. Luke (1999), referring to the work of Newman and his associates (1996) points out that "the worst enemy of equitable and socially just outcomes is the phenomenon that we could call "dumbing down" (p. 11) of the curriculum. Hence the focus on only one demand is not only misguided - by failing to deal with significant determinants of participation and achievement in mathematics - but also counterproductive - in leading to results contrary to what we are aiming to achieve.

Education is often posited as the most effective solution to disadvantage in society and between societies. After at least fifty years of development and reform in education, it is important to raise the question as to whether education has been able to address this challenge. Perhaps the evidence is not very encouraging. In a study commissioned by the US congress, Coleman, Campbell, Hobson, McPartland, Mood, Winefeld, and York, (1996) reviewed the long term effect of many interventions to alleviate economic disadvantage through education and concluded that schools do not reduce social inequality. Rather, research consistently shows that the family socioeconomic wealth is the best predictor of educational success. Similarly, the increasing gap between the rich and poor in many western countries (and between countries) does not support this utopian view of education. Perhaps Basil Bernstein (1971) was correct in his conclusion that schools do not compensate for society.

However, there is some good news. Coleman and his colleagues demonstrated that under school reform the most disadvantaged students benefited the most. In other words, although good teaching benefits all students, under certain conditions it also closes the gap between the least disadvantaged and the rest of the students. As Christie (2005) commented, "it is for the most disadvantaged children that improvements in school quality will make the most difference in achievement" (p. 245). Further, out of all the school factors that effected students' achievement, one of the most effective was the teacher. Hence good teaching "can make a difference, but not *all* the difference" (Hayes, Mills, Christie & Lingard, 2006, p. 178). Research evidence points to the fact that quality education assists *all* students. The danger is not in challenging disadvantaged and under achieving students to higher intellectual quality, but in "dumbing down" the curriculum for them - thus locking them into marginalization and disempowerment.

Hayes, Mills, Christie and Lingard discuss how concerns about quality pedagogy can also be socially just pedagogy. They refer to a framework developed in the state of Queensland in Australia, called Productive Pedagogy[2] The framework was based on the previous work of Newman and his colleagues (Newmann & Associates, 1996) at the University of Wisconsin on Authentic Pedagogy and based on a longitudinal study conducted in that state (Queensland School Reform Longitudinal Study, 2001). Similar to the previous frameworks, the Productive Pedagogy model does not provide ready made techniques for teaching. Rather, it is an approach to creating a place, space and vocabulary for us to get talking about classroom instruction again. It isn't a magic formula (e.g., just teach this way and it will solve all the kids problems), but rather it's a framework and vocabulary for staffroom, inservice, preservice training, for us to describe the various things we can do in classrooms – the various options in our teaching 'repertoire that we have – and how we can adjust these … to get different outcomes. (Luke, 1999, pp. 5-6).

[2] *Further information about the Productive Pedagogy can be available from the Website of the Queensland Department of Education and the Arts at http://education.qld.gov.au/corporate/newbasics/*

The Productive Pedagogy framework consists of four main categories:

- ✓ *Intellectual Quality*
- ✓ *Connectedness*
- ✓ *Supportive Classroom environment, and*
- ✓ *Recognition of difference*

The above discussion of how pedagogy can support dealing with the dual imperatives for quality and equity in education derives from research on disadvantage and general sociology of education. What does the focus on the ethical response-ability add to this discussion? Ethical response-ability places the primacy of ethical considerations in the teacher-student encounter. There are two dangers in this encounter that erodes ethical response-ability of the teacher and hence of the student. First, to deal with the students as individuals with no regard for their gender, ethnicity or socioeconomic background – factors that are demonstrably related to student achievement in mathematics - is to relate to an "abstract" student. Not only is this a recipe for failure – it also is dehumanizing and is unethical as argued by Neyland (2004) above. Similarly, the other extreme of seeing a student *only* as being of a particular gender, ethnicity or social status is equally counterproductive. This stereotyping also limits the possibility of an authentic encounter with the *other*. An ethical encounter attempts to be open to any possibility that exposes itself and responds to *other*'s needs and aspirations rather than in a stereotypical fashion. In supporting the students' response-ability a teacher can provide the opportunity to develop the high intellectual quality to the maximum of the students' needs and capacities. This is consistent with Vithal and Skovsmose's (1997) argument that a focus on the background of the student can obscure and hinder a focus on the *foreground* that sees possibilities as to what the student can be rather than a focus on where they have come from.

SUMMARY

Although the mathematics education literature during the past fifty years has taken a "social turn" by adopting a variety of sociocultural perspectives, there is a noted absence of discussion of *ethics* as it relates to the discipline. This absence is paralleled by a lack of consideration of the topic in general education and philosophy in our Western culture. This paper argues that ethical responsibility provides moral foundations for concerns about social justice. Ethics relates to the face to face encounter with the other that precedes concepts and reflection. Reconceptualising ethical responsibility for the other as its etymological meaning of response-ability, we have considered its implications to mathematics education.

We argue that the aim of mathematics education in this perspective is to support student response-ability as members of society. This support must necessarily go beyond the provision of mathematics that is needed for a minority of jobs and economic development to include mathematics that is needed by the majority of students and adults as active citizens of an increasingly mathematised society. School mathematics should support students' response-ability not only to *read* the world but also to *transform* the world. From this ethical perspective, in order for mathematics to contribute to the response-ability of the student as citizen, it should attempt to engage the student in meaningful and authentic "real world" problems and activities that not only develop the mathematical capability but also develop an understanding of the social world and contribute to its transformation whenever possible.

Similarly, a focus on socially just pedagogy supports the social response-ability of the teacher to meet the response-ability of the student. A socially just pedagogy does not sacrifice quality in the name of equity nor does it sacrifice equity in its pursuit of quality. Although these implications are consistent with the critical mathematics education movement, they highlight the role of pedagogy that attempts to balance concerns about quality and equity in the discipline.

In conclusion, this ethical stance, rather than being a normative criterion which dictates a particular line of action in different situations, establishes a means to reflect on action and policy towards the achievement of more equitable access to high quality mathematics education

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Translating a "Relevance Imperative" into Junior Secondary Mathematics and Science Pedagogy

Linda Darby
RMIT University, Bandoora, VIC, AUSTRALIA

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Inquiries into the state of mathematics and science education in Australia express the need to make curriculum and teaching practices more relevant and meaningful to students' lives. This vision requires that teachers understand how relevance can enter the classroom in meaningful, appropriate, and subject-specific ways. In this paper I use interview data and classroom excerpts to explore junior secondary teachers' responses to what I call a "relevance imperative". The data shows that relevance is a multi-faceted construct that is constructed differently by teachers depending on their socio-historical experience with the subject culture. Implications for teachers teaching out-of-field and how we conceive of teachers as subject specialists are discussed, and suggestions for future research are given.

Keywords: Science Education, Mathematics Education, Curriculum, Relevance, Subject Culture, Teacher Beliefs

INTRODUCTION

In recent years, there has been a push to reframe curriculum and pedagogy in ways that ensure that students' experiences at school are meaningful and relevant to their lives and perceived needs. This reframing of a "relevance imperative" ensures that the curriculum and the school experience as a whole is relevant to the lives of students. This paper explores how "relevance", as an imperative coming from the wider educational setting, is translated into the pedagogy of mathematics and science teachers, and the difficulties that can arise for teachers as they come to understand, appreciate and teach the subject. Teachers must understand how subject culture differences lead to subtle differences in what can be promoted as relevant in a subject, as well as how relevance may be meaningfully and appropriately achieved. Clarity in these areas is important for all teachers, particularly those who move into unfamiliar or changing subject cultures.

Correspondence to: Linda Darby, Lecturer,
School of Education, RMIT University,
PO Box 71, Bundoora 3083, VIC, AUSTRALIA
E-mail: *linda.darby@rmit.edu.au*

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The development of a "relevance imperative" in Australia

While relevance is a long standing imperative in education, the meaning of what might be considered relevant is not without debate. According to Newtown's discussion on the meaning of relevance in science education, "relevance requires a relationship in the presence of some need, aspiration or expectation" (1988, p. 8). He distinguishes between "external relevance" and "internal relevance". External relevance is outward looking and refers to science that is relevant to life in some way. Internal relevance is inward looking and presents knowledge as a neat, structured, coherent and unified assemblage; pattern and unity is more attractive and the content easier to acquire.

In both mathematics and science, a history of curriculum reform has resulted in movement towards emphasis on external relevance. This raises questions about what might be considered relevant to students' lives and interests. The Relevance of Science Education (ROSE) Project (Schreiner & Sjøberg, 2004) is an international comparative study that is gathering and analysing important data from 15 year olds about their attitudes to science and technology, and their motivations to learn about science and technology. For example, boys in England were found to be most interested in "destructive technologies and events", while girls were interested in "health related issues" (Jenkins & Pell, 2006). Osborne and Collins (2001) found that students were most interested in science topics that were perceived as relevant to their lives. While this research provides insight into what students consider to be relevant, further research is needed into pedagogies that make for relevant teaching and learning.

In Australia, debates surrounding the relevance of education have drawn partly from US discussions about the purposes of schooling, and from Australian based research that focused particularly on the middle years of education, which is typically for students between the ages of 11 and 14 years. This includes the junior secondary school levels on which this research focuses. A concern with the middle years in the 1990s prompted research into the needs of young people (Eyres, 1992). Research revealed that a curriculum that fails to recognise the personal and social lives of young adolescents results in student alienation and disengagement (Australian Curriculum Studies Association, 1996; Eyres, 1997). Some educators claimed that part of the problem is the fragmentation of the curriculum into distinct "subjects". In the US, Beane (1995) argued for an integrated curriculum more representative of students' life experiences. In Australia, the Queensland New Basics (Education Queensland, 2001) was developed to blur boundaries between traditional subjects. "Rich tasks" are used to integrate problem based learning experiences that tackle real life multi-disciplinary issues and problems. Rich tasks are informed by educational theory, including Dewey's emphasis on "integrated, community-based tasks and activities [that] engage learners in forms of pragmatic action that have real life value in the world" (p. 4); and Freire's emphasis on the solving of problems that have "relevance to the immediate worlds of students" (p. 4).

Concern with the relevance of education is a response to declining student interest in mathematics and science. Despite reforms since the late 1980s the disparity between the science and mathematics being offered and the needs and interests of students continues to be of concern. Recent inquiries into the state of school science and mathematics in Australia (Department of Education Science & Training, 2003; Education & Training Committee, 2006; Goodrum, Hackling, & Rennie, 2001) report on falling enrolments in post-compulsory science and mathematics, and student disenchantment with curriculum they often consider irrelevant. The Education and Training Committee (2006) found that a major factor contributing to student disengagement in secondary mathematics is the lack of connectivity between students' lives and mathematical problems. Similarly in science, the Committee recognised a need for curriculum approaches focused on, among other things, relevance to students' lives, as well as making strong links between future education and career pathways.

This research has informed curriculum development in Victoria. In 2006, the Victorian Department of Education and Training introduced the new Victorian Essential Learning Standards (VELS) as the guiding curriculum document. Relevance to students' lives features as one of the premises of the "Discipline-based learning strand": "students develop deeper understanding of discipline-based concepts when they are encouraged to reflect on their learning, take personal responsibility for it and relate it to their own world" (Victorian Curriculum & Assessment Authority, 2005, p. 3).

While this imperative exists, teachers' ability to respond will depend on them understanding how relevance can be incorporated into mathematics and science classrooms in meaningful ways.

This paper draws on interview data and critical incidents from classroom practice to explore how three teachers made the subject matter meaningful for their students by representing a humanised and relevant subject. Questions addressed in this paper are:

How does the subject and its associated pedagogies shape how a teacher can make links between subject matter and students' lifeworlds?; and

What issues relating to relevance arise for teachers as they move between mathematics and science?

Participating Schools and Teachers

The analysis reported in this paper formed part of a larger project aimed at improving the teaching and learning of middle years mathematics and science through the development of a school improvement process based on ction planning, which involves teachers evaluating their classroom practice. Four school clusters[1] were involved in the Improving Middle Years Mathematics and Science (IMYMS) project. Two of these clusters were invited to participate in my research on the basis of proximity to the researcher. Two secondary schools were selected, School A and School B.

School A was a co-educational Government school in a provincial city in regional Victoria, offering Years 7 to 12 to about 1,300 students. School A became the main research school due to teacher availability and proximity. Most of the data generated by the study came from four teachers: Rose, Donna, Pauline and Simon.

School B was located in an eastern suburb of Melbourne. It was a co-educational Year 7 to 12 Government secondary school with over 900 students from neighbouring suburbs. Data from three teachers, Ian, James and Marg, were included in the analysis.

Schools selected the teachers on the basis that they had a teaching allotment that included mathematics and/or science subjects in Years 7 to 10. For each teacher, data generation focused on two mathematics classes, or two science classes, or a science class and a mathematics class. Table 1 summarises the teachers and their involvement in the research.

Research design

The research involved observing and video recording teachers' mathematics and science lessons, then interviewing them about their practice, their views of school mathematics and science, and how they see themselves in relation to these subjects. Various data generation methods were involved (see Darby, 2009, for more detail).

Classroom observations allowed me to directly experience the school setting, the classroom and the teachers' practices (Carspecken, 1996; Goetz & LeCompte, 1984). Observation notes were generated for all observed lessons. The focus of the classroom observations changed depending on the purpose of the lesson and the opportunities that the lesson provided. One lesson in each lesson sequence was video-recorded. A total of 52 lessons were observed, 23 of these were video-recorded.

A sequence of modified video-stimulated recall and reflective interview occurred on two occasions. Normally video-stimulated recall (also called "video reflection", see Senger, 1998) involves video recording an event, followed by an interview between the participant and the researcher where the video is replayed to stimulate and lead discussion. In my research, I gave a copy of the two video-recorded lessons to each teacher. Teachers were asked to view the videos privately and reflect on a set of questions focusing on intentions for classroom actions, and beliefs about teaching, learning and the mathematics and science subjects. I called this a "modified video-stimulated recall" technique because the video served as a stimulus for reflection, which teachers would then discuss in a reflective interview. A trial of this process was conducted with a trial teacher who was not a participant in the IMYMS project (see Darby, 2004).

This sequence of videoing, reflection and interviewing occurred twice for teachers at School A (once for Pauline), and once for teachers at School B (none for Marg). During the first sequence, a set of directions and reflective questions were given to each teacher to reflect on while they watched the video. During the reflective interview that followed teachers were encouraged to:

- *talk generally about their approach to mathematics and/or science teaching, including background in, commitments to, and beliefs about each;*
- *respond to the reflective questions asking teachers to break up the lessons into phases and consider their intentions, evidence of subject culture expectations and practices in the lessons; and*
- *respond to questions relating to lines of inquiry that emerged from preliminary analyses of classroom observations or prior interviews.*

During the second sequence, teachers were asked to view their video-recorded lessons and use an annotated lesson plan I developed to record "things" they considered to be important in their teaching. During the interview, the teacher discussed their notes.

A focus group discussion involving the four teachers from School A followed the first round of data collection, with discussion based around three statements arising from a preliminary data analysis. Each statement was accompanied by excerpts from their reflective interviews that contributed to the development of the statement, and supportive experts from literature that expand on or correlate with the teachers' ideas. The statements related to the demands that school mathematics and science place on teachers and students; the translation of practices across mathematics and science; and influences on teachers' treatment of content in their teaching, and their attitude to the subject.

Informal discussions were used to gather demographic data, such as teacher background, and information about the units within which the video recorded lessons were included. They ranged from unstructured to semi-structured, and occurred prior to or following a lesson.

Data generation took place over four school semesters. The research was divided into "Data Sequences" that focussed on different dimensions of pedagogy in order to build up a rich picture of what the teacher was doing, and reasoning behind teachers' actions. Artefacts were collected on an opportunistic basis at all stages of the research, and included planning documents and classroom resources. Table 2 summarises the various data events within each Data Sequence.

An on-going preliminary analysis of observation notes and researcher reflections generated preliminary lines of inquiry and questions for further investigation. Part way through the research, a categorical analysis of the interview transcripts produced a list of emergent codes. Flexible lines of inquiry, or themes developed at this time. After all of the data was generated, the emergent codes were used during a thematic analysis (van Manen, 1990) of the interview transcripts, focusing on various themes and other areas of interest relating to teacher practice and subject culture (Darby, 2009).

Table 1. Teachers and Their Classes Represented in the Research

SCHOOL	TEACHER	INVOLVEMENT	TEACHING CAREER	TEACHING ALLOTMENT*	TEACHING PREFERENCE
SCHOOL A	Rose	2 x Maths classes	>20 years	Snr & Jnr Maths	Maths
	Donna	2 x Science classes	4-5 years	Jnr & Snr Science Jnr Maths	Science (Biology)
	Simon	1 x Science class 1 x Maths class	3-4 years	Jnr & Snr Maths Jnr Science	Maths
	Pauline	1 x Science class 1 x Maths class	2-3 years	Jnr & Snr Science Jnr & Snr Maths	Science (Physics)
SCHOOL B	James	2 x Science classes	>20 years	Jnr & Snr Science Jnr Maths	Science
	Ian	1 x Science class 1 x Maths class	>20 years	Jnr & Snr Science Jnr Maths	Science & Maths
	Marg	2 x Maths classes	>20 years	Jnr & Snr Maths	Maths

* Mathematics and science allotments only.

Table 2. Data Events in Each Data Sequence

DATA SEQUENCE	DATA EVENT	DESCRIPTION
Data Sequence 1 (S1)	Data Event 1	Familiarisation with the classroom, teachers, and schools through classroom observation and informal discussions with teachers
	Data Event 2	Modified VSR trial
Data Sequence 2 (S2)	Data Event 3	Classroom observations, video recording
	Data Event 4	Modified VSR and Reflective Interviews based on discussion questions
Data Sequence 3 (S3)	Data Event 5	Comparing ideas about what it means to teach the subject through a Focus Group Discussion
	Data Event 6	Classroom observations, video recording
	Data Event 7	Individual informal discussions to place the video recorded lessons into the context of the broader unit
	Data Event 8	Modified VSR and Reflective Interviews based on annotated lesson plans

One of four themes, translating relevance into mathematics and science, emerged from a common imperative of these teachers to make the subject meaningful by relating the subject to students' lives and interests. The theme interrogates how teachers translated the rhetoric of "relevance" as a generic pedagogical imperative into their conceptions of the subject, teaching and learning, and into their teaching practice. One part of this theme focusing on teacher's personal experiences with understanding and translating the relevance imperative into their pedagogy is represented in this paper. Another aspect of this research, the development of a classification of types of stories, is published elsewhere (Darby, 2007, 2009).

The following analysis begins with a narrative of how story and relevance emerged during the research process, followed by snapshots of the responses of three School A teachers (Donna, Pauline and Rose) to the relevance imperative, and issues that arose for two of these teachers as they negotiated subject boundaries between mathematics and science. These teachers demonstrate how differences in teacher background, beliefs and knowledge lead to a variety of pedagogical responses to the relevance imperative.

Finding links to students' lives in the classroom

During classroom observations I became interested in how teachers and students used stories to situate themselves or their personal experiences within the content-related dialogue. In science these stories were commonly introduced by either teachers or students and they appeared to have the purpose of situating the subject matter, and sometimes the scientific endeavour, into students' lives. In mathematics, fewer stories were used to explicitly connect students' lives to the subject matter. This raised the question as to whether stories in mathematics took different forms, possibly suggesting a different dynamic of engagement in mathematics and science.

I questioned teachers about the nature of, and potential for, telling stories in mathematics and science. Teachers recognised that stories were used, and were important in both subjects, but that science generally had more opportunities for story telling. Also, teachers and students had different roles to play in contributing stories. Simon stated that "there is no spectrum for [using stories in mathematics], whereas in Science you can do anything like that" [S2AS: 209]. On prompting, Simon was able to offer situations where he could use real-life applications of either science or mathematics. In mathematics, however, his experience was that, "most kids can't do that, like I have to lead that" [S2AS:211]. When asked whether stories were as common in mathematics as in science, Dona said "Probably not, no" [S2AD: 140], but she related this more to her limited mathematics background. Pauline believed that there are fewer stories in mathematics than science because "This is our world, this is what we live in, and explaining it, the science is all about explaining it. You just don't get stories like that in Maths, do you?" [S2AP: 44]. These differences suggest that stories play a different role in mathematics and science.

My attention turned to the pedagogical assumptions underpinning the use of stories: teachers referred to an imperative to link the subject matter to students' lives. By broadening the notion of "story" to include the notions of meaning-making, relevance and connectivity to students' lives, there was greater scope to explore in the data the various ways that teachers made the subject matter meaningful for students. The analysis presented in this paper targeted meaning-making. The notion of "story" is, therefore, referred to in a *typical narrative sense*, where stories about people, objects and experiences are "told" and become part of the teaching and learning experience, and in a *metaphoric sense*, where the lifeworld experiences of the teacher or student, and the subject matter, are not necessarily woven into a narrative but are linked in order to demonstrate the cultural and human dimensions of mathematics and science. Storying the subject reveals something of the "teller's" understanding of how the subject can link with human experience.

Snapshots of three teachers' approaches to making the subject relevant

ll teachers involved in the research said that relating the subject matter to students' lives was important; however, what they chose to relate, and how they did this, differed. In this section I present snapshots of three teachers—Pauline, Donna, and Rose—to show these differences. The snapshots illustrate how they made the subject matter meaningful by making it relevant to students' lives. The snapshots emphasise teaching strategies and approaches, and teachers' personal experiences of the subjects and disciplines.

Pauline

Pauline was in her second and third year of teaching during the study, having completed a three-year Bachelor of Science majoring in physics, then a two-year primary and secondary teaching degree. Her methods were general science and senior physics, and mathematics as her "fallback method".

Pauline demonstrated an appreciation for the human side of both mathematics and science as she talked about the effect of mathematics and science on students' lives, their prevalence in society and the impact on decision making. In particular, Pauline placed a strong emphasis on humanising science:

> *Science [provides an] understanding of how your world works and I find my knowledge of science extends to everything. It extends to when I go to the Doctor and I talk about my health … Everything I do is informed by my science knowledge, and I just think that scientific literacy is so important for kids to get the most out of themselves, out of their world… I just think scientific literacy informs everything that we do, personally, and the way we interact with the world and being more responsible. [S2AP:80]*

In this quote, science is made part of what it means to be human and a global citizen through a scientific literacy imperative. Science is constructed by people in an attempt to understand the world we live in, and to take some control over the decisions we make.

Pauline valued stories as a part of her own learning, and expressed these in the classroom where possible. In the following quote she explained that, when she was a learner, a science teacher had stirred in her an interest in science through his stories. She reflected on the role of stories in her developing interests and in her teaching:

> *I like collecting [stories]. I don't think I have enough. I like telling stories and getting the kids' stories out as well. And I have found that when I studied science they were the things that got me excited when a teacher told me a really interesting story and I don't know if mine are interesting or not, but I know that they were the sort of things that got my interest going in science and why I wanted to do more. It is unfortunate but it is true that sometimes it is the teacher's personality rather than the content that they are teaching that gets kids engaged … like I had a fantastic Year 10 teacher who revved us girls into doing physics and chemistry in Year 11 and Year12 and that was more his personality, the way he told stories, his passion for science, that got us into it. [S2AP:48]*

The way Pauline became interested in science is evident. The teacher's personality, rather than content, had been instrumental in shaping her perception of science as personally interesting and worthy of attention. The teacher's "passion for science" that was transferred to students through engaging stories resonated with Pauline. A subsequent interest in science led Pauline to a career in physics and a commitment to science as a way of thinking about the world and informing life's choices.

Stories were a major component of Pauline's teaching repertoire. She was able to convey through story her commitment to science, passion, her experiences and her appreciation for what science offers. An example was her introduction of the theory surrounding static electricity with the story of Benjamin Franklin's discovery of electrical charge during one of her Year 8 science lessons:

PAULINE:I want to talk about what we did see. Now, Benjamin Franklin conducted a lot of experiments with electricity, his most famous one of course, flying a kite in a thunderstorm with a key attached to the string and having lightening strike that string and then come out of the key. Now he was really lucky that it hadn't rained yet and that the string he was holding wasn't wet because another scientist tried to replicate that experiment only a couple of months later and was killed because of the large amount of electricity going down the string. Benjamin Franklin was really really lucky. So Benjamin Franklin postulated, he came up with this idea, a model, that these, he'd done these types of experiments as well, that there was something that he called an electrical fluid that you could put onto substances and that if you took it away from substances that had one type of charge, and if you added it, it had a positive charge, if you took it away it had a negative charge. We can pretty much say we experienced that charge. Something, the most spectacular thing we did with the van de Graff when we did the discharge rods, what did we see?

STUDENT: Sparks!

PAULINE: Sparks. I always thought that sparks were the most impressive evidence of static electricity… We've got evidence for it. Benjamin Franklin postulated that there were two types, positive and negative. [Lesson P2]

Here Pauline represents a scientist's search for understanding natural phenomena. She represents part of the scientific process—Benjamin Franklin postulated, developed a model, experimented, and another scientist replicated. She also provides a positive aesthetic response to the phenomenon of static electricity by using such terms as "spectacular" and "impressive", thereby modelling a fascination with science.

Pauline was confident that her style of teaching was effective and suitable for the science classroom. She used illustrations to link the subject matter to students' lives, as well as humanising stories to bring the subject to life; stories about people and events, the development of ideas, and connections with her own and students' lives.

Pauline professed that she was less confident in mathematics than science because she knew less about engaging students in mathematics, even though her teaching allotment had always included both mathematic and science. Pauline was frustrated that she struggled to translate this personal approach to mathematics, and felt disempowered by her lack of stories in mathematics.

Donna

Donna was in her fourth and fifth years of teaching. Donna had intended to becoming a veterinarian, but decided to explore her interests in zoology and ecology through a Bachelor of Science. Prior to doing a Graduate Diploma of Education, Donna worked at a tourism park as an education officer, taking tour groups on possum prowls and conducting other environmental activities. She also worked at a horse-riding park, and was involved in dolphin research. She recognised that these experiences impacted on her teaching practice by providing examples and stories of science-related ideas, experiences and phenomena.

Donna referred to her use of stories to provide contexts for investigations in order to make the subject matter relevant. She selected learning experiences that would be meaningful for students, focusing particularly on making connections between science and students' interests:

If you've got an idea of where your kids' interests are you can use things they like, because in that Year 8 class there's a lot of girls into horses so you can use different examples where that's relevant. And the boys: football or cricket. [S3AD: 149]

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Donna also referred to her use of phenomena that students would be familiar with that could act as contexts for student investigations. She replaced "regurgitating questions" with student generated questions; for example, exploring refraction by investigating "the distance that light comes out of a lighthouse in terms of where the boats are coming, how they work out where to put the lighthouse, does the light run out at a certain point?" [S2AD:126]. Lighthouses were familiar to these coastal students. In both mathematics and science, such stories were regarded by Donna as "favourite topics" [S2AD:140].

As a result of her involvement in Year 9 and 10 subject selections, Donna was aware that students often felt intimidated by science and mathematics. Donna appreciated that students would find the subjects less intimidating if they had a coherent and connected understanding of the subject matter. Therefore, many of her pedagogical choices were based on providing students with a set of experiences with which they could relate. The way she constructed a narrative around the conceptual ideas testify to her commitment to providing a science experience meaningful to students' lives.

Rose

Rose had been a mathematics teacher for more than 20 years. At the commencement of this research, Rose had been teaching at School A for eight years, teaching mathematics at all year levels. Although qualified to teach science she chose early on in her teaching career to teach only mathematics. In the second year of the research, Rose assumed the role of Head of Junior Mathematics.

Rose made pedagogical choices based on what she believed students needed in order to be successful in mathematics, and in preparation for future mathematics studies. She used stories that provided meaningful applications of mathematics processes and concepts, such as buying a present for a colleague and using percentages to work out value for money. She used familiar objects, or more realistic representations of otherwise abstract mathematical ideas, in order to improve students' opportunity to engage with the mathematics meaningfully. For example, she drew chocolate blocks to illustrate fractions. Also, Rose expressed the personal meaning that mathematics offers. She humanised mathematics by modelling her enjoyment of mathematics. "I tell them I love maths" [S2AR:64] was echoed throughout the interviews. "It appeals to my logical brain" [FGD:108].

Rose conveyed her strong commitment to getting students to a point of understanding mathematical concepts and mastering skills and processes. Her experience with teaching across all year levels gave her an understanding of the difficulties students experienced and how to present the mathematics in meaningful ways. She appreciated the connection between student confidence and student success. Her attempts to situate the subject in students' lives were aimed at supporting skill development and conceptual understanding.

Rose's care for her students was played out in a particular way in mathematics classes. She wanted students to enjoy mathematics, to be comfortable with mathematics, and to recognise that it is preparation for senior mathematics and "preparation for life" [S2AR:54]. Such beliefs and attitudes stem from her personal success and experiences with mathematics, and her years of teaching experience. Rose regarded herself as being "mathematics-trained", which means having some degree of training that appropriately prepared her for mathematics teaching. She had no other career that involved mathematics, so her personal interest in mathematics, use of mathematics in the "real world", success as a learner, and university education provided the basis for her teaching career in mathematics. Unlike Donna, who had work experiences to draw stories from, Rose's examples emanated from her experiences of mathematics in life, learning and teaching. Such stories illustrate her commitment to ensuring students have a strong foundation in mathematics, both for life and to support future mathematics learning.

Different pedagogical approaches to making the subject meaningful

The above snapshots give a sense of how these three teachers emphasised the relevance of the subject. Their approaches reflect the teachers' beliefs about the purpose of the subject and the value that the subject can have in students' lives. For Pauline, stories were important in capturing students' interest through the use of *humanising stories of historical figures* that represent the human dimension of scientific discovery, thereby making the subject worthy of attention. The subject is made relevant through intriguing stories of the activities and attitudes of scientists and mathematicians. For Donna, investigations of *contexts* were pivotal in making connections between ideas. The subject is made relevant by using contexts that are built around students' interests or generative of new interests. Rose made direct links to students' lives by *illustrating* how the mathematics can be used. These illustrations make spontaneous, relevant and purposeful links between students' lives in order to make the subject matter more meaningful. Rose also expressed her love for mathematics as a way of thinking, thereby modelling the *human response* of appreciating the subject. The subject is made relevant because these stories demonstrate what it means to be passionate and committed to the subject, they empower students by demonstrating how ideas and modes of inquiry can be used, and they illustrate discipline-specific ways of thinking and operating that are accessible, engaging and appealing. These stories serve the purpose of situating the subject matter historically, culturally, socially and personally. In Darby (2007) I refer to these story types as Categories of Meaning Making.

The diversity of ideas represented by Donna, Pauline and Rose raises not only the question about the nature of relevance in mathematics and science teaching, but also why relevance is interpreted differently by teachers of the same subject, and differently across subjects. Understanding subject differences requires a teacher to interpret and understand the subtleties of what the subject has to offer their students. For teachers learning to appreciate, understand and teach mathematics and science, knowing the stories of the subject is vital to their response to the relevance imperative.

Knowing the stories of mathematics and science

Teachers' stories reflect something about themselves. Stories are "gathered" and "constructed" through their socio-historical interactions with science and mathematics. Teachers' backgrounds and experience with the discipline or subject provide the sum of their "lived experiences" (van Manen, 1990) from which teachers can draw. In their research into professional identity, Connelly and Clandinin (1999) refer to this as a person's "professional landscape" on their professional lives, metaphorically described as a "storied landscape". The landscape comprises multiple stories, "stories to live by". As a knowledge base, this landscape can include knowledge of events, processes or conceptual understandings, feelings, attitudes and values that stem from their experiences. Kerby (1991) states that a sense of self is generated through stories. The stories teachers tell are based on their experiences and the actual telling of stories shapes the self. For example, Ritchie, Kidman and Vaughan (2007) explore the importance of telling stories of science during teacher education in order to bring identities relating to both science and teaching to the foreground. Teachers' histories are evident in the stories that they tell. In the snapshots of Pauline, Donna and Rose, the influence of the discipline is evident as they share their experiences of learning at university, working in the field, personal experiences, or their personal orientation to particular ways of thinking. Their personal histories predispose them to particular ways of talking about the world.

For example, Donna's work experiences provided her with stories that she could bring into the classroom. Pauline's view of the subject had developed over years of studying science and enculturation into certain ontological and epistemological positions, including an appreciation of the use of stories and the problems this creates as she moved into mathematics teaching. Rose had spent most of her working life in the school environment, but she too had particular experiences as a learner and teacher that led her to develop positions ontologically and epistemologically.

It is clear that the schooling imperative reshapes teachers' experiences. When teachers enter the teaching profession stories and experiences become pedagogical tools. This knowledge base could be considered more complex than "content knowledge", or even "pedagogical content knowledge", as described by Shulman (1986) because their knowledge is impregnated with beliefs about teaching and learning, the subject, and the aesthetic dimensions of what it means to personally engage with the subject and discipline.

But what happens when teachers have few positive experiences with the subject or do not understand how their lived experiences can enhance learning opportunities for their students? Both Pauline and Donna valued stories but lamented having fewer stories to tell in mathematics because of their inexperience as

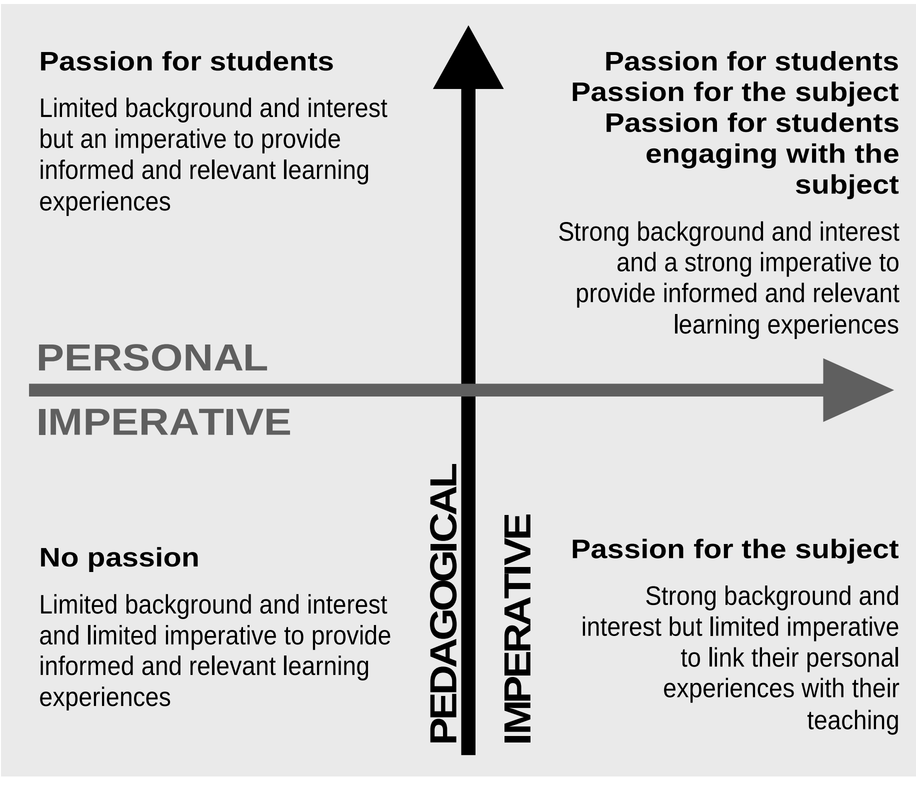

Figure 1. Relationships between personal and pedagogical imperatives

mathematics teachers. This restricted the way they connected the subject matter to students' lives. Donna explains this:

> *Probably not, no, and again I think that would probably be where I would find that, I'm predominantly a science teacher, and until I started here I hadn't taught maths before, so I am new at maths teaching, which means I try and do it where I can and I am still trying to learn where I could actually, what topics I can do that in. Because sometimes I think "algebra, how am I going to—" Whereas then you actually hear what other people are doing or you go and research a bit and you go "oh, yeah I wouldn't think of that". So now I know from last year what I can actually do with algebra, or different concepts this year. [S2AD:140]*

Clearly, Donna is relatively new to teaching and is building up a repertoire of stories as examples and conexts. Donna finds her students' lives and interests a wealthy source of contexts that she can draw on. Ideas also come from other teachers. Collegial sharing was referred to in every interview with the teachers as being valuable for curriculum development and broadening the teachers' pool of activities and resources.

The teaching imperative, therefore, motivates teachers to seek out stories. The discussion between Pauline and Donna below emphasises this teaching imperative. The discussion begins with a reflection on how they tend to be attentive to stories in the media relating to their disciplinary knowledge and research, and how these stories feed into their teaching:

> *DONNA: I'd watch a dolphin documentary before I'd watch the new latest technology in optics. I could talk about what dolphins do in their prides and family groups because I've done dolphin research, like a report to the Council. Whereas if I'd walked in cold to an optics or lenses lesson I would probably have to use what I know, what I've already researched myself or what I've taught in the past. I couldn't just go off and give them examples from industry, or this is how the newest camera works, there's this great new lens.*
>
> *PAULINE: Yeah, its an interesting thing isn't it. I'm doing optics at the moment, and I said to the kid, Did you know that the Hubble Telescope is about to be decommissioned? I think you should go off and research that. Because it is, it's our interest. And I think, if you're a biology person, then you go and watch a doco, actually I would watch a doco on dolphins too because I love dolphins, but if you're a physicist your ears might prick up when there's a story on, if you're skimming through the paper you'd go, what's this about the latest theory on how the earth was created, or whatever. And these things stick in your mind and you use them later when you're talking to kids.*
>
> *DONNA: But if I was teaching a unit on that, I would probably watch it. Because you'd help yourself out, you've got to know your stuff when you walk in class. But apart from that, with it not being an interest area, and you don't necessarily have a need for it. [Focus Group Discussion:102-104]*

These stories are different from those mentioned by Donna in the earlier quote where she used stories from the students' lives to enhance her teaching. The above discussion focuses on stories that emerge from the teachers' lived experiences with the discipline that they think the students might identify with. These stories from the discipline represent for teachers (and potentially for students) something about the nature of the knowledge and the nature of the scientific endeavour itself. They represent the subject as being a part of the larger science culture because they draw on the same body of knowledge, and that science can influence society through technology or social action. The teachers immerse themselves in these stories. These are personal stories that have interest for the teacher, and come from the teachers' historical interaction with the discipline rather than emerging out of a pedagogical imperative. Pauline indicates that these stories find their way into the classroom because of their usefulness to teaching.

There are two imperatives operating here: one is an expectation to prepare oneself for teaching, a "pedagogical imperative"; and the other is the role that a person's background and interests play in making a teacher sensitive to experiences and ideas, a "personal imperative". These two imperatives drive practice, that is, they indicate where a teacher's passions lie. Drawing from van Manen's (1999) description of pedagogy, a pedagogical imperative is when a teacher is concerned with what is and is not appropriate for their students; they are passionate about their students. A personal imperative is when the teacher is driven by their commitment to and appreciation for the subject, its bodies of knowledge and modes of inquiry; they are passionate about the subject. When a teacher recognises that their subject is of value to their students, they are passionate about students engaging with the subject. The model in Figure 1 represents the relationship between the pedagogical and personal imperatives as intersecting axes, and the passions that drive teachers' practice. This relationship is significant in driving teachers to make meaningful links between the content and students' lives. It also identifies problems that can arise when teachers are lacking commitments to the subject, or to their students.

Teachers located in the top right quadrant display a strong personal imperative, resulting in teacher confidence in content knowledge and personal interest in the subject. The teacher also displays a strong pedagogical imperative to ensure these experiences inform teaching and learning because of a personal commitment to sharing the subject with students. Donna believed that her biology teaching is more enthusiastic and informed because she can draw on her experiences of working in the area. She is committed to making such stories available to her students in order to make the subject more meaningful.

Teachers located in the top left quadrant display a weaker personal imperative. They are less informed about the subject because of limited background in the discipline, resulting in a lower level of personal interest and commitment to the subject, and confidence in content knowledge. However, these teachers have a strong pedagogical imperative to improve their understanding of the content in order to be well prepared for teaching the content. Donna referred to paying attention to programs on television because they relate to her teaching, not because she is interested in them. Teachers teaching out-of-field who have a strong commitment to their students may fit into this quadrant because they have a strong pedagogical imperative to ensure students are engaged, but lack the stories of the subject to make relevant links to students' lives.

Teachers located in the bottom right quadrant display a strong personal interest in the discipline. However, these teachers see little relevance of these experiences, or perhaps lack the opportunity to draw these experiences and knowledge into their teaching. Pauline expressed an interest in problem solving with her senior mathematics students, but found little opportunity to do so, nor did she have the pedagogical content knowledge of how to do it. Alternatively, a teacher may be extremely passionate about the subject but not distinguish between what is and is not appropriate for their students as may occur in the case of an over-zealous teacher who ignores students' learning needs.

Teachers located in the bottom left quadrant have neither the personal interest in the subject, nor the commitment to make their representation of the subject interesting. Rose was trained to teach science but decided early in her teaching career that she did not like teaching science and became a mathematics-devoted teacher. Teachers who teach subjects out-of-field may fall into this category if they lack a personal commitment to the subject as well as the stories to bring the subject alive.

A strength of this model is that it is not discrete. The same teacher can be situated in different quadrants depending on their level of confidence and knowledge of the subject. This is demonstrated by Donna who is situated in two of the quadrants. The model is, therefore, privileging subject matter knowledge as a key determinant of teacher practice.

Negotiating subject boundaries

What stories of the discipline does a teacher need when they cross the subject divide into unfamiliar territory? Teaching "out-of-field" is a reality in many secondary schools. For example, research has shown that the future junior mathematics teacher in Australia is likely to be a female biology graduate (Harris & Jensz, 2006). A new teacher or a teacher teaching out-of-field is in danger of lacking or not knowing how to use common or previous experiences to enhance the teaching sequence. They may attempt to bring in a style appropriate for a different subject with a different set of demands. As Pauline experienced, pedagogy suitable for one subject will not automatically translate to another subject. For Pauline, movement across the boundary from science into mathematics was hampered by her lack of stories, as well as a limited understanding of how to use stories to make connections between the mathematical ideas and students' lives. While she was fluent in explaining the presence of science in students' lives, the impact of mathematics on students' lives was more difficult for her to explain. Pauline's response suggests that crossing the boundaries between subjects can be seen as a cultural border crossing for teachers in the same way as it is for their students (Aikenhead, 2001; Aikenhead & Jegede, 1999). Negotiating the boundary can be difficult for the teacher who has limited background and aesthetic understanding of teaching the subject.

Subject culture, school culture imperatives, and the individual teacher

The culture of school imposes certain imperatives for teaching, such as engagement, support and relevance, which teachers must translate into their subject teaching. A number of influences eminating from within and outside the subject culture were evident in teachers' respondes to the school imperative of relevance.

Teachers recognised that an imperative to make the subject relevant was in opposition to more traditional approaches that de-contextualised the content. This refers to long standing traditions of practice that teachers were socialised into through their historical encounters with the subject.

In addition to this traditional subject culture, teacher's pedagogical responses can be shaped by the local subject culture, that is the culture of teaching at the school that is developed through dialogue and sharing of practice with colleagues within their subject department. The provision of structures to support curriculum development requires space, resources, and a loosened hold on traditional curricula structures focused on canonical content and the textbook.

These experiences contribute to a teacher's view of the subject. Other experiences may include work experiences and training that a teacher can draw on to tell stories about what it means to be or think like a scientist or mathematician. Background in other subject areas may assist with forging productive links with the knowledge and skills from other subject areas, thereby situating the subject within the student's broader school experience. General pedagogical experiences and beliefs developed as a learner might prompt a teacher to reject their own experiences of a disconnected subject matter and ensure vigorous attention to relevance and connectedness between the content and the lives of their students. Personal life experiences, such as a teacher's hobbies provide examples of how the subject knowledge, processes and skills of the subject can impact on one's personal and daily life.

A teacher's orientation to relevance depends on what the teacher knows, believes and values about the subject and what the subject can mean for their students and themselves. This is ultimately a personal response. Hipkin's (2006) investigation of science teachers' approaches to the teaching of the nature of science found that teachers tended to replace formal accounts of the way science knowledge is generated with more impassioned accounts based on the practices and objects of their own scientific inquiries. She found that some teachers' narratives revealed passion for their personal learning, as well as an ethical concern for their students' learning to care for the natural world and for science as a means of investigating the natural world. In the context of my research, this emphasises an aesthetic dimension to the way teachers approached their interpretation of cultural beliefs and practices, and therefore, teaching of a subject.

CONCLUSIONS, IMPLICATIONS, AND FUTURE RESEARCH

This research demonstrates that expecting teachers to make the curriculum relevant is not necessarily unproblematic because the meaning of relevance is not collectively understood, nor is it the same for mathematics and science. For teachers moving between mathematics and science teaching, especially when moving into a subject where they have limited appreciation or experience, understanding how the subject can be made relevant for their students, and themselves, is an important aspect of their pedagogical content knowledge.

Elbaz-Luwisch (2002) describes the practice of teaching as being constructed when teachers tell and live out particular stories. While the teachers recognised the importance of humanising a subject in order to give it some level of significance in the lives of their students, how the teachers embraced and responded to this challenge depended on each teacher's personal commitments to, and historical interaction with, the subjects and the subject cultures. Therefore, "having stories to tell" was not simply a cognitive issue, but also required a personal response from the teacher. It is likely that evaluative judgements about what might be of interest in the subject shape the teacher's pedagogical choices; judgements arising from what the teacher knows and values, which are aesthetic in nature.

Stodolsky and Grossman (1995) claim that subject content provides the context for the secondary teacher, not just in terms of the subject matter to be taught, but in the ways teachers think about learning, assessment, and their roles as teachers (see also Grossman & Stodolsky, 1995; Siskin, 1994; Stodolsky, 1988). My research has shown that, for these teachers, the content as context placed demands on their interpretation and response to a "generic" imperative to make schooling relevant. Teachers' beliefs about the value of the subject were bound up in the perceived potential purposes that the content could have for students and themselves. Their response to this generic "relevance" imperative was, therefore, subject-specific because of the subject matter context, but also because their teaching was based on their historical interactions with the subject. Pedagogical and personal imperatives ultimately drive teachers' response to the relevance imperative.

The data suggests that having a background in a discipline is likely to equip teachers with the disciplinary knowledge to draw on in their teaching and an appreciation and enthusiasm for the subject that can be transmitted to students, qualities that are often used to define effective teachers (Darby, 2005) and potentially lacking for teachers teaching out-of-field (Ingvarson, Beavis, Bishop, Peck, & Elsworth, 2004). Other research shows that, while a teacher's practice is dependent on the experiences that the teacher has had with the subject or discipline, these experiences are not necessarily related to exposure at university level. For example, other factors, such as career trajectory (Siskin, 1994) and professional development (Tytler, Smith, Grover, & Brown, 1999), have been found to be cogent in determining how teachers approach teaching and learning. These research outcomes highlight the importance of paying attention to teachers' experiences of the subject they are teaching. Evident also is an assumption that teachers are inducted into the culture of a subject through their experiences, and that, with further training, teachers can improve their competence and confidence in teaching a subject in which they have previously had limited background. Further research is needed that problematizes the assumption that disciplinary training automatically and alone leads to effective teaching. Such research could explore those experiences that teachers teaching out-of-field believe are instrumental in developing confidence and competence in their teaching. Further research is also needed to develop rich descriptions of those knowledge, skills and attitudes that teachers bring into their out-of-field teaching from their in-field subjects, particularly in terms of how the demands of the subject come to bear on their translation for teaching in the out-of-field subject.

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Bridging the Literacy Gap: Teaching the Skills of Reading and Writing as They Apply in School Science

Mary Hanrahan
RMIT University, Bandoora, VIC, AUSTRALIA

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Whereas science teachers in the last century were trained to place empirical activities at the heart of school science (Yore, Bisanz & Hand, 2003) and give relatively less attention to language issues, fundamental literacy (as defined by Norris & Phillips, 2003) is now recognised as having a crucial role in learning science. However, there have been few research reports detailing just how experienced secondary science teachers go about teaching the language and literacies necessary for school science, especially for students who have low literacy skills. This paper explores the literacy-teaching practices of a teacher of "learning support" students during a double-period Earth science class. While the focus was on the science content, many reading and writing skills were taught either as part of the lesson plan or incidentally, thus ensuring that all students could participate more fully. Implications for science teaching and teacher professional development are discussed.

Keywords: Literacy, Pedagogy, Reading, Writing, Science Literacy

INTRODUCTION

The language and literacy aspects of science have attracted significant attention in recent years, with everyday literacy now recognised as an important tool for learning in science. For example, Norris and Phillips (2003, p. 224) argued that "literacy in its fundamental sense is central to scientific literacy" and Wellington and Osborne (2001) showed that the learning of many science students was impeded by their misunderstanding of everyday terms such as logical connectives.

Norris and Phillips (2003) made an important distinction between scientific literacy in the "fundamental" sense and scientific literacy in the "derived" sense. Hand, Alvermann, Gee, Guzzetti, Norris, Phillips, *et al.* (2003) explained it thus:

> *The international science education reforms enunciate the fundamental sense of [science literacy] as peoples' abilities, thinking, and emotional dispositions to make sense of nature and the communications to inform and persuade other people about these ideas, and the derived sense of science literacy as the understanding of the nature of science, scientific inquiry, relations among science, technology, mathematics, and society, and unifying concepts of science. (pp. 608-609)*

Correspondence to: Mary Hanrahan, PhD in Science Education,
School of Education, RMIT University,
PO Box 71, Bundoora 3083, VIC, AUSTRALIA
E-mail: *mary.hanrahan@rmit.edu.au*

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One could argue that the teaching of the language skills of reading, writing and speaking can and should be left to language arts teachers. Research in literacy education, however, suggests that language arts need to be taught across the curriculum, that, in fact, literacy is specific to each discipline (Yore, Bisanz & Hand, 2003); further, Lemke (2004) has argued that there can be "multiple literacies" in a discipline (Lemke, 2004), and that these can best be taught in context.

Moreover, bodies such as the National Science Foundation (NSF) in the USA believe that science should profit from recent research in language education research and this led to the setting-up of international conferences to bring together researchers in literacy instruction and in science education (e.g., Hand *et al.* 2003; Saul, 2004). The latter have argued that much is to be gained by teaching the literacy (or literacies) of science at the same time as the content, and that in fact, it is not possible to become science literate as it is understood in the 21st century without the development of student skills in reading, writing and argument.

Yore *et al.* (2003), writing about research on "the literacy component of science literacy" addressed the research on reading and the research on writing in school science separately. With regard to research on reading instruction, they reported that there has been increasing recognition among teachers that reading is an active feat of meaning-making rather than the simple, transparent task that it was seen as previously. They argued, however, that success in reading should not be seen simply as the aggregation of skills, but as an interpretation process requiring both metacognitive awareness and control. The process, according to van Dijk and Kintch (1983, cited in Yore *et al.,* 2003), involved interpreting the print text, remembering prior knowledge of the topic, and recognising the limits of the sociocultural context. Thus comprehending a science text required a reader to access the cues in both the textual and sociocultural contexts, and to activate both the content and literacy areas of memory and to integrate these to achieve the most meaningful reading possible. Yet science teachers may argue that instruction in reading is not properly part of the science teacher's role and should be left to language arts teachers.

In countering the latter argument Kamil and Bernhardt (2004) report that the skill of reading an informational text, crucial for science as a "critical mediating factor in the storage, transmission, and retrieval of scientific information" (p. 138), is not well taught elsewhere, since it demands reading skills specific to the area of science. They argue that "[c]urrent reading instruction deals primarily with the generalisable reading skills, not with those specific to genres" (p. 130), leaving students unprepared for difficult texts which they then find boring. They implied that what is needed is discipline-specific knowledge about how the various factors involved in reading comprehension interact in content-specific texts, and the explicit teaching of such content-specific comprehension strategies. This is because a different combination of genres is used in different content area texts, depending on how inquiry happens in that discipline. They wrote, "Combined with the notion of understanding the structure of domain knowledge, genre knowledge is a key to comprehension. Becoming familiar with the way in which texts are structured is one more parallel to understanding the discourse of science inquiry" (p. 127). In a similar vein, Lemke (1990) emphasised the significance of knowledge of the specific genres found in science for reasoning in science.

These days, however, reading in science needs to be expanded to take in the multiple modes of communication. Hand *et al.* (2003) comment that language arts have now been expanded to include representing, and viewing as well as speaking, listening, reading and writing in science classrooms. However, rather than seeing these as separate skills, it is more likely that they will be used in combination and hence the teaching of reading needs to take this into account. Lemke (2004) reported that one aspect of reading that differentiates science from other disciplines is the multimodal nature of most science texts. It follows that literacy-related science instruction must go beyond traditional reading, writing, and talking tasks to include instruction about "reading" the significant portion of science communication that is multi-modal (cf. Saul, 2004).

With regard to writing, Yore *et al.* (2003) found that, in parallel with an improved understanding of the complexity of reading, there has recently been an increasing understanding of the power of writing-to-learn (Tynjala, Mason & Lonka, 2001). The knowledge-transforming model of writing described by Yore *et al.* (2003) includes a more explicit focus on the tools of language and on developing metacognitive awareness and control by the students of the writing process and writing strategies. This did not mean that science content became any less important since such work was centred on authentic science inquiry. Yore *et al.* further argued that an increased focus on literacy would not diminish scientific literacy in the traditional sense. They stressed the importance of convincing teachers that these aspects of science literacy can empower future citizens to be scientifically literate in a more authentic way.

According to Bernstein (1990), children of middle class families were likely to be pre-socialised into "official pedagogic communication and the inner structure generated by its pacing rules" (p. 78), whilst children from "disadvantaged classes and groups" (p. 78) were doubly disadvantaged, as not only were they not equally socialised into the discourse of schooling but they were also affected by the sequencing and pacing rules of schooling, which meant they quickly got behind and missed out on accessing deeper levels of meaning.

Because Gee (2004) believed that the majority of students may have significant problems with specialist academic discourses such as (school) science and history, he introduced the need for lessons on "expanded texts". He saw the problem as a matter of different "social languages" that needed to be learnt for use in different social contexts, each with its code, that is, its own "grammatical patterns and styles of language (and their associated identities and activities)" (p. 14). He argued that until students are exposed to the "expanded language" of the written code, they will not be able to argue clearly and unambiguously and make real progress in understanding the finer distinctions involved in what they are learning. He then went on to point out the pedagogical implications of this claim in terms of the need for explicit teaching as part of "reading lessons" on "expanded texts", highlighting the genre conventions of discipline-specific written texts. For Gee, success in argument depends on knowing the formal code of a discipline and thus is enhanced by expert teaching of how to read science texts.

Roth (2004) added another element when he argued that gestures which accompany talk in school science were important for students grappling to communicate their understanding of scientific concepts and hence that iconic student- generated diagrams were a stepping stone between these and formal written communication in science. He advised that "[s]cience and literacy educators ought not to overlook the complexity of the change from spoken to written language" and should make use of this intermediate stage of student sketches. As with reading, oral argument and writing in science also need to be seen as necessarily multimodal.

In spite of these more sophisticated understandings of the importance of fundamental literacy skills in the learning of science, Yore *et al.*'s (2003) review shows that this is not yet mainstream in the science education research literature. National and international Reading Associations produce monographs on such topics from time to time (e.g., Santa & Alvermann, 1991). In these there are excellent examples based in science classrooms of how to teach reading for comprehension (e.g., Aulls, 1991) or conceptual change (Roth, 1991), and using writing for learning science (e.g., Santa & Havens, 1991). Programs are now readily available for integrating the teaching of science with the teaching of literacy (see Thier and Daviss's (2004) text for "using language skills to help students learn science" in the USA and AAS's (2007) "Primary Connections: Linking Science with Literacy" in Australia), with activities and/or lesson plans and modules provided. These may be readily accessed by primary teachers who are generally teachers of language arts at the same time as being teachers of science, and who may even prefer this way of teaching science. However, as long as middle years and secondary science teachers see rivalry between language and inquiry with respect to the central focus of classroom science, as Osborne (2002) suggests, they are likely to see literacy teaching as being the domain of language arts teachers.

However, as has been suggested above, literacy in science is different from literacy in language arts. For example, Kamil and Bernhardt (2004) cite research that shows that informational texts, which are often central to work in science classrooms, have a very minor place in the language arts curriculum and hence students do not have much practice in reading or writing them. In primary school classrooms, where the science teacher is often the language arts teacher, students may receive the help they need to comprehend these dense, complex texts, and write notes and reports, but in secondary schools, teachers who have had no specific training in teaching reading and writing, are often at a loss, or, rather, mistakenly take for granted that students will have the necessary skills to comprehend science texts and write notes and reports and read and answer questions in written examinations. What is needed is a range of examples at the secondary school level of approaches to integrating the teaching of science with the teaching of the related literacy skills. That is where this article fits, as supplying one example. It is a detailed example, showing, in the minute-by-minute dialogue of a lesson, how science learning is enhanced when the teacher helps students develop the literacy skills they need to handle the reading and writing tasks that are part of a lesson on weathering.

METHOD

In this article I document the literacy-teaching practices of a teacher of students deemed to need "learning support". The teacher, Mrs Donna Savige[1] (DS in the transcript excerpts), was recruited as part of the larger "Exploring Motivation in Science" (EMS) project, reported in more detail elsewhere (Hanrahan, 2006a). Teachers in this project were selected because they—or their colleagues—were reasonably confident that practically all their students in at least one class were positively engaging in learning science. Because I was interested in access and equity issues, I was looking for classes that included students from a range of sociocultural backgrounds, levels of educational advantage/disadvantage, and likely fit with school science.

Mrs Savige had been recommended to me by an administrator in a school in a lower socio-economic status (SES) area, because he was impressed by the inclusive and skilled nature of her teaching. I visited a class to observe the teacher in action and interviewed her in depth after the class to get information about the local, institutional, and social context back-grounding the lesson observed. Both the lesson and the (1½ hour) interview were audio taped and later transcribed, after which they were checked by the teacher for content accuracy, but no changes were requested. I used N-Vivo software to help me categorise the teacher's practices and identify any literacy teaching episodes. The latter were interpreted in the light of both the literature on literacy in science and my prior experience as an adult literacy teacher. Then, as I analysed the discourse within these episodes more closely, I identified further literacy teaching practices addressing finer points of science literacy.

The lesson I observed was designed to have as much in common with regular science classes as possible so,

Table 1. Stages in DS Lesson Year 10 Sci004 Unit on Geology

1.	Pre-lesson as students arrive: settling students down as they gather outside the classroom
2.	Greeting the students and bringing them into the classroom
3.	Transition into the lesson
4.	Beginning the lesson on Earth science
5.	Looking at the heading structure
6.	Building interest by relating to everyday life
7.	Reading the introduction and introducing the idea of weathering
8.	Making notes on a worksheet
9.	Reading about frost action
10.	Highlighting a process
11.	More writing of notes on the worksheet
12.	Answering text-book questions in the notebook
13.	Representing new learning on a concept map
14.	Updating the vocabulary list
15.	Checking progress on a flow chart
16.	Concluding the lesson and distributing awards for appropriate behaviour

based on advance advice from the students about what they valued most, it was taken by a regular science teacher using the regular science textbook and in a science laboratory, not in a "learning support unit" classroom. On the other hand it was designed to be manageable by special needs students (e.g., having a "resource" teacher as well as a science teacher, and addressing only half of each unit (module of work) in the time normally allocated to a mainstream class).

Hence the context was not that of a typical secondary science class, since both the teacher I observed and the students were atypical, and other features of the class, including the curriculum and the way the teacher communicated, had been adapted. The class observed was co-taught by the two teachers, with the teacher I interviewed, a part-time teacher called Mrs Donna Savige being the main teacher for the two days a week that she met with them. She had previously been a science teacher but had more recently taken a Diploma in Resource Teaching and become part of the "Learning Support" (LS) team at the school, thus allowing the school to offer LS Science as well as LS English and Mathematics in what was a large high school in a lower SES area in the state capital. The second teacher unobtrusively supported students individually during the lesson as they needed it, with part of her role being described by Mrs Savige as "putting out bushfires" as they spotted and before they had a chance to flare up and seriously disrupt the lesson. The students were in the class not so much because they were slow learners but because they were at risk of failing in regular classes for other reasons, such as behavioural or literacy problems. The students were in Years 9 and 10, and about half the class (of whom nine were present on the day of my school visit, eight boys and one girl out of a possible 11) were English as a second (or further) language (ESFL) speakers, including two Aboriginal boys and two Samoan boys.

This was the last of four modular units offered to such students in Years 8 to 10. Students were not given homework and left both the textbooks and their notebooks (both of which were provided by the school) with the teacher between classes. The lesson, a double period theory lesson, addressed the "Earth and Beyond" content strand and, more specifically, the concept of weathering. Mrs Savige stated her goals as being "to get the nitty-gritty about the kinds of weathering that we were looking at but also to relate it to their own experience as Australians" [DS interview, lines 30-31]. She also mentioned a conscious goal of drawing their attention to the structure of the text.

FINDINGS

I will first summarise the stages in the lesson, paying particular attention to language-related episodes, and giving examples of how Mrs Savige helped the students with reading comprehension and writing skills. Then I will summarise the types of literacy-related skills that she addressed during this lesson.

The first three stages of the lesson consisted generally of conversational exchanges with individual students about administrative/procedural matters. Then the lesson began with an update of where the class were up to and what they did in the previous lesson. The teacher maintained a conversational tone throughout the lesson engaging in real dialogue with the students who frequently initiated questions. (See Hanrahan, 2006b, for an analysis of the teacher's style in terms of equity and access.) Reminders and corrections were interspersed with instructions and exchanges whenever students' attention wandered or they behaved inappropriately.

Skimming for an overview of the structure of the chapter

The first literacy teaching strategy used was a reading one, as the class prepared to read a text-book chapter as a whole-class activity. Mrs Savige drew the students' attention to the headings as they leafed through the chapter as a whole class activity, in order to help them get an overview of the structure of the chapter (and hence the unit). Then she read out the headings with some assistance from students who called out. This is an important reading skill since any new scientific terms to be introduced to the students will have their discipline-specific meaning within the larger structure of the science topic of Earth science. Hence this is a way of beginning to build up what Lemke (1990) called the "thematic pattern" of a topic. If students can distinguish between major headings and minor headings, they will also begin to be aware of a hierarchy within the geological classification of weathering. When Mrs Savige was drawing attention to the four major headings, she commented on the way they were formatted and the sub-headings that appeared under each. My experience with adult literacy students tells me that without this activity, students with a low literacy level would have been more likely to see the whole chapter as undifferentiated new content, just hundreds of new facts, one following the other, and, as such, overwhelming. The episode proceeded as follows[2]:

DS Okay, page one-fifty. We're going to have a look at the structure [.] *of the chapter: major headings, minor headings and get some idea as to where we're heading.* [1] . . . *Now, |if we have a look, page one-fifty, it starts off with*
S |[indistinct]
DS "Wearing away Rocks"↑ That's a major heading. It's done in [.] *a block capitals.* [1] *When we go through one-fifty-one,* [1]*there's a minor heading "Cracks in Rocks". Over the page, one-fifty-two, "Chemicals and Rocks": one-fifty-three: "Limestone Caves". . . . "Rocks and Plants". one-fifty-four . . . "Weathering" at the top of one-fifty-four. Then we have another* ***major*** *heading. . . .*
*So, we, that section finishes "Wearing away Rocks" and then we start the heading "Erosion". . . . Right, and we've got some minor headings under Erosion: "Transportation↑"—some big words here—"****Dep****osition"* [1] *deposition—sounds interesting.* [2] *Over the page, another big heading: "Sediments". . . . "Layers of Sediment." Over the page, page one-fifty-eight: "Ayers Rock." . . . . Uluru. ...Okay, we've got "Layers of Rocks" and we've got "Layers of Rocks* ***Bending****". . . . Page one-fifty-nine at the top . . . . We've got "Joints and Faults", a major heading↑, and we've got "Rocks Bending and Breaking". And then, over the page, there's the activity that we will be doing at the end of this. And then a heading on page one-sixty-one: "Cycling* [.] *Sedimentary Rocks", looking at the cycles.* [Lines 194-241]

Mrs Savige does not leave it there, however, with the students as passive recipients of this structuring, but challenges the students to find the four major headings for themselves, so that they can see where the work to be covered in this double period fits. Connections have also been made to recent work on different types of rocks:

DS Where have we heard the word "sediments" before?
S Yeah, I know where.
DS Sedimentary rocks?
S Yeah, I have.
DS Okay. And have a look, we've got [.] *in the pictures there you can see rocks in all sorts of layers. We're used to seeing that when we we're talking about sediments.* [.] *So some of this* [.] *we will already* ***know*** [.] *something about it. "Layers of sediment".* [Lines 218-224]

New terms have been heard, even repeatedly (e.g., weathering, erosion, deposition, sediments, joints and faults), and enunciated clearly with emphasis so they will be more familiar when the reading of the chapter takes place, but without pressure at this stage to remember the actual terms. As well, hints have been given about what is to come, ("And then, over the page, there's the activity that we will be doing at the end of this" (p. 234)), and Mrs Savige possibly hoped that interest has been raised about some of what the students have heard and read and that students may be thinking such things as "Why would there be `cracks in rocks'"? "Can rocks actually bend?" "What's it like inside a limestone cave?" Students have also had their attention drawn to text formatting ("block capitals"), an important cue for the finer points of reading comprehension, such as noticing different levels of headings. Finally, for students who want to experience a real science class, scientific terms are being introduced, such as "chemicals", which should reassure them that they are in a science rather than a "learning support" class.

Vocabulary-building

Some hints of vocabulary building are evident within this reading episode (even though others have been omitted for the sake of brevity), for example, the introduction of new scientific terms such as weathering, erosion, deposition and abrasion, the differences between which will be explored later in the lesson., as also will be the difference between "abrasion" and "abrasives". During the lesson it is notable that any new words introduced are elaborated on: students are not expected to acquire new vocabulary without multiple connections being made between each new word and their prior experience.

Another feature of this class was that students felt able to challenge the use of words. A challenged the use of "trapped" for water caught in cracks. Interestingly, Mrs Savige's response was unusual in comparison with science teachers who may treat the scientific meaning as the only valid one. She did not insist that she was "right" and hence imply that the student was "wrong", but rather treated the situation as a case of usage, thus implying that it was a convention in science rather than a case of right or wrong. In this way, she avoided one of the common ways of alienating students: assuming that the scientific meaning of a word is the only "right" meaning.

DS [1] *So* [.] *we have a process. First thing that happens is "Water is trapped" . . . .*

S [Indistinct: not really trapped, it's not]
DS Well, when it can't get away, we use the word trapped. [Lines 849-862]

Connecting to intertextual meanings

An important skill in reading is relating the content of a text to prior knowledge so that its full significance can be recognised. According to the interactive-constructive model of reading referred to above (e.g., Yore et al, 2003), words do not have meaning in themselves but have to be interpreted in relation to the text in which they occur, to prior episodic and semantic memory, and to knowledge about the immediate sociocultural context. Mrs Savige commented in the interview that some of the students have few prior experiences relevant to the science content and hence need additional help in relating new learning to old. One of the ways she created significance for the students, was by telling them stories they could relate to, in one case, about her recent trip to Uluru, a geological feature in Central Australia managed by Indigenous people. Several of her students were Indigenous and this would have had special significance for them, and indirectly for the non-Indigenous students because of their Indigenous class-mates.

DS And today [.] we're going to focus on the first one [2], but before we do [.] um, [.] one of the reasons why I find this section of work really interesting is because Australia, our country..
S |[Indistinct]
DS is considered |to be [.] I was born here too, David. [.] Okay?
S [Indistinct]
DS It's considered to be [1] the oldest [.] continent, the oldest country on the planet, and for that reason, sh, for that reason, [.] weathering has been happening here longer than it has almost anywhere else. So when we're talking about rocks weathering [.] right [.] we're talking about what's been happening to Australia for a very, very, long time. Now, as I said to you just recently, I was out at Uluru.
S Uluru
DS And I brought back some books.
S Can we have a look?
DS Yes, we're going to have a quick look through these because [1], all right, Uluru holds a fascination for most Australians and it's there because of weathering, and weathering is one of the things we're going to [.] to study. [Lines 259-275]

Along with the books, at this point in the lesson, Mrs Savige showed the students satellite maps of both Central Australia and their local area, pointing out features of the landscape that show weathering, such as the remaining core and rim of a nearby ancient volcano that the students have studied previously. She also gives other examples in the Northern Territory and New South Wales interspersed with travel stories and/or descriptions that include many of the key words in the text being read.

This relationship between a text and related texts has been called intertextuality. Defined broadly, it refers to all the other texts that a given text depends on for reader understanding, which Fairclough (2003) describes as "the dialogicality of a text, the dialogue between the voice of the author of a text and other voices" (p. 29). For example meaning in a textbook chapter might depend on the reader having read earlier chapters, having conducted an investigation in an accompanying practical workbook, or being aware of the periodic table of elements. When I refer to inter-texts, I mean all the other texts referred to explicitly or implied in a given text.

Another intertextual allusion Mrs Savige makes (and I know of its pertinence for this class because during the interview she referred to the fact that most of the students are currently taking woodwork as a subject) is to sandpaper, to further connect them to the idea of weathering, the main topic, and to the sub-topic of abrasion.

DS Thanks, David, you can keep reading. That last paragraph
S [Sound of reading, indistinct] is called abrasion [Indistinct, but sounds like another two or three sentences]
*DS Good. . . . . There's the "wearing away by substances rubbing together is called a**bras**ion".* [.] *Okay, so that is any kind of wearing away when things rub together. So any sort of sandpaper effect,* [1] *ok, where you have those small particles* [.] *bumping into and grinding at* [indistinct] *is called abrasion.*
S And what's this one, miss?
DS And ***abrasives*** [.] *are the substances that* ***do*** [.] *the abrasions*
S [Indistinct]
DS Mm, it has friction between the two. [Lines 575-587]

Another example comes soon after, during a note-taking exercise:

DS [Much expression and emphasis is used during the following monologue.] *Now, one thing it didn't talk about* [.] *was glaciers,* [1] *okay? And glaciers occur* [.] *in* [.] *shallow-bottomed valleys, where they have a lot of snow on the mountains and the snow packs down* [1] *and the snow packed down into ice and gradually moves down the valley. As it moves down the valley, it picks up rocks, and stones, and grit, and sand,* [.] *and because it's moving down the valley very slowly, those rocks and* ***boulders****, on some occasions they actually* ***grind*** *into the bottom of the valley. And if you've been—if you ever get the chance to go to a valley where there* ***used*** *to be a, um, glacier, you can actually* ***see*** [.] *the lines of, of where the rocks have been* ***dragged*** *across the surface of the bottom of the valley. And that's very similar to sandpaper. You know if you get a really coarse sand-paper?* [.] *and drag it* *across a smooth surface, you have all of those* [.] *lines that you've dug into it. Well, that's what a glacier can do, because it's very heavy, it's got very, you know, it's really thick ice,* [.] *um sometimes hundreds of metres thick↑, bearing down↑ and it has, a, these big rocks and boulders in the bottom of it, being dragged along. [Lines 708-721]*

Similarly when reading about "wave action", she compares it to their probable experience with surfing and feeling the force of a wave against their bodies, but noting that that's just an ordinary wave without the force of some of the waves full of sand and grit that pound against some cliff faces, especially during storms. The reading of the chapter is continually interrupted for similar graphic explanations of key concepts.

Later in the lesson, during the reading relating to frost action, Mrs Savige arouses the students' attention by explaining that they will not be doing the activity in the text-box because is it now considered too dangerous. In making such allusions, even though they do not have the hands-on experience, Mrs Savige has provided some intertextual context that will make the next section more meaningful for the students. Not only that, she makes this explicit for the students ("in this section, `Cracks in rocks,' it assumes that you might have done that experiment" [lines 86-87]), thus helping them understand something of how texts work, with one section being dependent on another if it is to be understood as the writer intended.

Reading the introduction as an introduction to the idea of weathering

After noting the overall structure, reading the detail follows. In line with her goal of helping students not only read for meaning, but also read to notice how the genre of a textbook chapter is written, Mrs Savige instructs the students to look for something that sounds like an introduction to the idea of weathering:

DS . . . . This first section is the introduction to the idea of weathering↑ . . . .

DS Ian, would you like to start reading for us?

S Where [indistinct] Miss?

DS Wearing away rocks. Okay. Page one-fifty. And we're looking for the sort of information that we would find in the introduction.

S "The photograph below shows rocks that have been worn away. This wearing away proceeds [indistinct] a long period of time. [indistinct] What do you think has happened to wear away [indistinct] rock?"

[Lines 443-458]

This is a signal for Mrs Savige to draw students' attention to the photograph and to teach some visual literacy, or in fact, multimodal literacy since the text and picture must be read together (see Lemke, 2004, above). Some teachers would expect students to take in what they need to from the photograph without further comment but this LS teacher knows that this is a literacy skill that her students will not necessarily have. She gets the students to look at the photograph in detail by asking a series of questions about what is in the photograph, why the cliff face is there in the landscape, what may have happened to it previously over a long period, and even whether the students would sit on the rock ledge in question themselves (why or why not?). As Lemke (2004) pointed out, recognising the importance of "visual representations of many sorts" in written communication in science is an important literacy of science and one that needs to be taught explicitly. Mrs Savige appears to appreciate this fact, both during reading and when getting students to make diagrams to accompany their own notes (see below).

Later, she explains to the students why they will not be viewing a film strip she had planned for the class and comments that this is disappointing because it was a great film strip and now they will have to get the information from the text instead. This should suggest to the students that visual information is a valuable way of learning and that the text is to some extent a substitute and perhaps a less satisfactory way of obtaining the same information, thus reinforcing the point she continually makes that it is their understanding of the science that is important, not rote learning a particular arrangement of words. This does not mean that she does not emphasise scientific terminology. On the contrary, she finds every opportunity to revise each of the key geological terms and their relationship to each other, including in anecdotes she recounts, in dialogue with the students (e.g., as they look at photographs in the illustrated travel books she has brought to the class), and by having students read and write them several times in different contexts (in the text, on the worksheet, in their notebooks in questions to questions, on the concept map, and in additions to their "vocab list"). The term "weathering", for example, appears 33 times in the audible part of the transcript. What she probably does not want is to have students think they will know something simply by reading the text-book at a superficial level.

The next move is significant for two reasons. Firstly, Mrs Savige is promoting the idea that a text is interactive—this one explicitly so—and that readers have to play their role and put questions to themselves about what they are reading. Secondly, during reading she scaffolds the students through the process of connecting the photograph to the concept of weathering:

DS Okay, let's stop there and answer that question. What do you think might have happened? [.] to form that rock ledge in that photo? [Quickening her pace] First of all, do you think it was always like that?

S No.

S Can I read again, miss?
DS In a minute, you've got to answer the question. What do you think has happened to make that rock formation? It's up in the mountains. [.] Does it look like a place that might be cold in the Winter?
S Yes.
S Yes.
DS Possibly↑ Or would they get—what sort of weather would they have? Would they have lots of rain?
S Yes.
DS In a [Indistinct] of wind?
S Yeah.
DS So what would happen. What has made those rocks look like that?
Ss [Silence]
DS The wind? The wind blowing what?
S Eroding the earth and the dirt.
S Blowing the dirt
DS Do you think that those rocks that are sticking out? Are they [.] harder or softer [.] than the rocks that are gone?
S Harder.
S Softer.
DS They would be harder. The rocks that are underneath that have worn away would be the softer rocks. You're right. Would you be keen to be that person sitting out there on the edge?
S Yes.
DS Yeah? I wouldn't. I'd I'd be much, rather be back at the top of the photo there where that other person is standing, on the [Indistinct]. Do you think at some stage in the future that might just topple into the valley?
S Yep.
DS Probably. [.] Things like that have happened.
[Lines 459-491]

After a student has read a little further on, Mrs Savige again stops the reading to make sure the students understand that the text refers back to the same picture. More significantly she does some "talk-aloud" to demonstrate her thinking process when she reads something which does not seem to make sense, a comprehension repair skill that poor readers are likely to lack:

*DS Just a minute, David. Just stop there. It says, it says. "***the** *cliff face was worn away by the action of waves and sand particles in the wind."* **Which** *cliff face are they talking about?*
Ss The one in the picture.
DS Do you really think that there were waves anywhere near?
Ss [Various answers] Yep. Nope. [Indistinct] *Ice Age.*
DS Probably, yeah, yeah, maybe that's. Yeah, cos I looked at that and I thought that's not a cliff at the beach. [1] *But yeah, maybe, end of –*
S [Indistinct]
DS That's right. So ***may****be that one was formed by* **wave** *action, but not in* **our** *lifetime.* [Lines 557-566]

Similarly with text, Mrs Savige helps students make the necessary connections, and at the same time understand that this is how such a text works. She has explained that this section is an introduction designed to get across the idea of weathering and now she is helping the students understand that, as well as using photos, the writer is reminding them of experiences that can help them connect to the idea being introduced:

S "Have you ever been on the beach and had sand blown in your eyes" [Several more sentences are read, all indistinct]
S Eyes.
DS And why would they be telling us about sand and dirt and grit damaging our eyes? when they're talking about wearing away rocks? [Lines 500-504]

As is recommended in the literature on reading, Mrs Savige is helping the students understand reading as an interpretation or problem-solving activity, one in which they need to work out what the writer is trying to communicate, based on clues in the text, such as that this in part of the introduction to the chapter, and other information they may have, such as prior experience of what it felt like to have the wind blow sand into their eyes. In this case, the text explicitly asks questions to help in this process, but, even when it does not, Mrs Savige, is teaching her students about the interactive nature of reading, especially for illustrated, informational science texts.

Note-taking: Writing about abrasion

The note-taking referred to previously happens as the students write on a prepared worksheet with Mrs Savige supporting those who get left behind. She first gives students ample time to write their own notes before writing on an overhead transparency (OHT) on the overhead projector. Rather than have students copy notes directly from the board or an OHT, Mrs Savige works with them to help them understand that the reading, note-taking and talking are all inter-related and that when they write notes, it is to help them remember what they have been reading and discussing:

However, with this class, much individual attention is needed before all students understand where the note is to be written. For these students, co-ordinating the reading, discussion and note-taking around an unfamiliar topic in which new abstract words are introduced is a difficult task. It would have been simpler to make each a separate task, but then the inter-relationship between the three tasks would have been less clear, and the point of note-taking as an active way of assisting in remembering what one has read would have been lost. Mrs Savige makes this reading comprehension-note-taking process explicit and scaffolds it step by step.

Several notes are made during the reading but as they stand they are not complete without one further step. Another of the literacies of science is illustrating the phenomena being written about. Mrs Savige encourages the students to draw little sketches that will represent visually what is in their notes. Even if the resulting diagrams are not clear to anybody else, the very act of attempting to transform the verbal information into a visual form will help fix the imagery and the facts in each student's mind in association with the notes on abrasion.

DS Now, what I'd like you to do over here, is just draw a simple little diagram or two that will help you remember [.] *what those notes mean. So for instance, with the, um,* ***wind***↑*, you might, sort of , you know, draw a bit of windy looking stuff with sand and grit being blown along.* [1]
S [Indistinct] *miss? We draw that, miss?*
DS If you want to↑*. The ocean waves, you could draw um,* [.] *a cliff* [.]*with um,* [.] *ocean waves coming up and pounding on to it. Like this - and draw some grit* [.] *in the waves.* [.] *Just to remind yourselves* [.] *what it looks like. If you want to have a go at the glacier, you could draw some* [.][.] *chunky rocks and boulders* [.] *that are imbedded* [.]. *Right?* [.] *and being dragged along.*
S [Indistinct]
DS I'm not very good at drawing diagrams. You might like to improve upon [.] *Okay, just draw yourself a couple of little diagrams there to help you remember.*
[Lines 724-737].

The activity also models for the students that, just as writing full sentences from the text-book is not required, neither is artistic ability necessary, since the point of the activity is that the notes are for their own understanding and to help them remember what they are learning.

Reading about frost action

The reading and note-taking are alternated. After this episode of note-taking, the next part of the reading dealing with cracking of the rocks is read as a whole-class activity, with continuing elaboration and repetition of new vocabulary (e.g., "shattered") and concepts ("e.g., frost action"), and attention being drawn to how the text is structured (see above in the section on intertextuality).

Highlighting a common genre in science: A "process"

Reading comprehension of informational texts is facilitated when students become aware of top level processes that can be found within paragraphs (Bartlett, 2003). As the students read further about weathering, Mrs Savige draws their attention to a genre that is common in informational writing in science and one (which I later learn in the interview) that they have met before: a process, in this case the process of frost action, which Mrs Savige then helps them review step-by-step:

DS Okay, Rose, can you read that last paragraph [indistinct] *weathering, please?*↓
S [Indistinct, but there is much expression in the voice]
*DS Good. And there's a process—shh, that's enough thanks, Rose, there's a ...****process*** *in that paragraph*↑*. Steps in a process. See if you can identify them. It says*↑
S [Indistinct]
DS Sometimes, yep, water gets trapped inside a crack in the rocks. That's step ***1****. Very cold days, it can freeze: step* ***2****. What happens when it freezes?*
S It expands
DS It ***expands****: step 3*↑*. And expansion can?*
S [Indistinct] *shatter.*
DS Shatter it—force the rock apart. And the rock may even be ***shattered*** *by the force of expanding ice!*
[Lines 810-824]

The process is reinforced a short time later when the students make notes on it on their worksheet. Further consolidation happens when Mrs Savige encourages the students to draw a diagram to illustrate the process, reminding them again of the purpose of the drawing being to help them understand what they have just read:

Answering text-book questions in notebook

Ostensibly "as a break from our note-taking now", but probably as a way of having each student revise and consolidate some of the knowledge gained through the reading and discussion, not to mention as a rough check on how much the students have understood, Mrs Savige has the students answer two questions from the text book in their own notebooks, questions which require understanding of what they have been reading. The first is a question about the photograph at the start of the section: "What do you think has shaped the cliff face?" During this process, she incidentally revises another school literacy: how to use the stem of a question to begin to write an answer. Just as importantly in terms of the literacies of science, she is also making students a little more aware of an aspect of science writing that is unlikely to be very familiar to them, viz, the passive voice:

DS Okay, let's take a break from our note-taking now and answer some questions. [2] [Indistinct] *You need to turn back to your notebooks where we put our* [1] ***heading***↑. [.] *We're going to answer Questions 1 and 2. Ian?* [5] [Lines 870-872]
DS [.] *Okay, just talking about that cliff face. What do* ***you*** *think has shaped the cliff face?*
Ss [Some low talk continues]

DS Shh. Have a look at your notes and come up with some answers. How would we start [.] *that question if we have to answer it. I won't* [.] *I won't get you to answer it in a full sentence but if we* ***did*** *have to answer it in a full sentence, what words from the question would we use? ...It says, "What do you think has shaped the cliff face?"*

S [Indistinct: *Do you mean?]*

S [Indistinct]

DS Good. That's a good start [.] *to the answer. "The cliff face was shaped* ***by****".* [Lines 900-910]

The passive voice (e.g., "was shaped by something" rather than "something shaped") is typical of traditional scientific report writing and is probably second nature to science teachers, so much so that they do not realise that this form of expression is not likely to be familiar to disadvantaged students in a low SES area. This is part of what Bernstein (1970) was referring to when he wrote about elaborated and restricted codes, which act to the detriment of children from lower SES backgrounds. Normally the elaborated code is expected and taken for granted, thus making it invisible. However, because Mrs Savige has altered the "pacing rules" in her class (halving the amount of content) she has the time to make visible the elaborated code and take her students further towards understanding the more abstract levels of knowledge. This has, of course, to be seen as operating within the limits of the further disadvantage of her "learning support" class.

Both during note-taking and here, Mrs Savige has stressed that the students are writing things for themselves, to help them remember what they are learning. Because of this they are usually given a choice about how to word what they write. During this question answering segment, she makes many efforts to get students to find their own answer before she provides one.

There are some occasions when she does consider it worthwhile to get the students to write a full sentence, such as when an explanation is required for an event. She has used the word "because" two dozen times since the beginning of the lesson and students have used it as well, but now she is helping them to write a formal sentence linking a cause and an effect, an important part of "talking science" (cf. Lemke, 1990). Given that Wellington and Osborne (2001) have reported that many senior science students have difficulty with a range of connective words, it makes sense that students at this level may need help with framing an answer that contains both the stem from the question and an explanation.

DS [.] *Question three.* [2] *I think it's worth writing a proper answer for something like this when it's asking us for a* ***reason****. How would we start our answer? Listen to the question again. "Rocks found in alpine areas have more cracks* [.] *than similar rocks found in coastal areas."*

S Okay, rocks in alpine areas will [1] *crack with um* [.] *crack* [.] *because of the weathering* |[indistinct] .

DS |*Because* [.] *right* [.] *bec**ause** is the word that we're after in our* [Indistinct]

S Because [Indistinct]

DS [Indistinct] *the difference about the weathering.*

S [Indistinct]

DS Okay. So let's write up on to the [.] *We'll start off with* [Indistinct] *"Rocks found in alpine areas have more cracks be**cause** [9]. Right, now "because" is the word that we* ***need*** *in that sentence because it's asking us for a* ***reas****on* [.] *and our reason needs to include something about* [.] ***ice*** [.] *melting and freezing and melting and freezing.* [1] *Okay?* [.] *See if you can finish that sentence.*

[Lines 1032-1048]

Another literacy of science that is addressed briefly during this question-answering phase in the lesson is the use of grammatical metaphor, more specifically, of nominalisation, that is, the use of an abstract noun to represent a previous action or process as an entity, a thing (cf. Gee, 2004). This is a particularity of science writing that makes for efficiency in explanations but is difficult for students to understand, especially when their written English is much weaker than their oral English. Nominalisation is used much more rarely in spoken English, especially in what Bernstein (1990) would call a "restricted code".

DS Okay, 2(d). "When water freezes it something?"

S [Indistinct]

DS What does it do?

S It expands.

DS What does it do? It expands [.] *all right* [.] *we'll find that word in our notes* [.] *"expand" –when the water freezes it expands. This* [.] *something* [.] *can cause rocks to split open.*

S The change in temperature.

*DS Yes, what does it say in your actual text? This ex**pan**sion-----*

S Expansion.

*DS They use the word "ex**pan**sion"*

S What [.] *expands?*

DS [Indistinct] *and expansion* [.] *the verb and the noun. Expansion.*

S So expands and expansion.

*DS Yes. When water forms ice it expands. [3 This ex**pansion*** [1] *can cause rocks to split open.*

[Lines 984-999].

"Expansion" is an example of an abstract word which sums up the previous sentence, the kind of discourse that helps a scientist make an argument clearly and succinctly through nominalisation of an earlier-mentioned process (cf. Martin, 1990, cited in Gee, 2004).

Table 2. Literacy teaching foci and strategies observed during the class

Domain	Lesson focus	Literacy teaching strategy	Inferred goals
Vocabulary building	Multiple meanings of a non-technical term	Distinguishing between two meanings of a word, each in its context	To build up awareness of words and the ways they can be used
	New technical terms	Repeating, discussing and making notes on new technical terms	To build students' familiarity with scientific terms
	Closely-related variants of Latinate words	Showing how a similar-sounding word can change its meaning as its ending changes	To help students distinguish between related, similar-sounding words
	Grammatical metaphor	Noting how a process can be represented by an abstract word	To help students understand and use abstractions in science texts
Reading	Reading for the gist using headings and the introduction	Getting students to find and notice each of the main headings and sub-headings and note the main topics	To help students get the gist of the chapter and become aware of how they did this
	Reading graphics	Scaffolding how to read a photograph in context and make connections to the text and other photographs	To promote student understanding of how graphics complement a text
	Interpreting the text	Making connections between concepts in the textbook chapter and everyday knowledge and experience	To facilitate reading comprehension by creating meaningful connections to a text
	Intertextuality	Making connections to texts outside the immediate text	To promote understanding of text interpretation intertextually
	Noting the genre-specific cues that signal meaning	Drawing attention to the functions of different sections of the chapter and how keywords are emphasised	To help students become aware of textual cues in an informational text of this kind
	Problem solving how to best interpret text	Using a think aloud to resolve an apparent anomaly in the text	To model comprehension repair when meaning breaks down
	Treating texts as interactive	Having the students answer both implied and explicit questions in the text as part of reading	To model how to interact with a text by asking oneself questions and answering its questions
	Noticing structural features of the genre	Helping students identify a process in the text	To help students become aware of textual top level structures
Writing	Note-taking	Using a prepared worksheet to capture key words and make notes	To promote understanding of writing to get down the gist
	Creating a visual representation	Creating drawings to illustrate notes made	To promote drawings as a useful way to represent concepts
	Writing an extended answer	Reorganising a question to frame an answer scientifically	To teach how to frame answers using the discourse of science
	Keeping track	Using graphic organisers and glossaries to summarise progress	To promote metacognitive awareness of the place of the parts in the whole
	Transforming information	Writing notes on a worksheet; answering questions in a student notebook; completing a concept map	To help students represent their understanding of concepts and relationships in a science unit

Representing new learning on a concept map

As part of helping students understand the gist of what they were learning in the context of the overall unit, we have seen how Mrs Savige got students to identify the main headings in the textbook chapter as a reading activity and then as a writing activity. Towards the end of the lesson, she also had students write on a concept map of the unit (a handout in the previous lesson), to identify where the material covered in this lesson fitted in the overall plan of the unit.

DS *Okay.* [.] *Can you turn* [.] *can you turn to your, um, concept maps? We're going to put some of these ideas into your concept maps before we go. . . . Okay. So 'Wearing* *away of the land↑" is the heading at the top of your concept map. Okay? "Wearing away the land"↑ And we said that there are a number of different ways that we can wear away the land so we need to just write in the ones that we have done so far which is abrasion.*

So I'm not going to write the whole heading up [.] *that says, "Wearing away the land." Can you draw a line over here and put "weathering". ... Okay and the first kind of weathering we looked at was* [2] ***abrasion*** [.] *and the second kind of weathering we looked at was* ***frost action*** *[5]* [These long pauses usually mean DS is writing on the OHT]. *We had* ***three*** [2] *three methods of abrasion.* [.] *Have a look in your notes and you will see we had ocean waves, wind and glaciers. So we'll just put "****waves*** [1] *wind* [2] *and glaciers* [.]*" and we have* [Indistinct] *frost action* [.] *we had the, um, "heat and cold and the ice* [.] *freezing.↓* [.] *Okay?* [3] *The main thing we were looking at today was "weathering:.* [2] *Two kinds of weathering* [.] *"abrasion" and "frost action". [Lines 1103-1124]*

This summary obviously serves the purpose of representing the day's learning in a graphical way in relation to the chapter heading, "Wearing away the Land", as well as consolidating learning during the lesson. It is another occasion on which key words are repeated in a meaningful context and written by the students.

Updating the vocabulary list

Another way of revising key concepts and creating awareness of the range of new vocabulary introduced during the lesson is the activity of updating the cumulative vocabulary list that the students keep in their notebooks. As is typical of this teacher, not only is the activity completed, but metacognitive awareness of the genre and its purposes are encouraged by explicit discussion. ("Vocab lists are mainly focusing on the new words that we should use, that we should know from [Indistinct]." [Lines 1083-1184]

Checking Progress on a Flow Chart

The final activity is another one that places new learning in relation to the overall goals of the unit, this time in terms of activities: checking progress on a flow chart of the unit. As it is a checklist, it is a way of helping students take some responsibility for keeping track of their own progress. It is also a chance for them to clarify anything they missed or are confused about, and, as happened in this lesson, ask their own questions about it. Having a visualisation of all the activities in the unit in front of them makes it possible for the students and the teacher to talk about what would otherwise be invisible.

This activity also serves another important purpose. In the interview, Mrs Savige talked about the importance of the flow chart for helping students have a sense of achievement each lesson as they see the progress they are making through a one-page summary of the unit activities. She tells her students, "We're halfway through the work-sheet, half-way through the questions (Line 1214)." For students who have missed classes, it allows them to see clearly what they have missed and need to catch up on. As well, the flow-chart also helps students pre-view what is yet to come and is a chance for the teacher to begin to acquaint them with new terms.

Lesson Closes and Students Choose Prizes

The final stage of the lesson is the time when students who have observed the basic rules of classroom behaviour over five periods get a small reward from the "prize box". This helps motivate them to behave appropriately in class and is a positive complement to the behaviour cards that add up to detentions and exclusion from class.

DISCUSSION

Even though Mrs Savige's primary goal in the double lesson I observed was to introduce her students to the science of weathering, in the process she used 17 different types of literacy teaching strategies, as detailed in the analysis above and summarised in table 2.

The low level of literacy of the students in this study means that the skills being developed were often those that can be taken for granted in a more literate, middle class community. However, there are also generic and specific science literacies being developed that would benefit students in a regular science class and make science more accessible and hence less alienating for them. Table 2 lists the types of literacy activities and some examples that were addressed with this class.

For each domain (of literacy) (column 1) I have listed the particular literacy foci addressed in this lesson (column 2). The third column in the table summarises the literacy teaching strategies used, and the fourth column shows what I inferred to be the literacy teaching goal behind the strategy.

I have divided the literacy domains into three: vocabulary-building, reading and writing. In fact vocabulary building was part of both the reading and writing instruction during this lesson and has only been abstracted because it was common to both, to save repetition or overlap. Kamil & Bernhardt (2004) cited vocabulary knowledge as one of the key factors in successful reading and it is no doubt included as a key component in Yore *et al.*'s (2003) model of an interactive-constructive view of reading, under the guise of "prior knowledge of the topic". As such, vocabulary-building could be seen as a pre-reading skill; here it is obviously included as part of the process of interpreting the *current* text. Because these students have so little knowledge of the pre-requisite vocabulary, Mrs Savige attempts to catch them up during the reading.

This process continues during the writing activities because developing understanding of the full meaning of each new word is a gradual, on-going process of building rich connections as part of the development of the thematic pattern of the topic. Each use of a new technical term is a step along the way, from the teacher's first mention of the word, to hearing it being read by another student, to hearing it in the context of an anecdote or analogy, to learning to spell and write it during scaffolded note-taking and question-answering, to recognising it as an addition to one's vocabulary during the "vocab list" exercise, learning to distinguish it from closely-related words, especially for the Latinate words so common in science texts, seeing its place in representations of the overall unit, to finally making independent use of it in a future note-writing exercise, or even better, using it competently as a communication tool in a context outside the science classroom. This also applies to non-technical terms, where each new usage of a word in context will help refine a student's understanding and control of the word.

Unfamiliar multi-syllabic (often Latinate) words are likely to confuse students when they have variants (e.g., abrasion and abrasives) that look and sound very similar but have different endings and usages. Hence Mrs Savige took particular care to distinguish between them and model how each variant was used. Nominalisation (e.g., expansion) which is so common in science texts, is not likely to be used by the majority of students in everyday talk, so Mrs Savige provides support in helping her students use it in the context of answering a question.

Table 2 shows that the reading skills that Mrs Savige covered with her class fitted with the interactive-constructive view of learning described by Yore *et al.*, 2003). The strategies were related to activating both episodic memory and semantic memory, and to accessing available cues in both the textual and sociocultural contexts. However, rather than merely reminding students to access such memories and cues, Mrs Savige needed first to teach students about the typical features of the science textbook chapter genre, such as the way the introduction and the headings indicate what the chapter is to be about and what the main topics to be covered are, the way formatting cues differentiate between more and less important headings and terms, what to expect in different parts of the chapter, and how different parts, such as the text and graphics, depend on and reinforce each other.

Further, she needed to encourage students to take an active role in interacting with the text and in interpreting it, when connections needed to be made between different parts of the text, and to model how to undertake comprehension repair when the meaning was not clear or seemed anomalous. This meant teaching her students to ask and answer questions about the text and graphics, whether or not such questions were explicit in the text. Further, with regard to episodic memory, she had to scaffold her students to make connections between their own experience and the science content of the chapter. They needed to be helped to see the connections between the chapter section they were reading, other texts Mrs Savige had introduced into the lesson, a photograph in the text, a text-box within the chapter, and texts which they had studied in the past. These connections all added richness to the frequent summaries of the key concepts they were studying or would soon study.

The final section of Table 2 summarises the writing skills that Mrs Savige was apparently aiming to develop in her students during the observed lesson. These were note-taking skills, question-answering skills, and ways of representing a snapshot of their progress in relation to the unit. As well, she modelled how to integrate the various literacy tasks they were engaging in, so that the reading, talking and writing were clearly linked.

Rather than have students copy down already prepared notes, Mrs Savige tried to help the students create notes and diagrams on the spot as she summarised orally what they had just been reading and discussing. In fact some had such difficulty with writing and spelling that they depended on Mrs Savige to write first and then copied from the OHT. Nevertheless, she communicated that writing notes was about getting down the key features to help one remember what one has been reading and discussing. She helped students translate the knowledge into a new form in a way that encouraged them to think about the concepts, allowed for repetition of new technical terms, provided a further chance to connect to their experience (such as when she made references to surfing and using sandpaper), took advantage of an attentive audience for the introduction of new factual material (about glaciers), helped them consolidate knowledge about textual top level structures such as a process, and provided a safe environment for students with very limited writing skills to complete a meaningful writing task.

Helping students write answers for comprehension questions about the text allowed Mrs Savige to introduce her students to ways of thinking and writing that are typical of informational science texts but with which they may not be familiar. In the first instance Mrs Savige scaffolded the process of rearranging words from a question into the passive voice to create a stem to begin an answer to a question, and in the second she scaffolded the construction of a complex sentence to create an explanation that would answer a "why" question. The final writing activities were designed to help students have an overview of where new terms fitted into the overall unit plan and included using graphic organisers (a concept map and a flow chart) and a glossary to note what had been covered in that particular lesson and what was still to come. In all cases of writing, the students were being asked to transform information from one format to another, which is in line with the knowledge-transforming model of writing that Yore *et al.* (2003) described. For example, they were being asked to spend more time thinking about the purpose of the writing (to help them remember new learning), specifying the audience (themselves), accessing and revising content knowledge, and, thinking and negotiating language use. Writing was not being used merely to transcribe predetermined knowledge or evaluate students' learning, although the writing activities may have involved elements of the former and the discussion around the writing would have provided feedback to Mrs Savige about the level of understanding of many of the students.

While some of the time was spent on reading and developing reading skills and some on writing and developing writing skills, it is notable that Mrs Savige integrated the various processes so that students could see how they were inter-dependent. She appreciated that this increased the complexity of the task from their point of view (cycling between reading the textbook section, talking about what they were reading, writing notes on a sheet about what they had just read, answering questions, and copying from an OHT) and prepared them to accept this complexity by making explicit the several processes in which they would be engaged. In this way science was presented as coherent and meaningful and not as a series of disjointed activities as it otherwise may have appeared to be for these students.

CONCLUSION

While the focus was on the science content, many reading and writing skills were taught, thus ensuring that the low-literacy students were given increased access to participation. However, this teaching did not happen subconsciously: Mrs Savige had explicit literacy-teaching goals even while focusing on teaching the science of weathering. She was not simply getting students to find information in the text and get a record of it, but wanted them to become independent readers who could find, interpret, and record such information for themselves. Like many high schools in Queensland at that time, particularly where the general literacy level was problematic, the school visited in relation to this exemplar was getting involved in the movement for whole school literacy development. When I asked Mrs Savige what this meant to her, she said she saw her role as a literacy teacher as being to make explicit processes that she herself was engaging in:

> *I think when I look at how much literacy do my students need to access science I look at my self talk [.] the literacy skills that I employ . . . to get that information. . . . I think literacy is more than just reading and writing. . . . when I'm looking for information I have an expectation as to what is going to . . . when you're working with the text whether it's a written text or visual text or whatever, I think it is important to, to point out to students quite explicitly where the information is and how it's organised . . . . And where they can expect to find it and what they can expect to find and whether they're going to find it in a picture or a table.*" [Lines 964-984].

This is a good example of what Gee (2004, p. 31) referred to as "reading lessons" on "expanded texts" in which people more expert than the students model how they read such texts, and engage the students in overt discussion about the language and genre conventions of such texts, "in the midst of practice". Of course, the fact that Mrs Savige trained as a resource teacher meant that she was much more aware of the breadth of literacy skills she was using than many science teachers would be and so had many more literacy skills about which she could be explicit. At another level, she was inexpert and needed to help both herself and her students understand a topic she had not studied formally herself. As someone who had not specialised in geology, she used travel to enrich her understanding of the topic and so provided her students with travel books and stories as texts to help them see the significance of the science they were studying during this lesson.

There are some obvious limitations to this study of literacy teaching strategies to help bridge the gap between students' current literacy skills and those needed for school science. In the first place, this was only one double science lesson during one module of one course unit for at a particular time of the year in a particular context.

It should also be noted that because this analysis was limited to one class, albeit a double period, this article has only covered a sample of all possible aspects of fundamental and science literacies that students will need. Mrs Savige herself may have addressed other aspects of literacies or more generic or more scientific ones in other lessons and other teachers will no doubt cover other generic and science-specific literacies.

Another limitation was the fact that these students had reduced content to cover when compared with a regular class. However, this is a good example of the benefits of reducing the pace at which new content is introduced for students who can be deemed to have a restricted language code in Bernstein's (1990) sense of the phrase. The students appeared to learn more and in greater depth and with better engagement when given time to make rich connections in a range of directions. I was amazed at how they generally maintained their interest in the topic for the duration of a double period.

As well, these were low level literacy students who needed extensive work on a range of literacy practices. It may be that this exemplar has more to offer primary school teachers whose students may need extensive scaffolding in the literacies of science. Students in regular middle years or secondary classes may be assumed to need less detailed and repetitive work but it is likely all the same that for at least some of these literacy practices they will benefit from having them made explicit. In aspects such as the use of nominalisation and the use of logical connectives, it may be a useful model not just for secondary science but in other academic subjects where abstract discussion is required. While this paper is perhaps an extreme case of the need for integrating literacy teaching with science teaching, it nevertheless demonstrates how reading comprehension and transformative writing can enhance learning in science.

One implication of this study relates to teacher training. If science teachers are to feel comfortable teaching the literacies of science they may need to have what is transparent for them made opaque again. What is needed may be a module focusing on discourse analysis preferably during teacher training, or later, when they are noticing early signs of deficiencies in the language skills of their science students.

The alternative, that language arts teachers should be responsible for developing such skills has been found not to be a solution, since both the literature and this study demonstrate the importance of a discipline-specific teacher in helping students work with both the specific content and the specific genres and literacies of school science. It is true that Mrs Savige had learnt literacy teaching skills as part of her LS role in the school, but it was her discipline-specific knowledge of science that enabled her to facilitate the processes of reading a science textbook and the processes of writing that are consistent with the discourse of school science. Both are necessary and another solution may be to team science teachers with literacy teachers.

Another implication of this study is that it is clear that literacy can be taught as part of science without wasting precious time for science content. On the contrary, such teaching enriches the learning of science, by enriching reading comprehension and the transformation of knowledge in ways that enable a deeper understanding of science concepts and processes.

In conclusion, while the class has been firmly focused on the Earth science topic of weathering, I have demonstrated that this teacher has also been able to teach the fundamental and scientific literacies required to understand the topic. The literacy skills she has been teaching are essential for learning the science being taught.

Throughout, learning is seen as an interactive process and this is not only good for learning, but it is also likely to be good for students' motivation and engagement. Just as the writing heuristic (SWH) has been found to lead to benefits in learning through the transformation of knowledge, having more metacognitive control over both reading and other writing processes is also likely to be beneficial.

Finally, with regard to equity and access, because she changed the pacing rules to allow time for "smelling the roses along the way" (DS interview, line 1085), Mrs Savige's curriculum made it more likely that students with a disadvantaged background and a restricted language code could progress beyond the initial concrete stages of learning to deeper, more abstract levels of meaning. She allowed time for her students to fill some of the gaps in literacy skills and background knowledge which meant that they could actively participate in learning science in spite of such disadvantages.

Notes:

[1]*I have permission from the teacher to use her actual name. I made sure this was part of the research arrangement because I think teachers such as this one should be recognised and acknowledged for their expertise and for what they have to contribute to research.*

[2]*The following conventions have been used for this transcription:*

- *Even though the teacher's real name has been used (for the reason given above), students have been given pseudonyms;*
- *"S" stands for an un-named student, and "Ss" for more than one student;*
- *Words in curved brackets are an acknowledgement that a word or several words was indistinguishable or, alternatively, they may represent the best guess at what the word(s) sounds like;*
- *Words in italics in square brackets are a comment by the transcriber to convey non-verbal aspects of the situation;*
- *Up and down directional arrows are used to indicate abrupt changes in pitch;*
- *A "|" has been used to align simultaneous talk by two parties when the talk overlaps;*
- *Other than by the use of a full stop at the end of a sentence, additional pauses are indicated within square brackets by a full stop for a momentary pause, or by a whole number for seconds of duration;*
- *Emphasized syllables appear in bold type;*
- *"..." or "...." represent phrases or sentences respectively that have been omitted from the transcript excerpt for the sake of brevity; with the constant (often indistinct) interruptions from students, teacher corrections of minor inappropriate behaviour and such like, excepts would have been inordinately long without contributing much to the point being made. Line numbers give an idea of how many lines have been omitted.*

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Exploring the Conceptions of a Science Teacher from Karachi about the Nature of Science

Mir Zaman Shah
RMIT University, Bandoora, VIC, AUSTRALIA

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The main purpose of this study is to investigate a science teacher's beliefs and understanding of the nature of science (NOS) in order to be able to relate these beliefs about the NOS to classroom practice and therefore student experience. Teachers' beliefs about the NOS are embedded in their experiences of learning and teaching science and hence, this research contains elements of a life history approach within a qualitative interpretive design. A single science teacher, Ikraam (a pseudonym), working in a community-based co-education school in one of the socio-economically disadvantaged areas in Karachi, was the focus of the research. His life story plays a vital role in this study to illustrate his views of the NOS. The data includes six life history interviews, two group interviews with his students, eight classroom observations and document analysis. The study revealed that the teacher's beliefs about the NOS were embedded in his own experiences of learning and learning to teach and indicates that in some cases Ikraam held informed conceptions about the NOS but in some important areas he displayed naïve views.

Keywords: Science Teacher, Epistemological Beliefs, Nature of Science (NOS), Life History Approach

INTRODUCTION

The main purpose of this study was to investigate a science teacher's concept and understanding of the nature of science (NOS). The study was conducted on a single science teacher, Ikraam (a pseudonym), a young male teacher working in a community-based co-educational school in one of the socio-economically disadvantaged areas in Karachi. Though gender was not a part of the variable in my study, for purely pragmatic reasons, I have chosen to select a male science teacher. His life story plays a vital role in this study in order to illustrate his views of the NOS. The data includes six interviews with Ikraam, two group interviews with fourteen students in two groups, eight classroom observations with post-lesson discussions, documentary analysis, and a number of informal conversations with Ikraam, his colleagues and students. Findings included how Ikraam's own experiences initially made him see science as difficult but he was able to change this perception when presented with opportunities to study in an Advanced Diploma in Education: Science (ADES) program. This study program allowed Ikraam to critically reflect on his practice and to develop theories about the contradictions between beliefs and practice that were identified during observation sessions. These were ascribed to a combination of constraints in resourcing and pedagogical skills. The ADES program was also found to have some limitation as there were assumptions in the approach about implicit knowledge and there was no acknowledgement that some learning may need to be explicit.

Correspondence to: Mir Zaman Shah, Doctoral Student, School of Education, RMIT University,
PO Box 71, Bundoora 3083, VIC, AUSTRALIA
E -mail: *mirzaman.shah@akesp.org*

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Background to the study

My experiences of working as a teacher and teacher educator for 15 years reveal that what a teacher considers to be desirable ways of teaching and learning, are likely to be influenced by his/her own knowledge of the nature of the subject s/he teaches. Similarly, all teachers of science have implicit and explicit beliefs about science, inquiry, teaching, and learning (National Research Council [NRC], 1996). Hence, in Harlen's (1992) words, "We teach according to how we understand the nature of what we are teaching and according to how we understand the nature of learning" (p. 1). Therefore, what constitutes good science teaching can be better determined by understanding what the teachers understand about the nature of scientific knowledge.

Many previous studies have shown that in most cases, both pre-service and in-service science teachers' understandings of the nature of science (NOS) are inconsistent with contemporary concepts of the scientific endeavour (Abd-El-Khalick & Lederman, 2000). The situation of Pakistani science teachers is no exception. They also have a linear understanding of science and so they consider science to be a body of knowledge characterized by facts, concepts, laws, and theories that are absolute and cannot be challenged. Most teachers assume that only scientists can construct scientific knowledge and learners have to strictly follow them. They believe that knowing science is to learn the scientific concepts translated by the teachers from the textbooks. Hodson (1998) calls such views a depersonalized image of science, which he considers a serious misrepresentation of the NOS and scientific practice. Thus teachers impart factual information to their students at the expense of "the most important objective of science instruction [NOS]" (Lederman, 1992, p. 340).

Such naïve conceptions of teaching science lead to classroom instruction that strongly emphasizes rote memorization of science content presented by the teacher or read from the textbooks. As a result of such instructions, students may learn facts, hypotheses and theories of science – the *what* of science, but they do not necessarily develop an understanding of where this knowledge originates from – the *how* of science (Duschl, 1994). While in the learning process, there is a place for memorization, this does not help the students to understand and develop concepts that enable them to make sense of new experiences and apply their learning in decision-making in their daily lives (Harlen, Marco, Reed & Schilling, 2003). In addition, learning science becomes a dry, difficult and boring activity for the students, and so they develop a negative perception of science and find it irrelevant to their daily lives.

Therefore, it appears that practices of teaching and learning science reflect the teachers' own ignorance of the nature of the scientific enterprise. Thus not knowing about science, science teachers continue to teach science as a collection of facts, and such teaching practices foster students who go on to become teachers who follow their own teachers, and the cycle continues (Halai, 2000). Esler and Esler (1996) state: "What science is *not* is a set of facts. Those who work with science know that what a fact is today is questioned tomorrow, and often ridiculed as nonsense a year from now" (p. 6).

The following comments of Lederman, McComas and Matthews (1998) rightly endorse the problem of the study:

> *What seems to be the problem? First, science teachers persist in portraying science in a highly idealized, stereotypic fashion. Even those teachers who do have more adequate views of science typically fail to address questions about the nature of science in their daily instruction. There is also inconsistency in how science is portrayed in textbooks. Most texts … [also] portray science in a distorted, positivistic, and 'final form' fashion. (p. 507)*

Science teachers in Pakistan, in most cases, have an inadequate understanding of the NOS (Halai, 2004). In their classrooms they dictate notes from the textbook and the students memorize them without understanding. Thus, not knowing about the NOS, they present science as a product, but they are unable to guide students to understand how scientific knowledge is constructed.

This paper identifies a problem related to the teaching and learning of science and describes a research project examining the experience of a science teacher in a community-based school in Pakistan. The teacher was chosen as a participant as his experience of science teaching, as both a pupil and a teacher, had not been positive until he had the opportunity to study for an advanced diploma in education. For the purposes of this present paper two of the findings are discussed (1). Science is seeing and doing and (2). Observations are independent of theory. These are important as the influence that teachers have on students can be intergenerational and therefore a case can be made that the teaching and learning of science needs to be reconceptualised.

The Research

This research posited the question of what is a science teacher's understanding of the nature of science, while teaching science in a school in Pakistan? The study was based on certain fundamental assumptions. Firstly, teachers can play a major role in developing students' understanding of science if they themselves have a sufficient understanding about the nature of scientific knowledge because conceptions/beliefs are likely to influence classroom instructions. Secondly, an exploration of teachers' concepts about the NOS will shed light on their beliefs about science, and the teaching and learning of science. This exploration in turn, will help science educators to identify ways to enhance teachers' conceptions through professional development programmes.

To contextualise the study I examined the literature on the meaning and the important aspects of the NOS, and the importance of teaching about the NOS to students in science education. I also reviewed some key studies on the teachers' conceptions about the NOS, including the relationships between their concepts and their classroom practices.

The literature

What is the nature of science?

The concept of the nature of science is a complex notion. Science educators are quick to disagree on specific definitions for the NOS (Abd-El-Khalick, 2001). Various writers have defined it differently. Cobern (2000) points out that "NOS researchers do not offer a single answer to the question, what is science? The variation reflects in part the variation among philosophers of science" (p.219).

Lederman (1992) picked up some common themes within the varied definitions and noted the phrase nature of science typically referring to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge. With this definition, he also notes that the nature of scientific knowledge and inquiry is neither universal nor stable. This is one the contemporary and frequently quoted definitions of the NOS in science education literature. Lederman, Wade and Bell (1998) further unpack the definition and explain that "these values and assumptions include, but are not limited to, independence of thought, creativity, tentativeness, empirically based, subjectivity, testability, and cultural and social embeddedness" (p. 596). Bell and Lederman (2003) further add "parsimony" to these values and assumptions.

Gess-Newsome (2002) defines the NOS as the epistemological underpinnings of science, which include characteristics such as empirically-based, tentative, subjective, creative, unified, and cultural and socially embedded. Both definitions share similar characteristics. Furthermore, McComas, Clough and Almazroa (1998) explain:

> *The nature of science is a fertile hybrid arena which blends aspects of various studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors. (p. 4)*

The philosophers of science have adopted, and continue to adopt a range of positions on the major questions and issues about science and scientific knowledge, which is problematic (Driver, Leach, Millar & Scott, 1997). Abd-El-Khalick and Lederman (2000) recognize that "this lack of agreement, however, should not be disconcerting or surprising given the multifaceted, complex, and the dynamic nature of scientific endeavour" (p. 666). However, Abd-El-Khalick (2001) points out that at one point and at a certain level of generality, there is a shared wisdom (though not complete agreement) about the NOS. Moreover, he also argues that at such a level of generality, some important aspects of the NOS are non-controversial. For this research, the NOS is understood to be directly related to the epistemology of science - the knowledge of the construction of scientific knowledge and the operation of scientific enterprise.

School science and conceptions of the nature of science

This study is focused on the aspects of the NOS in the context of school science. Halai (2005) points out that there is a measure of agreement on a number of points relevant to the school science curriculum. Lederman (2000) indicates that students of science at the school level should learn about the aspects of the NOS such as: scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), theory-laden (subjective), necessarily involves human inference, imagination, and creativity (involves the invention of explanations), necessarily involves a combination of observations and inferences, and is socially and culturally embedded. One additional aspect is the function of, and relationships between scientific theories and laws.

More recently, Halai and Hodson (2004) provided an abridged version of the aspects of the NOS as identified in the National Science Teachers Association (NSTA, 2000) position paper. This affirms the following premises that are important to an understanding of the NOS in the context of school science:

- ✓ *Scientific knowledge is simultaneously reliable and tentative.*
- ✓ *Although no single universal step-by-step scientific method captures the complexity of doing science, a number of shared values and perspectives characterize a scientific approach to understanding nature.*
- ✓ *Creativity is a vital ingredient in the production of scientific knowledge.*
- ✓ *A primary goal of science is the formation of theories and laws, which are terms with very specific meanings.*
- ✓ *Contributions to science can be made and have been made by people the world over.*
- ✓ *The scientific questions asked, the observations made, and the conclusions in science are to some extent influenced by the existing state of scientific knowledge, the social and cultural*

context of the researcher and the observer's experiences and expectations.

✓ *The history of science reveals both evolutionary and revolutionary changes. With new evidence and interpretation, old ideas are replaced or supplemented by newer ones. (Halai & Hodson, 2004, p. 106)*

The characteristic features of the NOS for school science mentioned by a number of authors are, to a great extent, similar and overlapping. I found the aspects of the NOS given by Halai and Hodson (2004) appropriate to use for my study because they encompass the characteristics and elements mentioned in other reform documents. Therefore, I have used these definitions of the NOS for the purpose of my study.

Methodology

For the purpose of this research a life history method was used to examine the impact of experience on a science teacher's understanding and teaching of science. Direct observations and interviews with key players, in this instance with students in the science teacher's classes, were also used. Life history has its roots in narrative research. A narrative inquiry is a form of inquiry in which a researcher explores the lives of individuals by asking them to provide stories or narratives about their lives (Creswell, 2003). In a life history study, the researcher and researched co-construct stories, that are interpreted and analyzed to draw conclusions about the understanding of the researched, regarding the topic under investigation. The fundamental assumptions behind using this approach are well stated by Goodson (1995):

That the teacher's previous career and life experiences shape his/her view of teaching and the way he/she sets about it; that the teacher's life outside school, his/her latent identities and cultures, may have an important impact on his/her work as a teacher. (p. 84)

Hence, there is a link between past, present and future, as Hitchcock and Hughes (1995) state, "The life story approach facilitates a deeper appreciation of an individual's experience of the past, living with the present, and a means of facing and challenging the future" (p. 186). As such, a life history approach lies within the qualitative research paradigm. As Hitchcock and Hughes (1995) state about life histories:

This approach uses qualitative techniques, in particular the unstructured or semi-structured interview, which are designed to provide individuals with the opportunity of telling their own stories in their own ways. This facilitates the reconstruction and interpretation of subjectively meaningful features and critical episodes in an individual's life. (p. 186)

Researchers have used a number of methods and tools to study teachers' conceptions about the NOS including: the use of critical incidents (Halai, 2005; Nott & Wellington, 1995), open-ended questionnaires (Abd-El-Khalick, Bell & Lederman, 1998), a life history framework (Halai, 2002; Halai & Hodson, 2004), combination of interview and classroom observation (Halai 2000). An open-ended approach using life history interviews provides more freedom for the respondents to express their own views on the scientific enterprise while helping them to avoid the impositions of the researcher's views (Bell & Lederman, 2003). During the past decades, there has been an increasing interest in the use of life history and narrative approaches to study teacher thinking and teacher development (Carter & Doyle, 1996; Cole & Knowles, 2001).

As a number of researchers advocate using a more open-ended approach to explore teachers' conceptions of the NOS, I used a life history framework for my study. For example, Hitchcock and Hughes (1995) advocate the life history approach because "it enables the researcher to build up a mosaic-like picture of the individual and the events and people surrounding them so that relations, influences and patterns can be observed" (p. 186).

The teacher's views were embedded in his talks about ordinary day-to-day life and the practice of teaching. Discussing and analysing examples from everyday and classroom experiences illustrate the teacher's knowledge. Similarly, his perceptions were grounded in professional practice (Nott & Wellington, 1998) and personal life (Goodson 1995; Halai, 2002). Interviews dealing with his personal and professional life, a combination of classroom observations and informal conversations capture the teacher's views and practices. As Smith (2001) states:

Teacher beliefs develop throughout their lifetime and are influenced by a variety of factors, including events, experiences, and other people in their lives. Teachers' life experiences and background affect what they believe, and consequently, how they teach. Consequently, a life history approach enables us to understand a teacher's life and work in terms of the meaning they have for the individual teacher. (p. 112)

DATA COLLECTION TECHNIQUES AND ANALYSIS

Data was collected from a variety of sources including interviews, classroom observations, post-lesson discussions, document analysis (including lesson plans, the teacher's diary, syllabus, and reading texts), group interviews from students and informal talks, with the major sources being interviews and observations. These were very helpful in maintaining the rigour of the data because as Maxwell (1996) observed, "triangulation of observations and interviews can provide a more complete and accurate account than either could alone" (p. 76). The main protagonist in the study was a science teacher who had undergone a change in his perceptions, about science and science teaching, after being given the

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chance to do some advanced study on the teaching of science. The document analysis also included handbooks from the Advanced diploma this teacher was undertaking.

Semi-Structured Interviews

In a life history study, data collection is primarily through semi-structured or unstructured interviewing (Goodson & Sikes, 2001). Hence I used an 'oral life history interview' as one of the main techniques. The interviews allowed me to invite information from the respondent about situations from his own perspective and in his own words (Kvale, 1996). The focus was on this stories of learning and teaching science, while opportunities to reflect on the meanings of his experiences were also provided.

Initially, I conducted three interviews of 45 to 55 minutes with Ikraam, the science teacher who was the focus of this research. The first interview was general discussion regarding his life. In the second and third interviews, we had specific and intensive discussions about his experiences of learning and teaching science, and his understanding of the nature of scientific knowledge. Whilst constructing his life story, I sought information from the participant on particular periods of his life such as his childhood, primary school experiences, middle and high school experience, college experiences and teaching experiences (Bogdan & Biklen, 1992). I often asked follow-up questions, probing questions and interpreting questions.

In addition to the three initial interviews, I had three more interviews during and after the classroom observations. The first of these was about a science exhibition which the school had organized and the other two interviews were conducted at the end of the data collection period in order to fill in gaps and double-check with the teacher on specific issues. I also interviewed the principal to collect information about the background of the school. I interviewed the science coordinator about the kind of support he provided to Ikraam. All the interviews were audio recorded and transcribed verbatim.

Group Interviews

A popular interviewing technique is group interviewing. A focus group has the potential for discussion that gives a wide range of responses (Cohen & Manion, 1994). I conducted two interviews with his students in groups to get some ideas regarding Ikraam's teaching practices. The first one was from a random sample of 10 students of Class 8. In the interviews, I inquired about their views of their experiences of learning science in Ikraam's class. The second interview was with a group of 6 students of Class 5 who were involved in the science exhibition.

Classroom Observations

Observation is a valid and direct way of obtaining data from people. Gillham (2000) argues: "it [observation] is not what they say they do. It is what they *actually* do" (p. 46). I therefore observed Ikraam's teaching during 4 lessons, four with Class 5 and four with Class 8, making a total of eight observations, Maxwell (1996) endorses the purpose of this observation when he states:

> *Observation often enables you to draw inferences about someone's meaning and perspective that you couldn't obtain by relying exclusively on interview data. This is particularly true for getting at tacit understandings and theory-in-use, as well as aspects of the participants' perspective that they are reluctant to state directly in interviews. (p. 76)*

The observations were intended to find out to what extent Ikraam's stated views were manifested in his classroom practices. The choice of two different grades was to get a better and broader picture of practice. During the classroom observations, I mainly focused on Ikraam's teaching techniques, use of resources, questioning skills, and interaction patterns with his students. I was hoping that these observations would allow me to see the translation of his views of the NOS in his practice. I took descriptive and analytic (Glesne, 1998) anecdotal notes of my observations of the classroom activities.

Analysis –Ikraam's Conceptions of the Nature of Science

The analysis of the data from the life history interviews and classroom observations showed that the following aspects of NOS were explicit in Ikraam's views and practices:

1. *Science is an in-depth inquiry and explanation of natural phenomena.*
2. *Science is "seeing and doing".*
3. *Observations are independent of theory.*
4. *Scientific knowledge is empirically-based while religion is belief-based.*
5. *Scientific knowledge is simultaneously reliable and tentative.*
6. *Scientists may not necessarily follow a single step-by-step scientific method.*
7. *Scientific theories evolve into laws on further evidences.*
8. *Models are not actual representations of a reality.*

In the following sections, I discuss two of the above findings (2 and 3) to exemplify Ikraam's concept of the NOS.

Science is "Seeing" and "Doing"

Ikraam believed that human senses play an important role in generating scientific knowledge, and observation is the starting point of a scientific inquiry. He considered science as a practical subject and believed that in the science classroom, in order to understand science, the students must be given the opportunity for *seeing* and *doing*. He was of the view that providing the children with abstract explanations is just like 'building castles in the air'. To understand science, they must see and do it, that is, experience it.

The analysis of his life history showed that this practice was rooted in his biography. While describing the characteristics of his favourite teacher, he mentioned that one of his teachers provided him the opportunity to "see" and "do" science in the classroom which helped him in understanding certain scientific concepts that were taught that way. But there had been very little opportunity for him to learn science by seeing and doing. He had pointed out that he did not get the opportunity to "do science", and due to this he could not develop an understanding of most of the scientific concepts. His teachers would mostly read the textbook, dictate notes, and he would memorize them.

The idea of seeing and doing for effective learning of science was also explicit in his classroom practices. He demonstrated the ambition to let his students see and do science, but he has not been able to do so yet. He stated that to learn science in a more effective way, such as through group work, it is necessary for the students to get the opportunity to manipulate the materials and discuss the emerging scientific concepts. He particularly highlighted the role of hands-on and minds-on activities in learning science. But because of the constraints, such as the lack of space and resources, fixed furniture and time limitation, he was unable to organize group work on a regular basis. Instead, he usually arranged for practical demonstrations in the classroom.

In Pakistan, carrying out practical work in the primary and middle classes is not a common practice. Practical work, if any, is done in Classes 9 and 10 only (Halai, 2002). Being a product of the Pakistani educational system both as a student and later as a science teacher, I myself have indulged in organizing practical work only in the secondary classes. But Ikraam's case was different. In his class, he was unable to provide children with an opportunity for doing hands-on activities individually or in small groups; therefore, he often made a concerted effort to arrange demonstrations for them.

He used low cost and no cost teaching materials. Out of the eight lessons I observed, he gave demonstrations in five lessons in the class. In a lesson about the *forms of energy* he gave five demonstrations by using a candle, matches, torch, toy car and electric switch respectively. The activities aimed at involving the students in discussions about the topic. The text was about atomic energy, which the students were asked to read from the textbook and discuss in the class. Similarly, while teaching the uses of carbon dioxide, he brought a fire extinguisher to the classroom and explained its structure and function to the students. He also brought a bottle of Pepsi to the classroom to show that it contained carbon dioxide, and he also explained why carbon dioxide was mixed in the drink.

During his demonstrations, he tried to involve students by using interactive dialogues and questions. While talking about the purpose of demonstrations, he said that demonstrations helped him in developing the students' scientific process skills such as how to predict, observe, infer, and compare their findings.

In the post-lesson discussion, he claimed that sometimes he used to arrange practical work in the seminar hall where the students themselves manipulated materials. During my presence in the school, he did not manage such group-based practical experiences for the students. I asked the students how often they got the opportunity to work in groups for doing practical work. They told me that it depended on the teacher's intention and the nature of the topic. One student reported, "Once a week or in two weeks, when our teacher wants us to do practical work, he takes us to the seminar hall and assigns us group work…but mostly he does arrange demonstrations for us" (Group interview, February, 17, 2004). During an informal talk, the science coordinator of the school said:

> *We are aware of the importance of the practical work for learning science and also about the factors that hinder our attempt to do so. For example, one of the problems is the lack of space in the classroom. But we often use the seminar hall for the purpose of group work. He [Ikraam] is a resourceful teacher who has brought a lot of innovative ideas from the course he is presently taking. (Informal conversation, February 17, 2004)*

One day he did not arrange any demonstrations for a lesson, and during the post-lesson discussion, he said that, as there were no materials, activities or demonstrations, the students did not take much interest in learning. Thus, according to him, giving demonstrations captures the students' interest. He considered the use of demonstrations as an economic and effective way of teaching science. While demonstrations are beneficial and cost effective in terms of expense, equipment, time, safety and effective teaching, there are a number of problems associated with demonstrations. The assumption underlying the use of demonstration is that "if a teacher arranges for an effect to be clearly seen, it will be clearly understood. But we all know that this is not true" (Ogborn , Kress, Martins & McGillicuddy, 1996, p. 2). The same idea is shared by Solomon (2002) who states, "If the teacher arranges for an effect to be clearly seen, will it be clearly seen? We all know that this doesn't happen" (p. 26). The problem with demonstration is that often students do not see what a teacher intends them to see. Ogborn et al. (1996) share interesting comments about students' feelings about demonstrations by saying:

> *Many a student [sic] has gone away from a demonstration saying, 'I don't know what it was supposed to show, but…. The event is there but it lacks meaning. The student remembers what could be seen, but lacks an idea of what the events are supposed to mean. (p. 79)*

This creates a problem if a teacher believes that seeing and doing is always necessary to learn and understand science. Sometimes we cannot "see" or "do" science for there are a number of concepts/phenomena that we learn and understand through other ways and means.

Regarding practical work Hodson (1998) states: "We seriously mislead students when we pretend that the kinds of experiments they perform in classroom constitute a straightforward and reliable means of choosing between rival theories" (p. 95). It is important that teachers realize that what they want the students to understand, is not necessarily what they have understood. Some teachers must conclude activities and demonstrations in such a way that they can be quite sure that the students have understood the purpose behind the activity.

Observations Are Independent of Theory

Ikraam's efforts in bringing activities to his class for demonstrations are to be appreciated. But he was not fully aware of the theory-dependent nature of observations. He often shared with me that students are not empty vessels and they come to school with their own ideas. In the classroom, eliciting children's ideas through brainstorming was his routine practice. He did not seem to realize that students' prior conceptions can influence their observations too. And this influence can affect observations positively and negatively.

In the classroom, Ikraam would sometimes use the Predict-Observe-Explain (POE) model and the students were asked to apply this to the demonstration under discussion. Looking at the same activity, the students' responses varied to a great extent. Though he did not discourage the students from giving diverse responses, he wanted them to believe in what he saw. His actions during the demonstrations showed that he was disappointed when he got responses that were not congruous with his expectations. Regardless of the students' responses, he explained his own inference from the observation of the activity. For example, in one of the demonstrations, the teacher fixed a candle on a saucer with some water in it. Then he inverted a transparent glass over the burning candle. Before that, he asked the students to make predictions by posing a question, "What would happen if the glass is inverted on the burning candle?" The students made predictions and later on compared their predictions against their observations. During "seeing" of the demonstration, a number of contradictory observations were made and shared by the students. For example, some students reported that there was smoke inside the glass while others pointed out that as carbon dioxide is a colourless gas, it should not be visible. A number of other inconsistent observations were reported regarding the rising of water into the glass.

Hodson (1998) maintains, "because knowledge is assumed to derive directly from observation, emphasis becomes concentrated on *doing* rather than on *thinking*, and little or no time is set aside for discussion, argument and negotiating of meaning" (p. 94). This seemed true for Ikraam as well, because he focused on the activities more than on the making of meaning from them. He perceived observation and experimentation as objective sources of scientific knowledge, and therefore expected his students to see what he himself saw during a particular demonstration.

During the post-lesson discussions, I drew Ikraam's attention to his expectations of the students during observations of demonstrations. He pointed out that his students were unable to see what he wanted them to see. He argued that different students explained a single phenomenon differently, which he thought was problematic. He explained this issue with the help of an example. He put a cassette on the table and explained that both he and I could see it differently because both of us were different. He explained that the same was happening with his students while observing the demonstrations.

Hodson (1998) contends that "doing science (choosing a focus, designing and conducting an inquiry and communicating findings) depends on who we are, what we know and what we have experienced. Some view of the world, some theoretical perspectives, precedes observations" (p. 11). Hence, teachers have their theoretical frameworks with them that guide their observations, but students usually lack such frameworks so it is very natural for them to come up with alternate inferences. Therefore, a teacher should guide the students without devaluing their ideas by challenging their ideas with thought-provoking questions. Halai (2002) argues that "even with very guided activities, students do not see 'eye-to-eye' with the teacher" (p. 272). Thus there always remains a gap between what the teacher expects the children to learn and what the students actually learn. Hodson (1998) explains the theory-laden aspect of observation, by saying:

> *The traditional school curriculum [practice] says two things about observation. First, nothing enters the mind of the scientist except by way of the senses – that is, the mind is*

tabula rasa on which the senses inscribe a true and faithful record of the world. Second, the validity and reliability of observation statements are independent of the opinions and expectations of the observer and can be readily confirmed by other observers. Neither is true. In reality, we interpret the sense data that enter our consciousness in terms of our prior knowledge, beliefs, expectations and experiences. (p. 10)

The purpose of this discussion does not necessarily mean that students should not be encouraged to observe correctly, but it means that students should be provided with "a sound theoretical frame of reference" (Hodson, 1998, p. 11), if they are expected to observe correctly. Making correct observations should not be the ultimate purpose, although making objective observations is not possible either). Thus one should be aware that though observation plays a central role in scientific investigations, this skill is tied closely to the knowledge, thinking and motivation of the observer (Chiappetta, Koballa & Collette, 1998). If teachers are aware of the theory-laden nature of observation, they can guide the students properly without confusing them further.

FINDINGS AND CONCLUSION

During this research study, several features about this elementary (Classes 1-8) teacher's conceptions of the NOS and its implications for classroom practices emerged. The following section discusses some of the general findings of the study.

Teachers' Conceptions of NOS are Not Innate and Stable

The study suggests that the teacher's conceptions about the NOS are not innate and stable. They were acquired, modified and changed as he experienced more appealing conceptions and plausible approaches to learning and teaching science. The data showed that many of Ikraam's long-held conceptions were inherited from his former teachers and the learning experiences he had had during his life. He frequently pointed out that he had been teaching the way he was taught. Before joining the Advanced Diploma in Education: Science (ADES) programme, he exclusively relied on the *chalk and talk* method as the only teaching method he was familiar with. The ADES programme helped him re-conceptualize his beliefs and practices about science, and shifted him towards more child-centred approaches for the teaching and learning of science.

When Ikraam was a student, he assumed science to be a difficult, in his own words it was "like climbing a mountain". He was not enamoured with science because of his teachers' practices and his own poor learning experiences. But later on, his conceptions about the NOS and the teaching and learning of science were changed. After being exposed to the ADES programme, he claimed that he loved science and its teaching and learning, which showed a significant change in his attitude towards science. He believed that the ADES programme changed his professional life as a science teacher.

Ikraam frequently compared his experiences after the course, and before the course. The study affirmed that a well-planned teacher education programme helps teachers transform their beliefs in a significant way. There are assumptions that teachers' conceptions/beliefs are resistant to change. But this study provides some evidences that one's epistemological conceptions change when s/he experiences alternative beliefs, which are more plausible and appealing to him/her. The study also highlighted some evidence of change in Ikraam's beliefs because of the influence of the course. This clearly showed that teachers' beliefs and practices may be reshaped as a result of the opportunities and the environment they are exposed to.

Change in Conceptions Occurs Through a Critical Reflection

The analysis of the findings indicated that a critical reflection on one's own beliefs and practices are can help to bring about change in an individual's belief system. There is a debate amongst educationists whether change in beliefs lead to change in practices or change in practices leads to a change in beliefs (Guskey, 2002). The analysis of Ikraam's experiences showed that he needed external assistance, in this case the ADES programme to challenge existing beliefs and provide alternative approaches to practice. Similarly, it is necessary to implement the new learning in the real classroom situation. Guskey (2002) found that neither training alone nor training followed by implementation is sufficient for effective change. Changes in attitude and beliefs occur only when training and implementation are combined with evidence of students' improved learning outcomes.

Mismatch Between Teacher's Conceptions and Practices

The comparison of the data collected through the interviews and field notes showed that in some cases there was a gap between the teacher's conceptions about the NOS and his classroom practices. For example, Ikraam strongly believed in certain aspects of science and its teaching and learning although the classroom observations revealed that in some cases he could not practice his stated beliefs.

Several times during the post-lesson discussions, Ikraam's attention was drawn towards those apparent contradictions between his conceptions and classroom practices. In response he frequently referred to the factors such as time constraint, a lack of space in the classroom, lack of resources (e.g. science apparatus), students' poor academic and socio-economic background, their lack of proficiency in English and his own lack of pedagogical skills in managing the class as major constraints. However, it was evident that the teacher had the commitment to accept and promote change in his classroom. He was persistent in his efforts to implement his learning from the ADES program into his classroom teaching.

Ikraam's also felt that his lack of pedagogical knowledge was hindering the translation of his conceptions (e.g. managing group work, holding discussion, etc) into desired classroom practice. It would therefore appear that conceptions about the NOS cannot be successfully translated into practice where the teacher lacks pedagogical skills.

Teachers Need Follow-up Support in the Real Classroom

The study indicated that a sound knowledge of content and knowledge about knowledge (meta-cognition) is essential, but this is not a guarantee that teachers can translate such knowledge into their classroom practice. For example, in some cases, Ikraam's classroom practices did not show a translation of his conceptions of the NOS into his classroom teaching. The reasons/factors, other than the teacher's conceptions of NOS, mentioned by Ikraam and my own observations were: a lack of resources, limited space, the socio-economic background of the students, and some internal factor of the teacher such as a lack of content knowledge and pedagogical content knowledge (PCK). These are not inconsiderable constraints. Therefore, in spite of Ikraam's willingness, he was unable to implement his learning for a number of reasons. This observation suggests that it is crucial to provide effective follow-up support in the real classroom situation, which is inevitable in dealing with the uncertainties and challenges, situational factors and conditions (Guskey, 2002).

Explicit NOS Instructions are More Effective

The analysis of the handbook for the ADES programme and conversations with Ikraam showed that there were no explicit instructions on the NOS. The programme assumed that the participants would come to understand about the NOS by doing science, which is known as an implicit approach of the NOS instruction (Gess-Newsome, 2002). Science educators point out that implicit instructional approaches to develop teachers' understanding about the NOS have been usually ineffective. This study found some evidence of the impact of an implicit approach for NOS instruction. For example, in Ikraam's case, the course he was taking, had a significant impact on his conceptions about NOS, and the teaching and learning of science. The study shows that to some extent the assumption seemed to be acceptable, as Ikraam understood some important aspects of the NOS. In some cases, Ikraam exhibited certain naïve conceptions about the NOS. As advocated by a number of educators (e.g. Abd-El-Khalick & Lederman, 2000; Gess-Newsome, 2002), explicit approaches to develop teachers' conceptions of the NOS have been more effective. This has a strong implication for teacher education programmes in Pakistan that explicit approaches should be employed while teaching about the NOS, so that teachers can develop an adequate understanding of it.

CONCLUSION

This study was focused on the understanding of a single teacher's conceptions about the NOS, the findings of which cannot be generalized to a large community of science teachers. However, the insight gained from the findings can be useful for others.

The nature of science is the soul of science, and so I propose it as a knowledge-base for the teaching and learning of science. Developing students' understanding of the NOS to help them learn science in a meaningful way is an important goal of science education.

Apart from teachers' conceptions of the NOS, there are other factors (e.g. content knowledge, pedagogical skills and PCK) that can also influence teachers' classroom practices. As teachers are the primary mediators between subject matter and the students, their conceptions of what science is and how it should be taught seems to direct their decisions in the classroom. Since teachers' conceptions are communicated to their students through their actions and attitudes, they should possess well-informed conceptions of the NOS. In conclusion:

We are confident that science education will be a richer discipline and our students will be more adequately prepared for their lives as citizens when they are afforded a fuller understanding of the nature of this thing called science (McComas, Clough and Almazroa, 1998, p. 33).

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Book Review

IN-DEPTH INTERVIEWING. PRINCIPLES, TECHNIQUES, ANALYSIS

By Victor Minichiello, Rosalie Aroni and Terrence Hays
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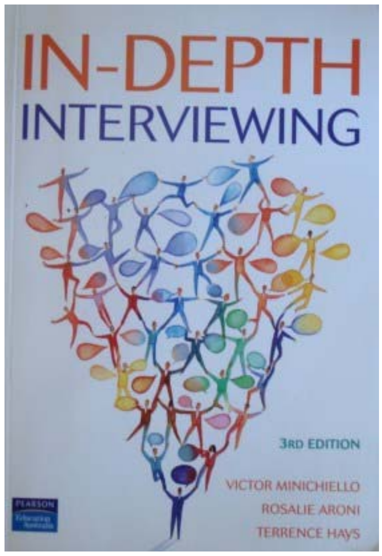

Research in any field involves a skilfully crafted synthesis of reflecting, critically analysing relevant literature, designing methodologically sound approaches to investigate a proposition, selecting contextualised data gathering techniques and fundamentally asking the most appropriate questions.

The 3rd edition of Victor Minichiello, Rosalie Aroni and Terrence Hay's Australian edition (2008) *In-depth Interviewing. Principles, Techniques, Analysis* is an excellent addition to any researcher's library. The book is written with an emphasis on teaching research students qualitative research design. However, experienced researchers and emerging postgraduate research students will find this new edition a treasure trove of information relevant to the processes and procedures of conducting research interviews.

As the authors state, "the interview is a complex and involved procedure when used as a social science research tool" (Minichiello, Aroni, & Hays, 2008, p. 1). Designing appropriate and insightful interview questions is much more difficult than many of us realise. How many of us have witnessed the inane question of the media interviewer who asks the victims of a terrorist explosion, "How do you feel?" Analogously, there is the naive question of the emergent researcher who asks, "What are you thinking?" Then there is the experienced researcher who contextualises the question by asking, "we were talking about the different principal leadership styles in terms of the effects on the classroom teacher. Can you describe your own experiences in relation to your principal's leadership style and your working relationship in this school?" Experienced researchers also often refine their interview questions; an apparently awkward question such as "What do you think of when you hear the word research?" can be simply restructured as, "What does it mean to you to be a researcher?" *In-depth Interviewing* has a wealth of information that will assist in the design of pertinent research questions. Chapter 3, 'In-depth interviewing', presents a comprehensive overview of the purpose and distinctive features of different types of interview, such as: telephone interviews, Internet interviews, group and focus interviews, interview proxies and memory work. This chapter is an excellent exposition of interview question types and for researchers in an Information Age dominated by electronic media this chapter is essential reading.

There is currently a variety of books on the market aiming to assist researchers in the design of different types of data-gathering techniques that involve questioning, such as questionnaire and survey design (Fink, 2009; Fowler, 2009) and semi-structured and focus-group questions (Kvale & Brinkmann, 2009; Yin, 2009). However, the in-depth interview is a particular kind of questioning that requires content knowledge (why do you want to know this particular piece of information?), communication skills (how will you structure particular questions?) and human experience

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(what do you need to know about the fellow human being you are interviewing?). Researchers will find invaluable advice on all these questions in this aptly named book. The book's content is structured to allow a very thorough coverage of all facets of the interview process, from planning through to implementation.

- *Chapter One explores the theoretical background and is an essential introduction to in-depth interviewing techniques.*
- *Chapter Two, which provides compelling reasons for contextualising the interview process by means of a literature review, will assist researchers in devising an appropriate research methodology.*
- *Chapters Three and Four describe interview models, the many different types of interview and the process of interviewing, thus preparing the foundation for selection criteria procedures.*
- *Chapter Five gives a detailed account of the Life History approach, "... the history of an individual's life given by the person living it and solicited by the researcher. It is a sociological autobiography drawn from in-depth interviewing and/or solicited narratives" (Minichiello, et al., 2008, p. 125). This chapter is very constructive and will assist readers' understanding of this often misunderstood methodological approach.*
- *Chapter Six explains the main features of a number of group interview techniques: focus group, reference group, memory work and consensus group interviews. The level of detail will assist researchers who may be contemplating this branch of interviewing techniques.*
- *Chapter Seven concentrates on the pragmatics of in-depth interviewing. The authors' description of the different modes of sampling in qualitative research is invaluable. The work of Patton (Patton, 1990, 2002) has always been a valuable resource providing a rational for various modes of sampling. This chapter is a welcome addition to the literature, relevant to current research design and methodology issues, and a valuable asset of the book.*
- *Chapter Eight, on the ethics and politics of in-depth interviewing, is another very valuable addition as it covers material often missing from books on research methodology. This chapter is particularly pertinent for researchers in the fields of criminal incarceration, juvenile, sexuality and cross-cultural research.*
- *Chapters Nine and Ten concentrate on the coding and analysis of data stages of research processes involving in-depth interviewing. These two chapters are invaluable, especially to the emerging researcher. For a researcher deciding whether or not to choose narrative, thematic, grounded theory or discourse analysis, Chapter 10 is a very beneficial exposition of these methodological constructs.*

The book is accessible, relevant and a valuable source of information on the design and implementation of in-depth interviewing techniques for qualitative research. I recommend this book to all researchers, whether in the scientific or humanities, and to experienced or novice alike. *In-depth Interviewing* will be an invaluable addition to your bookshelf or library collection of resources for qualitative research design.

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Correspondence to: Heather Fehring
Deputy Head, Research and Innovation
School of Education, College of Design and Social Context,
RMIT University
Bundoora 3083, VIC, AUSTRALIA
Email: *heather.fehring@rmit.edu.au*

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