ALD06755

Engaging Pedagogies in Mathematics and Science Education: Some Key Ideas, Issues and Implications for Research and Teaching in South Australia

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This paper discusses six key ideas and issues related to mathematics and science learning and teaching. These ideas encompass notions of (1) Equity, (2) Service to humanity, (3) Literacy, (4) Knowledge dimensions and their changing emphases, (5) Affective as well as cognitive responses to mathematics and science, and (6) Connections to technology. The implications of these ideas in identifying new directions for research in mathematics and science education are considered. In particular the need to explicate the connections between content, process, context and affect in mathematics and science learning and teaching is highlighted. Research in creative problem solving within the field of novel mathematics problem solving is pointing to a way in which these links may be found. Such research, it is hoped, will engage the future pedagogy of mathematics and science to be more efficacious benefiting all students.

Introduction

The enactment of change for the greater good is often preceded by personal reflection and considered debate between individuals. The key ideas and issues presented in this paper are an example of some such personal reflection and discussion. While not an exhaustive account, the ideas and issues presented here are intended as a basis for further debate around matters of concern to mathematics and science learning and teaching. As the proportion of Australian students electing to study science and mathematics related subjects in the senior years of secondary schooling continues to decline(Brinkworth, 1999; Dekkers & De Laeter, 2001; Dekkers, DeLaeter, & Malone, 1991) and the number of tertiary students electing to pursue degrees in science and mathematics remains wanting (Batterham, 2000; Raison & Etheridge, 2006), the urgency with which mathematics and science educators need to engage with such issues increases. In the so-called 'lucky country' where innovation and creativity are seen as economic and political imperatives, mathematics and science educators constantly seek new and improved pedagogies for engaging students in mathematics and science. Indeed with ongoing debate new levels of complexity are very likely to appear.

In this paper reflection on six key ideas relevant to mathematics and science learning and teaching leads to the identification of six key issues. These issues form a framework around which some implications for research and teaching are discussed. Explicating the connections between content, process, context and affect in mathematics and science learning and teaching, it is argued, presents a way forward in engaging new pedagogies in mathematics and science. Some findings from research in novel mathematics problem solving are given as an example.

Six Key Ideas and Issues

Key Idea 1: Mathematics and Science based on Equity

The notion that all students can learn mathematics and that all students can learn science through the principles of access, participation and success is something that educators now-adays tend to take for granted (AEC, 1994a, 1994b; Fensham, 1987). While these ideas have their basis in educational, behavioural and social science research (Keeves & Stacey, 1999), their credence relies on the adoption of liberal-progressive and socially-critical orientations to curriculum (Kemmis, Cole, & Suggett, 1993) and coincides with increased politicization of education in the western world (Keeves, 1999).

Such emancipatory views of mathematics and science learning and teaching have not always held favour with education systems and government. A careful review of history, for example, reveals Australian girls in the first half of the twentieth century not being given access to senior school mathematics and science. Further science education, beyond some nature study, was not contemplated for most children.

In more recent times, awareness of equity concerns (equitable outcomes for all) in mathematics and science have been expanded to include, not only girls, but other disadvantaged groups e.g.: students who have a disability, students from non-English speaking backgrounds, Aboriginal and Torres Strait Islander students, students operating at a distance and students living in poverty, together with the intersection of these groups. In the light of this it is perhaps worthy of note that the currently adopted wisdom suggests that a socially just science and mathematics education

> 'occurs only when all students are treated according to their needs as individuals not according to their membership of a social group such as gender, culture or ethnic background'(Goodrum, Hackling, & Rennie, 2001, p 28.).

In light of the ideas expressed by Goodrum, Hackling and Rennie (2001) that placing worth on individuals and meeting individual needs is important to the production of a socially just mathematics and science education, it is interesting to note the performance of minority groups in international mathematics and science studies of achievement (Greenwood, Frigo, & Hughes, 2002). These studies suggest that, in some countries including Australia, the gap between socio-economic status and success is widening (Fensham, 2002).

The OECD Programme for International Student Assessment (PISA) of which Australia is a member, is measuring how well students aged 15 years are being prepared 'to meet the challenges of today's knowledge societies'(de Lange, 2002p.33) by assessing literacy in reading, mathematics and science. Having begun in the year 2000, PISA operates on a three-year cycle. Each assessment cycle focuses on one particular subject although all three subjects are assessed in each cycle. Reading was the focus in 2000, Mathematics in 2003 while Science is to be the focus in 2006 (De lange, 2002). In a number of countries, including Australia, the studies have found a strong relationship between socioeconomic status and achievement. Further, this relationship is more profound in indigenous groups (ACER, 2006; Greenwood et al., 2002). This may be interpreted to mean that among indigenous populations a higher socioeconomic background does not necessarily translate to better performance in mathematics and science.

Issue arising:

Is the inequity in schooling associated with socio-economic status and mathematics and science learning increasing? What does this mean for future mathematics and science teaching and learning?

Key idea 2: Mathematics and Science as Service to Humanity

Governments throughout the western world make arguments to the effect that a nation's social and economic well-being depends for its success, on the productive development of a scientifically and mathematically literate community (Batterham, 2000; Dow, 2003; Millar, 1996). Indeed these sentiments can be found at the heart of OECD member nations in the PISA studies mentioned above.

In Australia, the meeting of State, Territory and Commonwealth Ministers of Education at the 10th Ministerial Council on Education Employment Training and Youth Affairs (MCEETYA) in Adelaide, reaffirmed mathematics and science as two of the eight key learning areas and as such these two are enshrined as part of Australia's national goals for schooling in the twenty first century (MCEETYA, 1999). However, unlike the Hobart declaration in 1989, there has been a shift in emphasis in the nominated curriculum areas to include the statement 'and the interrelationships between them'. Needless to say, all levels of schooling have been challenged to explicate the interrelationships and to integrate the learning areas including those of mathematics and science.

However, not withstanding the importance placed on mathematics and science by state and commonwealth authorities (Batterham, 2000), the number of students pursuing studies in these areas in the senior years of schooling and at the tertiary level continues to decline (Dekkers & De Laeter, 2001; Dekkers et al., 1991). This represents an anomalous outcome for governments seeking to maintain social and economic advantage in the global and technological scene.

A recent study into the reasons for such a decline (Raison & Etheridge, 2006) indicated that many secondary students considered the sciences as being too difficult and were opting for subjects that would return a higher university entrance score. In many instances potential mathematics and science students knew little about future career options in these areas and furthermore, a career in mathematics or science was perceived as not being very lucrative when set against a backdrop of social pressure to make money (Raison & Etheridge, 2006).

Issue arising:

Given that the number of students undertaking studies in mathematics and science is falling what will this mean for future teacher education in mathematics and science?

Key idea 3: Mathematics and Science Framed as Literacy

OECD countries have identified that the purpose of a mathematics education is to develop mathematical literacy and that the purpose of science education is to develop scientific literacy. In each instance the important thing for students of mathematics and science is to be confident users of mathematical and scientific skills and knowledge in their everyday life. Thus the OECD/PISA (de Lange, 2002) defined mathematical literacy as

> ' … an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded judgements and to engage in mathematics in ways that meet the needs of that individual's current and future life as a constructive , concerned and reflective citizen'(de Lange, 2002, p.33).

The OECD/PISA defines scientific literacy as an individual's

> ' … capacity to use scientific knowledge, to identify questions and to draw evidenced-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity' (OECD/PISA, 2003, p.133).

Thus two broad purposes of a mathematics and science education can be identified. One is to develop future professionals in the fields of mathematics and science (i.e. mathematicians and scientists) as is inferred in the discussion in the Key Idea Two described above. The other is to equip students to function as informed citizens in society, able to use and apply the principles of scientific and mathematical skills and knowledge. While each purpose serves a valid need, tensions may arise between individuals or groups holding differing perspectives giving rise to different needs. This is nowhere more likely than in advanced learning institutions where competition for the limited amounts of the curriculum resources of time and space tends to be acute (and intensified by the advent of double degrees).

However it is well to remember that this tension is not a recent phenomenon. In an 1847 lecture entitled 'Science for all' given by James Wilkinson, a member of the Royal College of Surgeons of London, Wilkinson is noted as saying that the 'ends for which scientists create knowledge and those who seek the application of this knowledge are not the same' cited in (Hurd, 2000, p284).

Issue arising:

Given the tension between those who view the purposes of mathematics and science education as being to generate future mathematicians and scientists and those who view its purposes more broadly in citizenry, educators need to find ways of embodying both aspects into curricula and teaching.

Key idea 4: Changing Emphases in the Knowledge Dimensions of Mathematics and Science

Putting the definitions of literacy into practice involves identifying three types of knowledge. These are:

- concepts or content;
- processes or competencies (associated with inquiry or problem solving); and
- contexts or situations (associated with epistemic understanding)

These types of knowledge map well to some generally accepted goals of science and mathematics education (Goodrum et al., 2001) which include:

- to acquire scientific and mathematical knowledge;
- to learn the processes or methodologies of science and mathematics; and
- to understand the applications of science and mathematics especially the relationships with technology and society (adapted from Bybee & DeBoer, 1994, p357).

It is interesting to note changes in emphases in each of these knowledge dimensions which have occurred over the past century and which have carried forward into the twenty first century. In the first half to two thirds of the twentieth century, content was the all-important thing (Rennie, Fraser, & Treagust, 1999). School programmes within Australia dictated what was to be taught and in what order the content was to be taught. But scant attention was given to the methods by which this content should be either taught or learnt. This situation was consistent with a view of teaching and learning prevalent at the time - one of student as empty vessel needing to be filled up with knowledge poured out by the teacher. The question of how students learn or the idea that learners may construct their own meaning was not, in the main, given due consideration.

While content was the focus in the first half of the twentieth century, by the late 1970's to mid 1980's, the process approach to teaching and learning had found favour. This shift in curriculum emphasis from content to processes arose largely out of reform movements in America (Adey, 2001; Keeves & Stacey, 1999; Rennie et al., 1999). Based on the ideas of American psychologist Gagné,

> 'the content of science did not matter: what young scientists needed to learn were the processes of science – measurement, observation, hypothesis generation, experimental design and so on'(Adey, 2001, p.45).

Memories of teaching 'science as a process', will not be uncommon to many present-day science teachers, both active and retired. But the links to content were both limited and tenuous and the impact of context was not particularly considered. In the words of Adey 2001p 45 'you cannot have processes without content, and in any case this is not the way that real science is conducted'.

The mid 1980's also saw efforts to improve the processes of mathematics teaching and learning in both primary and secondary schools. The advent of 'process mathematics' in primary schools is one such example. Another is a series of resources developed by the national Mathematics and Curriculum Teaching Programme (MCTP)(Lovitt & Clarke, 1988) funded through the Curriculum Development Centre. These resources were influential in demonstrating ways of employing mathematical processes in concrete ways.

By the 1990's changes to upper secondary mathematics and science curricula were in evidence in South Australia (Mercurio, 2003) as assessment practices broadened to include directed investigations and project work, providing more opportunities for open-ended problem solving and the demonstration of mathematical and scientific processes.

Finally, in relation to the last knowledge dimension - that of context, the closing years of the twentieth century and the first years of the twenty-first century, saw some attempts to incorporate authentic contexts into mathematics and science learning and teaching. However, these initiatives operated largely as ‘add-ons’, rather than as integral components of the curriculum. The inclusion of essays in senior secondary science linking science technology and society and the adoption of junior secondary science texts propounding the teaching of science in context (see for example Dangerfield, Pike, Feutrill, & Holper, 1996), are examples of this. While it is fair to say that the contexts for learning and teaching mathematics and science are at least being considered in present times, there is still much that remains to be done in relating mathematics and science to real life situations which have personal meaning and relevance for students.

Indeed if the PISA framework for measuring mathematical and scientific literacy is compared with the nationally developed curriculum statements and profiles for Australian schools as well as the framework developed for South Australian schools namely the South Australian Curriculum Standards and Accountability framework (SACSA) a progressive pattern emerges. This pattern is outlined in Table 1.

Table 1: International (PISA), National and South Australian frameworks compared

Type of Knowledge	**Content/**	**Concepts**	**Processes/**	**Competencies**	**Context**	**Situation**
	Maths	Science	Maths	Science	Maths	Science
PISA	*1.Quantity* *2.Space & Shape* *3.Change & relationships* *4.Uncertainty*	*Thirteen major themes chosen on relevance, usefulness Combined with scientific processes*	*1.Reproduction* Recall problems *2.Connections* Different areas/aspects *3.Reflection* Complex problem solving Mathematical thinking	Investigations *1. Recognize investigable questns* *2. Identify evidence* *3. Draw & evaluate conclusions* *4.Communicate conclusions* *5. Apply concepts in novel situatns*	Authentic tasks based on situations encountered in real life	Tasks situated in contexts relevant to everyday life: Clusters *Science in life & health* *Science in earth & environment* *Science in technology*
National Statements & Profiles	*1.Number* *2. Space* *3.Measurement* *4.Algebra* *5.Chance&data*	*1.Earth & beyond* *2. Energy & Change* *3 Life & Living* *4. Natural & processed materials.*	Working Mathematically *1.Investigating* *2.Conjecturing* *3.Problem solving* *4.Applying & verifying* *5.Using mathematical language* *6. Working in context*	Working Scientifically *1.Planning investigations* *2.Conducting investigations* *3.Processing data* *4.Evaluating findings* *5. Using science* *6. Acting responsibly*		
SACSA	*1.Exploring, analyzing & modelling data* *2.Measurement* *3. Number* *4. Spatial Sense & geometric reasoning* *5.Pattern & algebraic reasoning*	*1.Earth & space* *2.Energy systems* *3. Life systems* *4.Matter*				

Knowledge dimensions compared in international, national and South Australian based frameworks for assessment

In line with the dimensions of knowledge described above, it can be seen from Table 1 that the international PISA programme for the assessment of mathematical and scientific literacy identified three broad dimensions. These include the contents of mathematics and of science, the competencies or processes specific to each and also some identified contexts applicable to each. The identified content, processes and contexts for both mathematics and science have been summarized in the first row of Table 1.

Using a phenomenological approach to describe mathematical concepts and structures relevant to real-life problems, the programme identified four categories. These are *Quantity*, *Space and shape*, *Change and relationships* and *Uncertainty*. In similar vein the specified content in science was conceptualized according to broad integrating ideas that help to explain aspects of the physical world. These concepts were drawn from thirteen main themes: *Structure and properties of matter*, *Atmospheric change*, *Chemical and physical change*, *Energy transformations*, *Forces and movement*, *Forms and function*, *Human biology*, *Physiological change*, *Biodiversity*, *Genetic control*, *Ecosystems*, *The earth and its place in the universe* and *Geological change*(OECD/PISA, 2003).

The mathematical processes identified included that of *Reproduction,* which consists of reproduction and recall of straight forward problems, *Connections,* which requires connections to be made between different aspects of mathematics and *Reflection,* which requires the problem solver to reflect, generalize and apply complex problem solving competencies. The scientific processes identified involved recognizing scientifically investigable questions, identifying evidence needed in a scientific investigation, drawing and evaluating conclusions, communicating valid conclusions and demonstrating understanding of science concepts by applying them in novel situations (OECD/PISA, 2003).

Of particular note is the context dimension which 'emphasises the application of processes and concepts in relation to problems and issues in the real world' (OECD/PISA, 2003, p.78). Thus mathematics is assessed by giving students authentic tasks based on situations that represent the kinds of problem encountered in real life (de Lange, 2002).

Similarly science tasks are set in contexts relevant to every day life with applications clustering around science in life and health, science in the earth and environment and science in technology.

However, when the nationally developed curriculum statements and profiles for Australian schools in both mathematics and science (refer second row of Table 1) are compared with the PISA framework for assessment with respect to the three knowledge dimensions, an omission of context occurs. As observed in Table 1, the explicit assessment of understanding about the application of mathematics and science to real world contexts is absent from the national framework.

This observation is not meant to suggest that the application of scientific and mathematical concepts, are neither implied nor implicit to the formulation of the framework. Indeed, within the process dimension 'working mathematically', the strand 'working in context' and the strands 'using science' and 'acting responsibly' within the 'working scientifically' process dimension can be located and interpreted as addressing the issue of real world contexts. However, the positioning of these contextual strands within the process dimension of the framework reflects their emphasis and relative importance within the curriculum. It should perhaps come as no surprise to learn then, that a national study into the status and quality of teaching and learning of science in Australian schools (Goodrum et al., 2001) found secondary teachers lacking confidence in knowing how to apply content in relevant contexts, including the use of appropriate teaching and learning strategies to engage students.

If the South Australian Curriculum Standards and Accountability Framework (SACSA)(DETE, 2001), is now compared with the National Statements and Profiles as well as the PISA framework an even more disturbing pattern emerges. Not only is the explicit assessment of applications to real world context omitted, but so is the explicit assessment of the process dimension as represented by the 'working mathematically' and 'working scientifically' strands in the national curriculum. This begs the question 'Has nothing changed in terms of curriculum review and reform?'.

To be sure, the process strands, it is claimed, have been embedded within the framework. What is needed therefore is for education leaders to work with pre-service teachers in particular, and in-service teachers where necessary, to draw the process components out and make this epistemic knowledge explicit. Moreover the so-called five essential learnings identified in SACSA viz: Futures, Identity, Interdependence, Thinking and Communication to be implemented across the curriculum, afford valuable opportunities for meaningful connections to be made between content, processes and contexts in mathematics and science, not solely in terms of the past, but the future as well. Indeed the 'thinking' essential learning describes the development of a sense of creativity, the capacity to evaluate and generate ideas and solutions using a wide range of thinking modes (DETE, 2001) - processes intrinsic to the conduct of mathematics and science.

Nevertheless the point of the argument stated here is that the emphases needed to make the connections between content, processes and context are not made explicit. Indeed science educator Fensham (2002) contends, that while Australian educators have done much over the last 20 years to inform pedagogical practice about the teaching and learning of conceptual content, little research has been conducted into the identification of pedagogical strategies that will promote the learning of the content/process connections (Fensham, 2002). The author of this paper however goes even further to state that there is a demonstrated need for teachers and researchers to explicate not only the links between content and process but also the links between content, process and contexts in mathematics and science learning and teaching.

Issue arising:

Australian mathematics and science education needs to explicate the connections between content, process and context.

Key idea 5: Affective as well as Cognitive Responses in Mathematics and Science

In a significant British report entitled *Beyond 2000: Science education for the future*, Millar and Osborne (1998) advise that sustaining and developing young people's curiosity about the natural and physical world, involves fostering

> 'a sense of wonder, enthusiasm and interest in science so that they feel confident and competent to engage with scientific and technical matters'(Millar and Osborne 1998) ; cited in (Fensham, 2002, p.32).

However, acknowledging the affective response to mathematics and science, not merely its cognitive aspects, is something that in the main has been overlooked in Australian curricula. Fostering mathematics as beauty, elegance and aesthetics or science as intrigue, mystery and wonder for example is not high on the education agenda (Goodrum et al., 2001). This contrasts starkly with popular culture where writing in the fields of mathematics and science place huge currency on the affective dimension never failing to present science and mathematics as exciting and mysterious fields of endeavour (Fensham, 2002).

This valuing of cognitive responses over affective ones, made manifest in much of the teaching and learning of mathematics and science, particularly in tertiary institutions, fails to take into account what neuroscience is now making plain, that feeling and thinking are inextricably linked. A recent study of 405 middle school students solving two novel mathematics problems as part of the Australian Mathematics Challenge for example, found students using a feeling approach to reasoning were more successful in finding solutions to the novel problems (Aldous, 2005). Neuroscientist Damasio (1994, p.xiii) explains that 'aspects of the process of emotion and feeling are indispensable for rationality' and that increasing rationality involves attending to feeling. Thus where once educators were of the view that feeling and emotion may interfere with thinking and reasoning particularly in mathematics and science, new research indicates that complex novel problems are unlikely to be solved in the absence of attention to feeling. Hence instead of trying to eliminate affect, mathematicians and scientists would be better served by trying to harness, both their own and their students' affective responses in mathematical and scientific activity, bringing about more effective teaching and learning.

Issue arising:

Australian mathematics and science education needs to find ways of embodying affective responses into its curricula and teaching.

Key idea 6: The Mathematics, Science and Technology Connection

Rapid development of new technologies is changing the nature of what is seen as important in science and mathematics and is influencing the ways in which scientists and mathematicians work. Where once students of mathematics and science found employment in universities, today's graduates are more likely to be found working in business and industry, where work is tending to focus more and more on problems of broad, social and economic interest that transcend traditional subject boundaries. In such contexts, today's graduates are likely to be working as members of a team, with experts from different fields collaborating together to find solutions to complex problems (Hurd, 2000). This requires skill in working with information and communication technology, the need to know where and how to research information of trustworthy quality and the ability to evaluate its usefulness.

In giving this description of the ways of working for today's mathematics and science graduates, the question arises in what manner do teachers of mathematics and science provide students with opportunities to work with real world problems, in situations that reflect the context of the future work place? To what extent should these teachers afford students the opportunity to experience group work and the interdependencies that such teamwork brings? Further how well are today's mathematics and science students and teachers prepared to meet the challenges of working with information and communication technologies?

Evidence from the Third International Mathematics and Science Study (TIMSS) 1999 Video Study (Hollingsworth, Lokan, & McCrae, 2003) for example, shows that Grade 8 students in mathematics classrooms across Australia are still solving problems of low complexity, with little novelty, requiring limited mathematical reasoning. Further, Grade 8 students in science classrooms across the nation are largely carrying out teacher directed investigations, being afforded little opportunity to formulate their own research questions, devise their own experimental procedures and analyse their own data (Lokan, Hollingsworth, & Hackling, in press). Thus the issue of embedding real world problem solving, along with any associated technologies into mathematics and science curricula and teaching is of particular concern.

Issue arising:

Australian mathematics and science education needs to find ways of articulating real world problems and current work practices into curricula and teaching and of providing students with the skills for accessing scientific information and examining its trustworthiness.

Implications for Research and Teaching

Past research into the learning and teaching of mathematics and science has tended to focus on the conceptual components of mathematics and science curricula. In light of the issues outlined above, new research is needed in the identification, description and implementation of engaging pedagogies that will scaffold in both curricula and teaching:

- the content / process connections,
- the content/process/ context connections; and the
- the content/process/ context and affective connections.

Ideally such pedagogies will expedite the processes of real world problem solving and be carried out in relevant and meaningful contexts.

The study "creativity and problem solving"outlined below is an example of a research initiative directed to this purpose. It is an attempt to:

- make explicit the thinking modes used in solving novel problems;
- find connections between mathematical content and the processes used to solve them;
- use a context which is more indicative of real world problem solving; and to

- value the affective dimension in solving novel problems.

A Research Example: Creativity and Problem solving

This study sought to investigate the connections between content, process, context and affect with a view to expediting their use in teaching. It involved 405 middle school students participating in the Mathematics Challenge for Young Australians. Students in this challenge event had three weeks in which to solve six novel problems. The problems were specifically designed by a committee to be novel, relevant, interesting, and challenging. Responses to two of these six problems were used in this study. One of these problems had a spatial analytical emphasis, the other a verbal analytical emphasis.

Using an instrument known as the Systems of Reasoning Questionnaire (SRQ) (Aldous, 2001) administered to each of the 405 volunteers participating in the study, five approaches to reasoning were identified. These are a:

- Systematic approach to reasoning, a
- Strategic approach to reasoning, a
- Spatial-verbal approach to reasoning, a
- Free-flowing approach to reasoning; and a
- Feeling approach to reasoning.

The Systematic and Strategic approaches to reasoning tap cognitive systems of reasoning and involve the faculties of deliberation and analysis. The Free-flowing and Feeling approaches to reasoning tap non-cognitive systems of reasoning and involve the faculties of feeling, intuition and imagination. The Spatial-verbal approach to reasoning taps both cognitive and non-cognitive systems of reasoning and involves successive and simultaneous synthesis depending on whether mainly verbal or spatial processing is used.

Of import to the discussion of issues presented in this paper, is the finding that Free-flowing and Feeling approaches to reasoning are crucial to success in solving the spatial problem. By way of contrast the Systematic approach to reasoning is crucial to success in solving the verbal numerical problem. However in neither instance was the problem solved in the absence of a Feeling approach to reasoning (Aldous, 2005, in press).

Thus the links between content, process, context and affect can be summarized thus. Solving novel mathematics problems with a spatial content involves the use of non-cognitive processes such as those associated with a Free-flowing and Feeling approach to reasoning while mathematics problems with strong verbal content require cognitive processes associated with a Systematic approach to reasoning. In both spatial and verbal mathematics problems, attending to affect through a Feeling approach to reasoning is vital for a successful solution to be achieved (Aldous, in press). Moreover a context where participants have time to incubate and reflect on the novel problems is integral to the creative problem-solving event.

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Conclusion

Reflection on six key ideas related to equity, service to humanity, literacy, dimensions of knowledge, affective as well as cognitive responses and the impact of technology in mathematics and science learning and teaching, has given rise to the identification of six issues. These issues involve:

- concerns about the widening gap between rich and poor in participation and achievement in mathematics and science;
- consideration of the impact of declining enrolments in mathematics and science on future teacher education;
- finding ways of embodying the dual purposes of professionalism and citizenry in mathematics and science curricula and teaching;
- explicating the connections between content, process and context in mathematics and science learning and teaching;
- embodying affective as well as cognitive responses in mathematics and science curricula and teaching; and
- articulating real world problems, current work practices and technologies into mathematics and science education.

While it would be true to say that mathematics and science educators are powerless in the short term, to directly impact the non-malleable variables of socioeconomic status and current low pattern of mathematics and science enrolment, they can, in the longer term, work towards impacting them indirectly through the development and implementation of engaging pedagogies within mathematics and science learning and teaching. Such pedagogy values and builds on the knowledge, skills and interest of every student, providing opportunities to work on challenging but achievable real world problems. The learning process scaffolds and maintains the integrity of both content and process in a context that is relevant and meaningful to each student and fosters an appreciation of the wonder and beauty of mathematics and science. It encourages the use of new technologies, fosters the development of higher order thinking skills and models current best practice in both collaborative and individual effort. It assesses understanding and its application to new situations and provides feedback that assists learning while fostering self-confidence in an ability to use mathematics and science in every day life and confidence in self as a life long learner.

While the ideals of such pedagogy are easier to articulate than to achieve, future research is needed to identify and explicate the strategies by which this may be brought about. Investigating and explicating the creative processes involved in solving novel real world problems is pointing to a way in which the content/ processes/ context and affective connections intrinsic to mathematics and science learning and teaching can be found. In cyclical fashion, understanding these connections will inform our pedagogy, which will in turn inform future research for the benefit of all students. Indeed a series of intervention strategies is already being planned to engage students with a range of thinking modes that incorporate both cognitive and non-cognitive processes of reasoning when solving real world problems in mathematics and science but much more is needed.

References

Australian Council for Educational Research (ACER). (2006). *PISA in brief from Australia's perspective: Highlights from the full Australian report: Facing the future: A focus on mathematical literacy among Australian 15 year old students in PISA 2003*.: OECD, Programme for International Student Assessment (PISA).

Australian Education Council (AEC). (1994a). *A national statement on mathematics for Australian schools: A joint project of the States, Territories and the Commonwealth of Australia initiated by the Australian Education Council(AEC)*. Carlton, Vic: Curriculum Corporation.

Australian Education Council (AEC). (1994b). *A national statement on science for Australian schools: A joint project of the States, Territories and the Commonwealth of Australia initiated by the Australian Education Council(AEC)*. Carlton, Vic: Curriculum Corporation.

Adey, P. (2001). 160 years of science education: an uncertain link between theory and practice. *School Science Review, 82*(300), 41.

Aldous, C. (2001). Measuring cognitive and non-cognitive systems of reasoning: Some preliminary findings. *International Education Journal, 2*(4), 1-18.

Aldous, C. (2005). *Creativity in problem solving: Uncovering cognitive and non-cognitive systems of reasoning in the solving of novel mathematics problems.*, The Flinders University of South Australia, Adelaide.

Aldous, C. (in press). Attending to feeling: Productive benefit to novel mathematics problem solving. *International Education Journal*.

Batterham, R. (2000). *The Chance to Change, final report by the Chief Scientist to the Minister for Industry, Science and Resources as part of the Australian Science Capability Review*. Canberra, ACT: DEST, Commonwealth of Australia.

Brinkworth, P. (1999). *An exploration of gender differences in subject choice and beliefs among year 12 students.* Paper presented at the Proceedings of the twenty-second annual conference of the Mathematics Education Research Group of Australiasia Incorporated:Making the difference, Adelaide, South Australia.

Bybee, R. W., & DeBoer, G. (1994). Research on the goals for science education. In D. L. Gabel (Ed.), *Handbook of research on teaching and learning of science*. New York: Macmillan.

Damasio, A. R. (1994). *Descartes' Error: Emotion reason and the human brain*. London: Papermac.

Dangerfield, E., Pike, T., Feutrill, H., & Holper, P. (1996). *Australian Secondary Science 2*. Melbourne, Australia: Cambridge University Press.

de Lange, J. (2002). *The meaning of PISA for teachers of mathematics.* Paper presented at the Australian Council for Educational Research (ACER) Research Conference 2002 Providing World Class School Education: What does the research tell us?, Sydney, Australia.

Dekkers, J., & De Laeter, J. R. (2001). Enrolement trends in school science education in Australia. *International Journal of Science Education, 23*(5), 487-500.

Dekkers, J., DeLaeter, J. R., & Malone, J. A. (1991). *Upper secondary school science and mathematics enrolment patterns in Australia. 1970-1988*. Perth: Western Australian Institute of Technology.

Department of Education Training and Employment DETE. (2001). *South Australian curriculum, standards and accountability framework*. Adelaide: Department of Education Training and Employment Publishing.

Dow, K. L. (2003). *Australia's Teachers: Australia's Future Advancing Innovation, Science Technology and Mathematics Agenda for Action*. Canberra, ACT: Department of Education Science and Training.

Fensham, P. (1987). Science for all. *Educational leadership, December1986/January 1987*, 18-23.

Fensham, P. (2002). *PISA Science: pointing the way forward for school science.* Paper presented at the Australian Council for Educational Research (ACER) Research Conference 2002. Providing world -class school education: What does the research tell us?, Sydney, Australia.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The Status and Quality of Teaching and Learning of Science in Australian schools*. Canberra, ACT: Department of Education, Training and Youth Affairs.

Greenwood, L., Frigo, T., & Hughes, P. (2002). *Messages for minority groups in Australia from international studies.* Paper presented at the Australian Council for Educational Research (ACER)Research Conference 2002 Providing World-Class School Education: What does the research tell us?, Sydney Australia

Hollingsworth, H., Lokan, J., & McCrae, B. (2003). *Teaching mathematics in Australia: Results from the TIMSS 1999 video study*. Camberwell, Victoria: Australian Council for Educational Research.

Hurd, P. D. (2000). Science Education for the 21st century. *School Science and Mathematics, 100*(6), 282-288.

Keeves, J. P. (1999). Research into curriculum change. In J. P. Keeves & K. Marjoribanks (Eds.), *Australian Education: Review of Research 1965-1998*. Melbourne: The Australian Council for Educational Research.

Keeves, J. P., & Stacey, K. (1999). Research into mathematics education. In J. P. Keeves & K. Marjoribanks (Eds.), *Australian education: review of research* (pp. 205-241). Melbourne: The Australian Council for Educational Research.

Kemmis, S., Cole, P., & Suggett, D. (1993). Orientations to Curriculum, *Orientations to Curriculum and Transition: Towards Socially-Critical School* (pp. 8-14). Melbourne, Victoria: Institute of Secondary Education.

Lokan, J., Hollingsworth, H., & Hackling, M. ((in press)). *Teaching Science in Australia: Results from the TIMSS 1999 Video Study*. Camberwell, Vic: Australian Council for Educational Research.

Lovitt, C., & Clarke, D. (1988). *The Mathematics Curriculum and teaching Programme, Professional development package: Activity book*. Canberra: Curriculum Development Centre.

Ministerial Council on Education Employment Training and Youth Affairs (MCEETYA).(1999).*The Adelaide Declaration (1999)*. Available: http://www.mceetya.edu.au/nationalgoals29-6-06].

Mercurio, A. (2003). *Questions as answers: Understanding upper secondary selection and certification practices in South Australia, 1950-2000*. Adelaide: Senior Secondary Assessment Board of South Australia.

Millar, R. (1996). Towards a science curriculum for public understanding. *School Science Review, 77*(280), 7-18.

Millar, R., & Osborne, J. (Eds.). (1998). *Beyond 2000: Science Education for the Future*. London: King's College School of Education.

Organisation for Economic Co-operation and Development (OECD)/ Programme for International Student Assessment (PISA). (2003). *The PISA 2003 assessment framework- mathematics, reading, science and problem solving knowledge and skills*. Available: http://www.pisa.oecd.org/dataoecd/46/14/33694881.pdf [2006, 29-05].

Raison, M., & Etheridge, M. (2006). *Macquarie University Science, Engineering and Technology Study*. Melbourne: Macquarie University.

Rennie, L., Fraser, B. J., & Treagust, D. F. (1999). Research into Science Education. In J. Keeves & K. Marjoribanks (Eds.), *Australian Education: Review of Research 1965-1998*. Melbourne: ACER.