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Numeracy across the curriculum: demands and opportunities

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Numeracy has become very much an “in-vogue” term in Australian educational circles. Systems across Australia conduct state-wide numeracy tests, linked to and reported against national numeracy benchmarks. In the Australian Capital Territory all schools are required to develop a school numeracy plan. Yet it is debatable to what extent these system-wide tests or school plans adequately reflect a view of numeracy as “having the competence and disposition to use mathematics to meet the general demands of life at home, in paid work, and for participation in community and civic life” (Willis 1992).

It would seem that an important aspect of developing the capacity to use mathematics in everyday life is, for students at school, developing the capacity to use mathematics to meet the demands of other curriculum areas. Just as literacy has become every teacher’s responsibility, so numeracy needs to be seen as integral to every learning area.

In this paper the authors describe the results to date of a project in which teachers are researching the demands of, and opportunities for, numeracy across the curriculum. Some views of numeracy are presented, some “conversations” to date described, and some ways forward for teachers and schools to develop numeracy across the curriculum are suggested.

Numeracy
The term numeracy first appeared in the literature in the Crowther Report (1959). Crowther noted the prevalence of statistical ignorance, and highlighted the dangers of a population unable to interpret and question statistical information.

“(Numeracy is) the mirror image of literacy...On the one hand an understanding of the scientific approach to the study of phenomena – observation, hypothesis, experiment, verification. On the other hand...the need in our modern world to think quantitatively.”

Cockroft (1982), in a report that prompted a minor revolution in mathematics teaching, not only in the UK but throughout the world, described numeracy as an “at-homeness” with numbers, and the ability to cope with the practical mathematical demands of everyday life.

Cohen (2001) describes the emergence of a “quantitative mentality” in United States society, tracing its development alongside the introduction of censuses for military and political uses, the use of statistics in medical experiments, and mounting numerical arguments to support the reform movements of the 1820s to 1840s. She describes changes in arithmetic teaching that emerged with mass education, which brought together the formal college-level mathematics of the
college preparatory schools and the rote-learned commercial arithmetic studied by boys entering the mercantile world. Cohen argues that, despite the continuing changes in the teaching of mathematics, we have not yet come to grips with numbers as contestable, or with the importance of quantitative literacy as a basic thinking skill parallel to verbal literacy.

The International Adult Literacy Survey (Clermont et al 2002) included quantitative literacy in its survey, describing it as:

"The knowledge and skills required to apply arithmetic operations, either alone or sequentially, using numbers embedded in printed material".

Steen (2001) highlights the increasing need for quantitative reasoning in modern society and pointed out the ever-increasing gap between the quantitative needs of citizens and their quantitative capacity. Paulos (1988), lamenting the tendency of the general population to believe almost any information that was presented with a justification involving numbers or statistics, coined the term "innumeracy" and discussed the consequences for society of a population that lacked the capacity to critically examine quantitative information.

Frankenstein (2001) introduced the term "critical mathematical literacy" to describe a project in which she used mathematical reasoning to assist youth and adults from disadvantaged backgrounds to examine their circumstances from a socially critical perspective. Her goal was to empower previously disempowered members of society by examining, for example, the political construction of unemployment data in the United States. By calculating the percentage of unemployed people using a variety of definitions of unemployed, her students not only learnt how to calculate percentages, but also learnt that the official figures are contestable, excluding large numbers of people who might reasonably be considered unemployed.

Internationally the Project for International Student Assessment (OECD 2001) adopted the term "mathematical literacy" to describe an individual’s “capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgements and to engage in mathematics in ways that meet the needs of the individual’s current and future life as a constructive, concerned and reflective citizen”.

Willis’ (1992) description of numeracy as “at the very least, having the competence and disposition to use mathematics to meet the general demands of life and at home, in paid work, and for participation in community and civic life” was later picked up by the Australian Association of Mathematics Teachers (AAMT 1998), emphasising that numeracy is context specific and relative, that all teachers have a role to play in developing students’ numeracy, and that numeracy is underpinned by mathematical concepts.
In an investigation of the Key Competency Using Mathematical Ideas and Techniques in the workplace, Hogan (1996) found that people frequently applied mathematics to a task automatically, and were unaware of the underpinning ideas. Yet he suggested that being able to recognise these ideas would enable better resolution of problems. In the school situation this means that students must grapple with authentic, practical tasks that contain mathematical demands, and that all teachers share in this responsibility.

Education systems have incorporated this view of numeracy in various documents and descriptions.

“To be numerate is to have and be able to use appropriate mathematical knowledge, understanding, skills, intuition and experience whenever they are needed in everyday life.” (Education Department of Tasmania 1995)

“Numeracy involves...interpreting, applying and communicating mathematical information in commonly encountered situations to enable full, critical and effective participation in a wide range of life roles.” (Department of Education Queensland 1994)

The Commonwealth Department of Employment, Education, Training and Youth Affairs (DEETYA 1997) also adopted Willis’ view of numeracy, and acknowledged that numeracy was “a fundamental component of learning, discourse and critique across all areas of the curriculum”. Numeracy = Everyone’s Business, the report of the Numeracy Education Strategy Development Conference, stressed the need to use mathematical and strategic thinking to achieve a purpose in a particular context.

Thus there is a long history of thinking about numeracy as contextual and practical, and as more than just arithmetic. It would appear that there is a very clear distinction between numeracy and school mathematics.

Yet even a cursory glance at the numeracy benchmarks (Curriculum Corporation 2000) suggests that this distinction has become blurred, and that numeracy is often seen as little more than school mathematics. The benchmarks are organised around three strands: number sense, measurement and data sense and spatial sense. Within those strands there is a clear emphasis on fundamental mathematical skills, and very little discussion of the use of mathematics to meet the general demands of life at home or in the community.

“Students are developing their knowledge of numbers to include larger whole numbers and simple decimal fractions in familiar situations.” (Curriculum Corporation 2000, p.4).

Here, in the introductory statement in the year 5 benchmark concerning number sense, the emphasis is clearly on mathematical skills and knowledge. It is instructive to note that an earlier consultation document mentioned familiar contexts, a phrase which was subsequently omitted in the final version. Any
mention of context in the Benchmarks could be considered to be, at best, tokenism, with little appreciation that mathematics can assist in understanding and interpreting the world, or promote better solutions to real problems.

The state-wide numeracy assessments adopt a view of numeracy that closely mirrors this emphasis on fundamental mathematical skills. For example, the most recent Secondary Numeracy Assessment Program (SNAP) assessment in NSW contained several questions relating to sides and angles in two-dimensional shapes, with no mention of context. Even those questions that were supposedly contextual contained synthesised information, specially written for the assessment, rather than information embedded in printed or visual material that might reasonably be considered to be part of students' world.

This focus on the essential aspects of mathematics, as embodied in the Numeracy Benchmarks and state-wide numeracy assessments, appears to embody a naïve view of improving student numeracy. It assumes that 'mathematics can be learned in school, embedded within any learning structures, and then lifted out of school to be applied to any situation in the real world' (Boaler 1993, p.12). However, this does not appear to be the case. There is a growing literature on the nature of transfer of learning and the evidence suggests that students do not automatically use their mathematical knowledge in other areas. Lave (1988) found that even experience in simulated shopping tasks in the classroom did not transfer to the supermarket. On the other hand, it appears that people use highly effective informal mathematics in specific situations (Carraher, Carraher & Schliemann 1985).

It would be easy to attribute this lack of transfer of mathematical skills to other contexts to a deficient mathematics curriculum and poor teaching, but the quite considerable debate about transfer of skills shows that even if mathematics were taught and learned very well people would not necessarily apply it to new situations (Griffin 1995). Researchers in the area of situated cognition argue that cognitive skills and knowledge are not independent of context, and that activities and situations are integral to cognition and learning (Brown, Collins & Duguid 1989; Resnick 1989).

In order to respond to these issues there has been an attempt to contextualise school mathematics using contexts which appear to be relevant to the students (Cohen 2001). It was hoped that this would help students to see the purpose and usefulness of the mathematics they were learning, and that the mathematics would make sense. However, despite teachers’ best efforts many of these ‘real world problems’ appeared contrived rather than real (Willis 1992); required students and teachers to participate in ‘a wilful suspension of disbelief about reality and mathematics’ (Williams 1993); and left out factors relevant to the real situation (Boaler, 1993). Further, these attempts still had a primary purpose of teaching mathematics rather than developing numeracy. It would seem that if students are to learn to use mathematics outside the mathematics classroom then that is where they need to experience using mathematics.
The MYN Project
The Middle Years Numeracy Across the Curriculum Project commissioned by the ACT Department of Education, Youth and Family Services (DEFYS) attempted to address the somewhat naïve concepts of numeracy outlined above by placing numeracy firmly in context, as the domain of all teachers. The Project was funded for a period of two years, commencing in 2002, as a partnership between the Australian National Schools Network, Redgum Consulting and the University of Canberra. The principal researchers, John Hogan of Redgum Consulting and Steve Thornton of the University of Canberra, worked with officers from the ACT DEFYS and teachers from several ACT schools to identify and document numeracy opportunities, and to design, develop and implement an effective and transferable model that would support ongoing, school-based engagement with numeracy across the curriculum. This model would:

- Help teachers identify the numeracy demands of their teaching area(s);
- Support teachers in implementing strategies for improving student numeracy outcomes and learning across the curriculum;
- Facilitate productive professional discussion on numeracy within and across all curriculum areas in schools;
- Support schools in developing productive partnerships with parents/carers in supporting their children’s learning as related to numeracy; and
- Include a range of appropriate support materials for teachers and parents/carers.

The project methodology was based on Research Circles (ANSN XXX), in which teachers came together for periods of time to discuss their work, to observe and evaluate classroom incidents, and document these case studies. Initially the focus was on identifying “numeracy moments”, with the focus later moving to school-wide planning for numeracy across the curriculum.

The first Research Circle involved eleven teachers from five schools. Three teachers came from the senior (years 6 to 8) campus of a middle school setting, with two teachers each from two feeder primary schools. The middle school teachers all taught across several learning areas of the curriculum, the primary teachers in year 5 classrooms. Of the remaining four teachers, three were from a traditional high school (years 7 to 10) setting, with one from a feeder primary school. One of the high school teachers taught predominantly mathematics, one science and one art. The primary school teacher taught a year 5/6 class, with children identified as gifted and talented. This Research Circle was facilitated by two teachers who had previously participated in a pilot project.

The second Research Circle involved eight teachers from three schools. Three teachers were from a high school that was beginning to adopt a middle school structure. Two of these taught mathematics and science, the third was a learning assistance teacher with a literacy background. Four teachers came from a K10 school, two from the primary section, with one science teacher and one mathematics teacher from the secondary section. This school was unusual in that it had a dual language programme throughout the primary section, with a
significant proportion of the curriculum taught in French. The eighth teacher taught year 2 students at a nearby primary school. Two of the teachers from the first Research Circle acted as facilitators for the second Research Circle.

Each Research Circle met initially for two days. The participants were first asked to write down their perceptions of numeracy and what they hoped to obtain from participating in the project. Teachers were introduced to the Numeracy Framework (Hogan 2000), which described being numerate as involving a blend of three knowledges:

1. Mathematical knowledge;
2. Contextual knowledge; and
3. Strategic knowledge.

The Framework suggested that being, or becoming numerate involved being able to, or learning to, take on three roles:

1. The fluent operator - Being (becoming) a fluent user of mathematics in familiar settings;
2. The learner - Having (developing) a capacity for the deliberate use of mathematics to learn; and
3. The critical mathematician - Having (developing) a capacity to be critical of the mathematics chosen and used.

By the end of these two days each teacher developed a classroom-based action research project that would enable them to examine students' numeracy in their classroom. These projects focused on numeracy moments, which were described as incidents in which students encountered mathematical ideas in other contexts. The teachers undertook to record, in as much detail as possible, the circumstances in which students encountered mathematical ideas, the problems they had in understanding the mathematics and/or the context, the action taken by the teacher and what the student did next.

The second workshop commenced with a group sharing and discussion of teachers' observations. The discussion provided a rich array of examples of teachers observing student numeracy, and a constructive forum through which others could provide feedback. It became apparent that the teacher-researchers had begun to look more closely at the students' responses to numeracy demands across the curriculum. They had begun to see that a student's numeracy problem might not be simply a matter of not knowing the mathematics, but might relate to the context, or their inability to continue work on the task once they confront something they can't do. When it was seen to be an issue with the mathematics the teachers were more sensitive to what the mathematical problem might be. During the second two-day workshop teachers were asked to plan a unit of work for the coming term, investigate possible and probable numeracy demands in the unit, and develop some strategies for dealing with these.
The third two-day workshop moved the focus towards planning for a school-wide focus on numeracy across the curriculum. Some teachers planned staff professional development activities; some asked other staff to document numeracy moments in their classrooms, and some involved students and parents in discussing numeracy. One high school introduced the “Numeracy Gnome” to all staff, using this as a stimulus to ask teachers from all areas of the school to document and share the numeracy moments observed in their classroom. As a result other staff became much more aware of numeracy as being part of their core business, in a similar way in which every teacher is seen as a teacher of literacy.

The fourth two-day workshop focussed on planning for school numeracy and asked teachers to take an active role in school numeracy planning, a task that had since become a requirement for every school in the ACT.

Each teacher was visited at their school by a researcher or teacher-facilitator between the various workshop. During these visits the teachers talked about their classroom observations and discussed some possible follow-up actions that they might undertake. The school visits provided an opportunity for researchers to talk to the teachers in situ, and to provide support and encouragement for their on-going work.

Teachers’ and school stories are being written, collated and developed into a Web site to provide guidance for other schools in the system.

Results of the project
The numeracy moments
Teachers observed and documented numeracy moments from a range of learning areas. Three examples are presented below.

The volume experiment
Viktor observed the discrepancy between students’ capacity to measure volume accurately in science and their ability to apply mathematical formulas for volume in mathematics. Despite measuring the same objects by displacement of water and using a ruler, students seemed unaware that obtaining divergent answers created a problem. They seemed unaware of issues such as appropriate levels of accuracy.

The formula experiment
Geoff and Felicity undertook a joint action research project investigating students’ uses of formulas in mathematics and science. They found that, even though students had learnt techniques associated with changing the subject of a formula in the mathematics class, they rarely used that technique in appropriate situations in the science class. Yet most were able to successfully calculate the required quantity using other means.
Measuring the soccer pitch
Phil had two students who were particularly reluctant learners in the mathematics class. Yet they were very keen on soccer. As another class was using part of the soccer pitch during the physical education lesson, Phil’s class could only use half the pitch. He asked the two reluctant mathematicians to measure the half pitch and place the goals, half-way line and corner points in the correct places. The students had little trouble doing this. Back in the classroom Phil gave the students a mathematics lesson and asked them to draw a geometric shape following his instructions. The resulting figure should have been a scaled-down version of the soccer pitch, but the two students who had successfully undertaken the task in a real context were unable to do it in the mathematics class.

These and other examples suggest that:

- The methods used by students in a mathematics classroom are not necessarily those used by them in other settings.
- Some students seem to be able to act numerately in the field but not be able to do the mathematics in the mathematics classroom, that is, out of context.
- When working in a context some students do not seem to realise they are using mathematics. Some students withdraw, stop or protest when mathematical ideas and techniques are pointed out and emphasised in some way, even when they are doing a very practical activity outside the mathematics classroom.
- The context strongly influences the mathematics being used. Knowledge of this context is important. Having dealt with a numeracy issue in one context, it seems to help to provide students with another context where they can practise using their numeracy.
- An important aspect of being numerate is knowing how accurate you need to be in a situation. Actually letting them make mistakes seems to be a key to developing their understanding about this.
- In contexts outside school mathematics students seem to be confronted with very large numbers, very small numbers, negative numbers, fractions and so on. How can we help them understand these? Maybe these contexts help students better understand these concepts.
- A close look at student work is necessary sometimes in order to diagnose their numeracy problem – is it a mathematical idea they do not understand? Or a mathematical skill they cannot do? Or is it they do not have the strategic skills to link the context and the mathematics? Is it that they are not fluent? Is it that they cannot do it so they give up? It seems that all students might need some practice at being critical of the mathematics they have used in situations. Getting to find out what each individual student’s numeracy problem might be in any particular situation is difficult and may not be always possible.
- There are many numeracy moments that potentially occur across the curriculum. Knowing when to explore them in depth and when to deal with them in a quick and pragmatic way is a difficult decision. As
teachers we need to focus on all aspects of being numerate not just the associated mathematical skill.

- Sometimes the mathematics in a particular situation will be beyond what the students have done in mathematics itself. What a teacher should do when a numeracy moment occurs and the mathematics is beyond what the students have done in school mathematics is not always clear. Finding a way that stays true to the situation seems better than going too deeply into the mathematics.
- Making links between the numeracy moment and the school mathematics program might be important. How to do this is not always clear.
- Asking questions of students about what they are doing, how they are doing it, why they are doing it that way might be important. Engaging the students in discussion about numeracy and mathematics will help them become more aware of situations when mathematics may be present or the need for it arises.
- Dealing with numeracy makes more sense to the students when they are deeply engaged in the learning, that is, when it matters to them. It helps student learning when they can see that the mathematics helps them to understand something new.
- Students do not seem to reflect on the mathematics they have used in doing a task – being critical of the mathematics seems to be something that has to be nurtured.

School-wide numeracy
Findings from teachers’ initial whole school approaches suggest that this is slow work. It is necessarily so because it is complex work. It involves working with the school culture, an understanding of school change, sophisticated skills in leading and managing change, and using a language about numeracy that is not well known or understood. So the confidence of teachers leading this work in a school is crucial.

Observations made by the teachers and researchers included:
- Most teachers do not have numeracy as a priority in their teaching. Most have a limited view of numeracy, usually as a subset of school mathematics skills (like number calculations) that were needed for low level social goals (like paying bills). A number of the teachers found talking about mathematics somewhat uncomfortable.
- Teachers across the curriculum tend to be surprised to see the extent of the mathematical demands in the work they ask students to do.
- Most teachers focus more on the possible mathematical demands of their curriculum rather than on the numeracy problems their students are actually having.

There are numerous issues facing high schools in getting teachers to work with other teachers across the curriculum. Most teachers – primary and high schools – talked about the difficulty of working with other staff in their school who were negative or uninterested.
Teacher action research
The action research process put in place a support mechanism in which there was no lag between input and implementation, as in traditional forms of research, which require understanding prior to commencement. In action research traditions, going back over a century, the emphasis on collaboration provides quality control and the sharing of expertise in the group, and also builds the pre-conditions of confidence and trust needed for the sharing of professional practice – what is often kept ‘private’ or ‘secret’ among teachers. The balance between existing expertise and the generation of new knowledge and practice is one which is judged cooperatively among the members of the whole group, ensuring that all can participate successfully.

The teachers enjoyed and appreciated the research circle methodology. They valued the time it gave them to think about the issues, the chance it gave them to talk to teachers from other learning areas and different phases of schooling, and the opportunity to work with other teachers in their own school. The teachers reported liking the way they got started by investigating their own classroom and by generating their own questions and observations. However, they have also enjoyed working with others. They particularly liked getting back together to share their successes, their problems and their questions.

A clear finding from the project is that short-term professional development in which teachers are presented with facts or theories about numeracy across the curriculum is unlikely to result in long-term change. An action research model seems to be an appropriate way of actively engaging teachers in observing their own classrooms and discussing the numeracy implications in a range of learning areas.

Issues arising and further research directions
A number issues requiring further thought have arisen during discussions. These include:

- What role do calculators play in numeracy across the curriculum, and what is the influence of technology generally?
- How do parental perspectives and confidence about mathematics and numeracy impact on students’ numeracy?
- What is the role of mathematics teachers in high schools? How can teachers from other learning areas work with mathematics teachers to develop students’ numeracy? Should the school mathematics programme be changed to reflect an emphasis on numeracy? Is less more in school mathematics?
- How do teachers’ own perspectives and confidence about mathematics and numeracy impact on student numeracy?
- How does systemic numeracy testing, or testing and assessment in general, impact on numeracy across the curriculum?
- How do we report to parents about their children’s numeracy?
- Teachers often have preconceived perceptions about students’ ability. Does this affect students’ capacity to be numerate in a variety of situations?
Conclusions

Whose job is to develop students' numeracy? If the role of school education is, at least in part, to equip the populations with the knowledge, skills and strategies to be thoughtful, productive and critical members of society, then numeracy is everyone's responsibility. Without an awareness of the underpinning role of mathematical ideas in problem solving, in communication and in public debate, it is debatable to what extent an individual can arrive at informed decisions or follow productive strategies. School mathematics alone is unlikely to develop this capacity in our students - it requires conscious effort by all teachers, and a willingness to engage in mathematical thinking in all learning areas. The action research approach used in the ACT Middle Years Numeracy Across the Curriculum Project provides a powerful model through which teachers can become aware of and plan for numeracy. Identifying and capitalising on numeracy moments not only develops students' capacity to be numerate, it also enriches their learning in other areas of the curriculum.

References


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