SUPPORT DOCUMENT

Learning numeracy on the job: A case study of chemical handling and spraying—Support document

GAIL FITZSIMONS

SUSAN MLCEK

OKSANA HULL

CLAIRE WRIGHT

Access and General Education Curriculum Centre

This document was produced by the author(s) based on their research for the report *Learning numeracy on the job: A case study of chemical handling and spraying*, and is an added resource for further information. The report is available on NCVER's website: <http://www.ncver.edu.au>

Contents

Literature review

Introduction

This literature review considers existing research with a view to answering the following questions:

- What is numeracy and how does numeracy relate to mathematics?
- How are mathematics and numeracy used in the workplace?
- What are the curricular and pedagogical implications for workplace learning?

This literature review approaches these questions using three perspectives on adult numeracy and workplace learning. The first perspective, following Bernstein (2000), concerns the institutional level. It is at this institutional level that major policy decisions such as the implementation of training packages are formulated. These kinds of decisions determine who is entitled to learn what. For this project, discussion concentrates on the distinctions between the institution of mathematics and the practices of numeracy in the workplace.

In the second perspective, decisions are made about how relevant knowledge and skills will be re-contextualised in an educational format, and how the knowledge and skills will be transmitted to learners. Here the relevant context is that of workplace learning and the relevant knowledge is numeracy education.

The third perspective focuses on the processes of acquisition by learners and on evaluating learner attempts at reproducing the intended knowledges and skills. This is the focus of the research project *Learning Numeracy on the Job in Chemical Spraying* associated with this literature review.

Numeracy and its relationship to mathematics

Defining numeracy

There are many possible definitions of numeracy (see for example Evans 2000, Gal et al. 1999, van Groenestijn 2002), and the importance of coming to a clear understanding of what constitutes numeracy is explored in the discussion below. The focus of this literature review is on teaching and learning numeracy on the job, and in this context the definition proposed by Coben (2003) seems one of the most useful. Coben wrote that:

> To be numerate means to be competent, confident, and comfortable with one's judgements on whether to use mathematics in a particular situation and if so, what mathematics to use, how to do it, what degree of accuracy is appropriate, and what the answer means in relation to the context. (Coben 2000:35 cited in Coben 2003:10)

This definition encapsulates the separate but interrelated nature of mathematics and numeracy. As Coben's definition suggests, being numerate means knowing how and when to draw on a body of underlying mathematical knowledge in particular contexts.

In many publications numeracy is described in fairly broad terms as a component of literacy. However, it seems likely that the earliest mathematics was actually a form of numeracy, predating literacy. Historically, material needs involving numbers and calculations, particularly the need for record keeping, were central to the development of writing (Ritter 1989). Only when this process developed into a codified set of abstractions could the separate discipline of mathematics be said to exist.

Bishop (1988), from a different perspective, describes early mathematics as a pan-cultural phenomenon having been founded on what he claims to be six 'universal' activities: counting, locating, measuring, designing, playing, and explaining. In other words, all people — young or old, schooled or unschooled — in all cultures normally perform such mathematical activities during the course of their lives.

As will be discussed further below, the international mathematics education research community distinguishes between mathematics and numeracy, yet maintains that numeracy must be underpinned by mathematical knowledge of an appropriate kind. Numeracy is taken to be much broader than facility with numbers or basic arithmetic, and includes spatial and quantitative (statistical) literacy. Throughout the influential Kearns review of generic competencies (2001), for example, there was a stress on problem solving, systems thinking, and analytic skills (generic numeracies).

Australian perspectives on numeracy

In recent years in Australia there has been significant discussion of literacy and numeracy practices in restructuring workplaces, especially in relation to automation, emerging communications technologies, and new approaches to workplace organisation and management (FitzSimons 2002). The Federal Government is committed to a policy of encouraging adult numeracy, as well as technological and other literacies, in adult/vocational education as an underpinning component of the drive to transform Australia into a knowledge economy. Not all workers have high levels of numeracy, so there remains an urgent need to provide opportunities for workers to continue to develop the numeracy skills they require.

In Australia, the idea of employment-related competencies was developed by the Finn committee in 1991 as part of a series of reports focusing on young people and their employment. This idea was passed onto the Mayer committee to develop a set of generic Key Competencies (Mayer 1992). These competencies were described as being essential for effective participation in work and other social settings. Mayer's Key Competencies have proven to be extremely influential in the setting of the Australian vocational education and training agenda over the last decade.

The key competencies are:

1. collecting, analysing and organising information
2. communicating ideas and information
3. planning and organising activities
4. working with others and in teams
5. using mathematical ideas and techniques
6. solving problems
7. using technology.

Since 1992 the term 'using mathematical ideas and techniques' has tended to be replaced by 'numeracy skills'. However, as will be discussed further below, numeracy is more than the ability to use mathematical ideas, and is also essential underpinning knowledge to achievement across many of the other key competencies.

Following on from the delineation of these key competencies, there has been considerable effort by researchers to develop mechanisms for assessing and reporting on numerical competency.

Griffin and Forwood (1991) conducted a literature review to underpin the development of their Adult Literacy and Numeracy Competency Scales. Griffin and Forwood claimed that 'a distinction needs to be made between the ability to comprehend text containing quantitative information and the ability to perform the mathematical operations which may be needed to solve specific numeracy problems' (p.17).

Griffin and Forwood argue that there are two major components of numeracy: mathematical literacy — understanding the concepts and the register of mathematics, and mathematical competency — operationalising the skills, applying the processes of mathematics.

They define numeracy as 'the ability to process quantitative information and to apply basic arithmetic and other mathematical operations' and speak of the development of numeracy as 'an increasing ability to process, apply and reflect upon quantitative information in a range of contexts.'

The National Reporting System (NRS) (Coates et al., 1995), which has been extremely influential in the last decade in the Australian adult and vocational education sector, was developed 'as a mechanism for reporting the outcomes of adult English language, literacy and numeracy provision in the vocational education and training system, in labour market programs and in the adult, community education sector' (p.1). There are five levels of competence in the NRS and for each level of numeracy there are four features: meaning-making strategies, problem solving strategies, mathematical knowledge, and mathematical representation — each with multiple performance strategies listed as behavioural exemplars typical for that level.

Despite the distinctions made between numeracy and literacy in work such as that of Griffin and Forwood and in the National Reporting System, recent reviews of numeracy still appear to lack clear definitions of what is meant by numeracy, except as a subset of literacy skills: 'literacy includes the recognition of numbers and basic mathematical signs and symbols within text' (Falk & Millar 2001, p.9). Watson, Nicholson, and Sharplin (2001) declare that attempts at a single definition are relatively futile, and the Australian National Training Authority (ANTA) is quoted to define numeracy merely as calculations needed in the workplace (Sanguinetti & Hartley 2000). In the Kearns review (2001), which stresses an increasing demand for generic skills, the word numeracy occurs several times, but the concept is neither defined nor problematised. Numeracy, in relation to basic skills, is however assumed to be an important pre-requisite for employability.

The fact that these review documents are premised upon literacy and numeracy being taught together and integrated into workplace training results in them being treated as a single entity throughout these reviews of research and in a related guide for practitioners (ANTA 2000). Even the Falk and Millar (2001) review treats numeracy as an appendix to literacy.

Sanguinetti and Hartley (2000) have identified a range of problems which arise from this situation, including:

> implicit numeracy competencies in industry standards require a high degree of analytical sophistication and educational expertise … not all enterprise-based trainers nor workplace trainers have such expertise. Often buried in training packages, literacy and numeracy competencies need to be made more explicit. (p.33)
>
> the assessment-driven model minimises need for teaching or support; there are limited opportunities for development of underpinning skills. More holistic and structured approaches are required. (p.34)

The Dawe (2002) report on generic skills in training packages does acknowledge that while the integration of generic and technical skill development provides for easier transfer of generic skills, there is still a place for the separate and prior teaching of specific language, mathematics or learning skills — especially in engineering programmes. Interestingly, this report also revealed that very little if any explicit mathematics or numeracy knowledge appeared to be required in many of the competencies in ten training packages which were examined for the Mayer key competencies. For example, in the Agriculture Training Package two of the six mandatory units of competency included 'Use hazardous substances safely' and 'Plan daily work routine'. Yet the report noted, 'in general, these units did not include using technology or mathematical ideas and techniques' (p.40). This suggests that perhaps there was a lack of recognition of the actual numerical practices which occur in workplaces but which are embedded in other key competencies.

International perspectives on numeracy

FitzSimons, Jungwirth, Maasz, and Schlöglmann (1996) trace a brief history of the development of official political interest in the topic of numeracy, predominantly in English-speaking countries. For example, in the UK, the USA, and Australia there has been a burgeoning public interest, and this has more recently spread to some countries of the European Union (DEETYA 1998; DES 2000; DETYA 2000; DfEE 1999; Lindenskov & Wedege 2001). Developing countries are also experiencing a push for adult numeracy, along with adult literacy (Clements 2001) — although literacy is usually regarded as of prime importance. (See also FitzSimons, Coben, & O'Donoghue 2003, for an overview of lifelong learning and mathematics education.)

Research has shown that many people are anxious about their mathematical competence and ability to apply mathematical knowledge in work and life. The 1982 Cockcroft Report in the UK was commissioned to enquire into the teaching of mathematics as it related to further and higher education, employment and adult life generally. Although there were some people who could cope confidently and competently with any situation requiring the use of mathematics in everyday life, there were many others for whom the reverse was true. The report observed (Cockcroft 1982):

> The extent to which the need to undertake even an apparently simple and straightforward piece of mathematics could induce feelings of anxiety, helplessness, fear and even guilt in some of those interviewed was, perhaps, the most striking feature of the study. (p.7)

There were no connections found between levels of qualifications and the extent of mathematics usage; between mathematical competence and occupational group; or of self-estimates of mathematical competence and level of usage. People with high academic qualifications experienced particular feelings of guilt about their lack of confident understanding of mathematics as there was a general imputation of superior mathematical ability. Others felt guilty that they had not used the 'proper' standard classroom algorithms. For many, if their single method for solving a problem failed, they lacked the ability and confidence to use an alternative approach — even an awareness of the possibility. Some felt that there always had to be an exact answer, and were unable to approximate or round off results. Others expressed long buried anxieties about speed and accuracy, as well as the requirement to show a neatly written solution, often to demonstrate a method that they had not personally used.

From the USA, Steen (2001) makes a clear distinction between mathematics and numeracy, arguing that students need both. Steen asserts that whereas mathematics requires a distancing from context, numeracy (or quantitative literacy, in his words) is anchored in real data that reflect engagement with life's diverse contexts and situations. Numeracy offers solutions to problems about real situations (Steen 2001).

Coben (2002, p.28) also discusses adults' engagement with mathematics and numeracy in terms of use and exchange value emphasising distinctions between adult numeracy as skill, practice, learning, and education. She summarises the major differences in perspectives in the figure below, labelling the domains as 'One' and 'Two', and notes that '… adults may engage simultaneously in more than one discursive domain of numerate practice and they may be aware of doing mathematics (or practising numeracy) only in Domain One' (p.29).

Figure 1: Adult numeracy learning in Domains One and Two (Coben 2002, p.29)

	Domain One use value low; exchange value high	**Domain Two** use value high; exchange value low
Why?	To gain access to institutions of modernity; based on the belief that to be numerate is beneficial both to the individual and to society	To do something; to understand something (not necessarily something mathematical *per se*)
What?	Through a formalised standardised certificated curriculum, positioned as 'basic skills'	Through informal, non-standard mathematics practices which may be (dis)regarded as 'just common sense' by all concerned; invisible mathematics
How?	Through teaching; learning materials may be technologised, unitised, commodified	Through social activity or alone 'in your head'
Who?	Learners: those deemed to be deficient in mathematics ('innumerate') Teachers: professional experts (NB this is problematic in adult numeracy as the concept of numeracy is debated and the field of professional practice is poorly defined); non-professionals; volunteers	Learners: everyone, as part of processes of enculturation into 'communities of practice' 'Teachers': more experienced people, who 'know the ropes'
When?	At set times (except in Open and Distance Learning [ODL]	Anytime, incidental
Where?	In set locations, except in ODL	Anywhere, in context, in 'real life'; 'everyday life'; workplace; at home

It appears that the discipline of mathematics as traditionally taught in schools and some post-compulsory educational settings aligns with Domain One and that how numeracy practices are learned aligns with Domain Two.

Lindenskov and Wedege (2001, p.5) in developing a Danish Adult Numeracy Curriculum proposed a two-pronged general definition of numeracy describing a math-containing everyday competence that everyone, in principle, needs in any society at any given time:

- numeracy consists of functional mathematical skills and understanding that in principle all people need to have
- numeracy changes in time and space along with social change and technological development.

They then proposed a two-level numeracy curriculum for adults with limited previous education in mathematics. The first level, *Figures and Quantity*, intends that:

> the participants clarify, improve and supplement their number sense and functional arithmetic skills for everyday practical use and personal organisation. The education is to ensure participants the possibility of developing their mathematical awareness and the ability to deal with, process, evaluate, and produce math-containing information and materials, as well as being able to communicate about these things. (p.20)

The second level, *Patterns and Connections*, has as its aim:

> that participants clarify, improve and supplement their understanding of functional arithmetic and mathematics skills in practical situations and in the organisation of their everyday lives. Furthermore, they develop their functional skills at interpreting, producing and reflecting on numerical, statistical and graphic information, as well as the ability to communicate this knowledge. The teaching ensures the participants the possibility of further developing their mathematical awareness and of preparing for possible further education. (p.22)

In Ireland, John O'Donoghue (2000) and colleagues have developed a numeracy assessment framework. In England, Diana Coben (2001 2003) teases out the tensions and contradictions in the new adult numeracy core curriculum: for example, between social inclusion and economic competitiveness, between maximising efficiency and developing creativity, between individual fulfilment and the need for constant retraining in an insecure job market.

The OECD-sponsored *Adult Literacy and Lifeskills* (ALL) survey (Gal et al. 1999, p.16) aims to enable international comparisons of numeracy levels of adults. Although it is not a curriculum project, comparative assessment surveys such as this have the potential to influence national curricula and some researchers have been concerned about such potential influence.

The *National Basic Skills Survey of Adults in England 2002-3* was designed by researchers in the UK as an alternative to the ALL survey, due to concerns about its methodology (Gillespie, 2003). According to Gillespie, consideration needed to be given to: (a) assessing the full range of adult numeracy abilities, (b) acknowledging the altruistic behaviour of participants, (c) not discouraging participants through a succession of difficult questions, (d) recognising the likelihood of 'spiky' profiles according to individual strengths and weaknesses, and (e) limiting the survey to no longer than 30 minutes. Gillespie also recognises some limitations: questions took the form of pre-determined multiple-choice items from the national core curriculum, and there was no opportunity for discovering reasoning behind adults' answers. In addition, this core curriculum was not based on the actual performance of adults, and the levels of curriculum do not necessarily constitute a natural progression for any adult. Possible next steps include revisiting a small sample of individual responses and framing them as short-answer questions, and structured interview techniques that allow examples of adults own numeracy skills to become visible. In this way, individuals' performances could be connected with the larger survey and their contexts addressed.

Critical numeracy

Concerns such as those expressed by Gillespie are important because they highlight the very significant point that a consideration in the development of numeracy frameworks and surveys is, or should be, whose knowledge interests are being served. Following the work of Habermas (1963/1974), it could be argued that many official reports and semi- or fully-funded numeracy programmes are serving primarily 'technical' or instrumental, manipulative interests, and 'practical' or hermeneutic, communicative interests. Adults are to develop the instrumental skills, confidence, and competence to function effectively in the workplace, the home, and society — as producers and consumers of commodities and/or information. An example of technical and practical interests in numeracy is given in the Cockcroft Report (1982):

> We would wish the word 'numerate' to imply the possession of two attributes. The first of these is an 'at-homeness' with numbers and an ability to make use of mathematical skills which enables an individual to cope with the practical mathematical demands of his [sic] everyday life. The second is an ability to have some appreciation and understanding of information which is presented in mathematical terms, for instance in graphs, charts or tables or by reference to percentage increase or decrease. (p.11)

In the last two decades many reports have focused on adult numeracy with greater consideration of the contexts in which people act, and the processes of being able to choose and use appropriate mathematical ideas (Willis 1990). Few, however, have adopted a critical stance towards the production and legitimation of power, including the impact of technological development on our society.

The third of Habermas's interests, 'emancipatory', focuses overtly on power relations, addressing questions about knowledge production and legitimation and exploring social structures which serve to maintain and reproduce the interests of those holding power.

The recent interest in numeracy by governments around the world has been concomitant with the upsurge of interest in educational outcomes and accountability. Baker (1998) argues against models of culture- and value-free numeracy; determining the basic skills (supposedly) needed by all adults. In standards models such as these, there is no debate about which skills are central, whose standards they are, or why they are needed (see also Coben 2001). Baker continues that the power relations operating in these purportedly value-free models of numeracy need to be made more explicit and open to challenge and critique.

Niss (1994) argues against mathematics education being limited to everyday private and social uses. Niss points out that:

> those not in possession of mathematical competence beyond what is used in everyday life will be excluded from influencing important processes in society that have a considerable impact on their lives as individuals and citizens. (p.376)

Adults who missed opportunities for mathematical competence in school should not in Niss's view be denied such opportunities in vocational education as such knowledge provides access to powerful social discourses.

Some Australian educators include numeracy as part of mathematics taught to university students in primary education (teaching) and electrical engineering courses. Yasukawa, Johnston, and Yates (1995) assert that numeracy is a:

> critical awareness [which] enables us to build bridges between mathematics and the real world, with all its diversity. Being numerate involves not only having this critical awareness, but also involves the responsibility of reflecting that critical awareness in one's social practice. Thus, being numerate means being able to situate, interpret, critique, use, and perhaps even create mathematics in context, taking into account all the mathematical as well as social and human complexities which come with that process. (p.816)

They continue that in order to engender numeracy it needs to be socially situated, incorporating personal reflection and social negotiation; it needs to 'excavate, uncovering assumptions and value systems, and whose interests are being served by any given representation of reality' (p.819). Numeracy is necessarily subjective. In addition, the wider institutional context will affect the extent to which teachers' and learners' ideologies can be enacted.

Klein (2000) considers numeracy not as a thing to be possessed, but as a capacity for action. Thus, in relation to numeracy, democratic power depends upon access to mathematical knowledge — information selectively derived from a range of possibilities and which is capable of being interpreted and understood — access to which is also unequally distributed. Klein argues that 'numerate behaviour reflects a certain agency with mathematics and comprises intellectual and social aspects of knowing mathematics' (Klein 2000, p.76).

The context dependence of numeracy

The last two decades have seen the burgeoning of new perspectives on the use of mathematical knowledge in practical situations of life and work which do not necessarily reflect the practices of the traditional mathematics classroom. All recent surveys stress the importance of a foundation of mathematical knowledge and that numeracy also goes well beyond being a sub-branch of literacy, important as it is in this field. However, no model of numeracy can be culture- or value-free. In the Australian context of training packages, the underlying assumption is that the selection of numeracy (and literacy) skills must be relevant to the particular industry. However, it appears that important connections between numeracy and occupational health and safety, for example, are being overlooked or treated as peripheral. As will be discussed further below, there is a tendency for industry personnel to see numeracy (or mathematics) as a set of isolated skills, to be transferred unproblematically to any situation.

In the above sections various approaches to adult numeracy have been reviewed, each of which somehow link numeracy with mathematics. Numeracy and mathematics may be distinguished with reference to Bernstein's (2000) concept of 'vertical discourse and horizontal discourse', linked with his performance and competence models of education.

Bernstein (2000) distinguishes between two fundamental forms of discourse, 'vertical and horizontal.' In the educational field they are known as: school(ed) vs everyday common-sense knowledge, or 'official' vs 'local' knowledge. Common sense knowledge is likely to be: 'oral, local, context dependent and specific, tacit, multi-layered, and contradictory across but not within contexts' (p.157). Mathematics is an example of a 'vertical discourse' on account of its coherent, explicit, and systematically principled structure. The discourse of traditional school mathematics recontextualises a selection from the abstract discipline of mathematics and is mostly only about mathematics, with very few external references.

By contrast, the knowledges of 'horizontal discourses' are 'embedded in on-going practices, usually with strong affective loading, and directed towards specific, immediate goals, highly relevant to the acquirer in the context of his/her life' (p.159). The construct of numeracy is an example of a horizontal discourse.

According to Bernstein (2000), the pedagogy of horizontal discourses is usually carried out face-to-face. It may be transmitted by modelling, by showing, or by explicit means. If necessary, the pedagogy is repeated until the particular competence is acquired. Bernstein continues that 'From the point of view of any one individual … there is not necessarily one and only one correct strategy relevant to a particular context' (p.160). He concludes that horizontal discourse 'facilitates the development of a repertoire of strategies' that will be activated in relevant contexts' (p.160).

Whereas in mathematics there is a well-known hierarchy between so-called common sense and so-called uncommon sense, with numeracy common sense is of the essence. High level abstractions alone are insufficient and may even prove counter-productive in the workplace. Numeracy cannot be said to have a specialised language, except at the most local level of use in context. For example, the use of the term 'thou' [i.e., thousandths] is widely used in the building and automotive industries, but may not have meaning elsewhere. Numeracy is not necessarily explicit or precise, and its capacity for generating formal models may be limited to the context at hand rather than being generalisable. Observations of workplace numeracy practices resonate strongly with Bernstein's concept of horizontal discourse and its associated pedagogy.

Mathematics/numeracy in the workplace

Workplace competence

There can be no universal conception of workplace competence, particularly in times of rapid social and economic change. The concept of workplace competence is often taken for granted, but the literature reveals quite diverse understandings of what constitutes competence.

Many definitions of workplace competence assume a functional perspective, defined and evaluated in terms of successful performance of certain given or predetermined tasks. However other theorists, for example Ellström (1998), argue for a developmental understanding of workplace competence. Ellström claims that the functional view 'fails to recognise the active modification and subjective redefinition of the work task that occurs continuously and with necessity during the performance of a job' (p.44). Ellström goes on to say that 'people have a capacity for self-management, and that they also are allowed and expected to exercise this capacity' (p.44). He continues that much developmental work is complex in character, with a need to move between routine and non-routine work. Cherns (1980, quoted in Engeström 1987) observes that in contemporary workplaces 'treatment becomes routine, diagnosis becomes the key'.

These sentiments are echoed by NBEET/ESC (1996) who recognised the requirement for systems thinking as an integral part of information literacy in the recent trends towards cross-disciplinarity and teamwork.

According to Onstenk (1998):

> Broad professional skill is defined as a multi-dimensional, structured and internally connected set of occupational technical, methodical, organisational, strategic, co-operative and socio-communicative competencies, geared to an adequate approach to the core problems of the occupation. (p.126)

Onstenk (1998) adds 'learning competence' as a further necessary element in broad professional skill. Workers are always learning, although not necessarily from formal training or in the manner (or matter) intended. Learning competence is critical to projects of lifelong learning, but is more often than not taken for granted. Learning competence refers to the metacognitive skills which need to be consciously developed. Such development could be achieved through the expertise of professional educators working in collaboration with workplace personnel. (FitzSimons 2001b)

Numeracy demands of workplaces

Over the last three decades there have been reports in many countries about the mathematics and numeracy skills required in the workplace. Writers in previous decades have largely focused on the supposed correspondences between lists of school mathematics topics and the required workplace skills.

More recent studies have researched workplace numeracy— that is, how mathematical ideas and techniques are used in practice, as distinct from in the school classroom. These include the following (unless otherwise stated, studies were conducted in Australia.): short-term work shadowing of workers in 30 workplaces (AAMT 1997); operators in the light-metals industry (Buckingham 1997); studies of 3 companies or organisations in each of 7 key UK sectors (Hoyles, Wolf, Molyneux-Hodson & Kent 2002); front-desk motel and airline staff (Kanes 1997a 1997b 2002); landless peasants in Brazil (MST) (Knijnik 1997 1998); supermarket shoppers in the USA (Lave 1988); CAD/CAM technicians in Slovenia (Magajna & Monaghan 2003); carpet layers in the USA (Masingila 1993); in the UK — commercial pilots (Noss, Hoyles & Pozzi 2000), merchant bankers (Noss & Hoyles 1996a 1996b), and nurses (Noss, Pozzi & Hoyles 1999; Pozzi, Noss, & Hoyles 1998); draughtspersons in Germany (Straesser 1998); spreadsheet use by UK police (Wake, Williams, & Haighton 2000), studies of 11 UK workplaces (Wake & Williams 2001); work shadowing of semi-skilled operators in Denmark (Wedege 2000a 2000b 2002) and swimming pool construction workers (Zevenbergen 1996).

These studies show that mathematical elements in workplace settings are subsumed into routines, structured by artefacts like workplace texts and tools, and are highly context-dependent. The mathematics used is intertwined with professional expertise at all occupational levels, and judgements are based on qualitative as well as quantitative aspects. Unlike students in the majority of traditional school mathematics classrooms, workers are generally able to exercise a certain amount of control over how they address the problem solving process. This control of course occurs within the parameters of the expected outcome of the task at hand, regulatory procedures, and available artefacts. (The quality of management and effective supply and maintenance of necessary equipment are another issue.) Finally, because the focus is on task completion within certain constraints (e.g., time, money), mathematical correctness or precision can be somewhat negotiable, depending on the situation at hand.

In a project designed to promote an informed view of the key competency, using mathematical ideas and techniques, the Australian Association of Mathematics Teachers (AAMT) (1997) collected about thirty reports of mathematics used in the workplace. They were based on accounts collected from mathematics teachers who shadowed workers, paid and unpaid, for about half a day. These work stories, as they were called, indicated that in fact all of the key competencies came into play in complex ways. In approaching a practical task, it appears that workers bring to bear a range of skills, attitudes, and knowledges which include: (a) situational (vocational and other) knowledges and skills (in particular, mathematical); (b) metacognitive skills and strategies (e.g., critical thinking, planning, problem solving, and evaluating); and (c) personal skills (e.g., communication, working with others, and understanding the culture), together with certain attitudes and dispositions toward the work and the workplace. The AAMT report summarises the key elements of using mathematics for practical purposes as:

- clarifiying the outcomes of the task and deciding on what has to be done to achieve them.
- recognising when and where mathematics could help and then identifying and selecting the mathematical ideas and techniques to be used
- applying the mathematical ideas and techniques, and adapting them if necessary to fit the constraints of the situation
- making decisions about the level of accuracy required
- interpreting the outcome(s) in its context and evaluating the methods used.

(p. 59)

The report concludes that although many practical situations require an understanding of some mathematics, this would always be specific to the particular work context. However, it was unable to determine any criteria for making a difference between good and poor performance.

The pharmaceutical manufacturing industry (FitzSimons 2000) provides support for the notion of the often invisible complexity of the workplace. In Australia this healthcare industry is highly regulated from a legal point of view; every procedure must follow strict guidelines, set down for workers in Standard Operating Procedures (SOPs) which are constantly updated. Accountability is of the essence and is policed by regular and random audits. At each stage of the production process every item — including packaging, leaflets, raw materials, creams, and tablets — must be recorded, counted or measured, checked and re-checked by designated operators. In the case of any discrepancy, at the very least the immediate production process is halted, and in the worst case the manufacturing licence is under threat, or product recall takes place with possible loss of consumer confidence. After a discrepancy is discovered, problem solving activities ensue calling upon a broad range of competencies from workers until a solution is found. Using Onstenk's (1998, 2001) model of workplace competencies it is possible to provide an illustration of the kinds of questions which may be asked by a line manager following a (hypothetical) breakdown in production processes:

- *Technological*: Was the machine functioning correctly according to specifications? Were the raw materials as specified in amount and quality?
- *Methodical*: Were the controls set appropriately (accurately, in-time, etc.)?
- *Organisational*: Were the appropriate staff (e.g., the optimal number, sufficiently qualified) performing their allocated tasks?
- *Strategic*: How am I going to deal with this problem? How serious is it, and what are the implications of my decision?
- *Socio-normative*: Which are the most appropriate staff to help find the most efficient and productive solution? (N.B. union demarcations, availability of staff)
- *Social-Co-operative*: How will I seek help without alienating the workers concerned? Can I 'borrow' workers from another task? Is the delay period in waiting for the engineer, maintenance person, etc. negotiable?

Working in a situation of economic contingency requires not only explicit mathematical knowledge but also a broad base of implicit knowledge together with higher order skills associated with systems thinking.

From the UK, Noss (1997) argues that sophisticated mathematical skills are required for interpretation of results as well as error detection or retrieval from catastrophic technological breakdown situations. He observed that, although in many work situations there is less reliance on traditional school mathematics skills which can be carried out more efficiently by computers, there is a greater reliance on an ability to think in a mathematical way. Noss, Hoyles, and Pozzi (1998 2000) and Pozzi, Noss and Hoyles (1998) found that there are complexities in relations between professional and mathematical knowledge, and workplace decisions are based on an interplay of these. Communication is critical, and in non-routine situations workers may draw upon underlying models which are rarely articulated, and which may indeed not have a mathematical orientation.

The effect of technological changes on people's lives in terms of increasing the complexity of mathematical or numeracy demands at work and beyond has been observed by many authors. For example, Lesh (2000) notes that the *USA Today* newspaper contains editorials, sports, business, entertainment, advertisements and weather sections which are filled with tables, charts, graphs and formulas 'intended to describe, explain, or predict patterns or regularities associated with complex and dynamically changing systems; and the kinds of quantities that they refer to go far beyond simple counts and measures …' (p.179). He gives the example of used-car advertisements which no longer simply state the selling price, but which are instead mathematised to incorporate repayment terms and conditions. These complexities of personal, civic, and professional life are echoed by Norton Grubb (2002) who observes that mathematics in the workplace often involves a complex series of applications of relatively low-level mathematics to ill-defined problems.

Based upon studies of numeracy in workplaces of the USA, Lloyd and Mikulecky (1998a) noted that in the banking industry:

> mathematics was usually called for to solve problems while gathering information from several sources, often requiring the use of technology (i.e., computer or calculator), and with a good deal of speed and accuracy since customers were often waiting for answers to questions. (p.4)

Beyond banking, they observed four general types of numeracy in the workplace:

1. Calculation — where the context often determines the method used and sensible estimates are essential.
2. Measurement — requiring care and accuracy, and appreciation of tolerances.
3. Handling data — much computerised; e.g., printed graphs, charts, blueprints.
4. Problem-solving — including skills of co-operation such as explaining clearly, listening carefully, and reaching consensus.

In terms of actual worker skills, they found that:

> … only the most basic jobs are limited to the simple use of addition and subtraction … Some degree of form filling is called for in 70% of jobs and this often involves taking information from one source (e.g. a table, chart, or machine display) and performing some kind of calculation upon the information. … Much more typical of changing workplaces, however, are tasks … which call for problem-solving, setting up computations, gathering information from several sources, and estimating to check the reasonableness of answers. Researchers have consistently found the vast majority of workplace materials — manuals, memos, new product information, trouble-shooting directions — to be of high school or college level difficulty. (p.9)

Not surprisingly, there are many workers in the USA whose numeracy skills fall far below acceptable levels in any given lower-level occupational category. Even though there has been no equivalent survey to the National Adult Literacy Survey (National Center for Educational Statistics 1993, cited in Lloyd & Mikulecky 1998a), it may be surmised that this is also the case in Australia.

Another workplace numeracy study in the USA was conducted by Smith (1999). In the automobile manufacturing industry, spatial and geometric reasoning, including visualisation, and problem-solving are essential skills. He observes that:

- Mathematical work in manufacturing is tool rich. Workers who are thinking mathematically use manual and digital tools to measure, compute, represent, or program.
- Numbers and computations come from measuring physical quantities that really matter in production.
- Workers need to know the conceptual qualities of averages in times of problematic data.
- Assembly work does not require 'more mathematics' but mathematics that is used and interpreted in context.
- Some high-volume sites directly involve production workers in improving productivity and quality. When the level of workers' responsibility increases, so does the range and sophistication of the mathematics required. Similarly for workplaces that produce small numbers of precision parts and tools for high volume assemblers. Almost no room for error exists in setup.

Wedege (2002) postulates five working hypotheses for the study of semi-skilled workers:

> 1. In every semi-skilled job, problems arise that can only be solved by quantification and use/evaluation of quantitative units.
> 2. Tasks and functions of semi-skilled workers require relatively simple formal skills and understanding in mathematics, but, informally, they are developed in complex working situations.
> 3. There are systematic differences between mathematics in the workplace and mathematics in traditional teaching.
> 4. While semi-skilled workers think mathematics is very important in the labour market, they do not regard mathematics as something of personal relevance to them.
> 5. Semi-skilled workers are not conscious of their mathematics activities in their daily work and, thus, of their 'mathematical' competence. This awareness only appears in a situation where there is a job they *cannot* manage due to their *lack* of mathematics skills. (p.25)

Steen (2001), referring to the 1991 SCANS report, notes that:

> problems in which mathematical expertise may be helpful do not come with course labels attached. … Some performance expectations that require mathematical competence are identified as "basic" skills (e.g., arithmetic, estimation, graphs and charts, logical thinking, understanding chance) and others as "thinking" skills (e.g., evaluating alternatives, making decisions, solving problems, reasoning, organizing, planning). Many fall under one or more advanced "competencies" involving resources (allocating time, money, material, and human resources), information (acquiring, evaluating, organizing, maintaining, interpreting, communicating, and processing), systems (understanding, monitoring, improving, and designing) and technology (selecting, applying, maintaining, and troubleshooting).

Wake and Williams (2001) observed workers at eleven sites in the company of college students in order to discuss with workers the mathematical practices identified by the workers themselves. They found that there were two main mechanisms that served to ensure workplace competence. These were the use of particular tools or artefacts to reduce the cognitive load, and the division of labour where social structures supported individuals and teams.

In summary, reports of workplace numeracy/mathematics suggest that the skills required are not necessarily to be found high up in school curricula; rather they are often regarded as 'basic' or high-school level, but are applied in complex ways to ill-defined and ever-evolving problems which themselves may not be inherently mathematical. I wish to argue that in order for workers to participate meaningfully in the many and varied discourses of the workplace—and in other social and civic problem solving and decision-making processes—they need a strong foundation in certain forms of mathematical thinking in order to be able to communicate across boundaries. Clearly, mathematical skills and knowledge developed in school and in vocational education play an important underpinning role in workplace numeracy practices.

Curricular and pedagogical implications

In this section some of the issues arising for school and Vocational Education and Training (VET) curriculum developers from the numeracy demands experienced by adults in the workplace are reviewed. A selection of the literature on workplace learning is then reviewed. This is followed by a brief discussion of mathematics/numeracy learning principles relevant to the workplace.

Issues for schools and VET

For workers to be able to achieve maximum benefit from workplace learning, attention needs to be paid to school and VET curricula and teaching methodologies. It is in these institutions that adult workers will have gained their underpinning mathematical competence and developed their attitudes and reactions to both learning and mathematics.

Arguing for a 'functional mathematics' curriculum, Forman and Steen (1999) suggest that

> … functional mathematics provides much greater emphasis on "systems thinking" — on habits of mind that recognize complexities inherent in situations subject to multiple inputs and diverse constraints. Examples of complex systems abound — from managing a small business to scheduling public transportation, from planning a wedding to reforming social security. At all levels from local to national, citizens, policymakers, employees, and managers need to be able to formulate problems in terms of relevant factors and design strategies to determine the influence of those factors on system performance. Although such systems are often so complex that they obscure the underlying mathematics, the skills required to address realistic programs very often include many that are highly mathematical. (p.12)

This stress on systems thinking resonates with the NBEET/ESC (1996) Australian study. Forman and Steen (1999) also provide multiple examples of mathematics in life and work, encompassing statistical quality and process control, computer-based technologies such as spreadsheets and CAD/CAM, stocking and storage problems requiring systems thinking, and cost comparison and risk evaluation.

Steen (2001) has made a series of recommendations for school mathematics of the 21st century which might well be heeded by designers of adult numeracy and vocational mathematics curricula. Steen's suggested curriculum would illustrate to learners the connection between mathematics and adult numeracy by making explicit how the mathematical skills being learned may be used in everyday life and work. In Steen's proposal:

- Mathematics would be presented in contexts that make sense to the learner. For example, commonly used topics such as data, graphs, and logical analysis would be stressed as much as formulas and algorithms so that students see mathematics as a tool for everyday decisions.
- Interdisciplinary applications would show the relevance of mathematics in real-world situations and students would understand how mathematics is important in other subject areas and in future careers.
- All school subjects would reinforce the role of quantitative thinking as a tool for discovering and verifying insights that are relevant to other school subjects.

- ✧ By emphasizing problem solving and reasoning skills, mathematics instruction would better prepare students to deal with unfamiliar situations.
- ✧ By learning how to ask questions and demand clarity in explanations, students would develop autonomy in reasoning.
- ✧ Mathematical and quantitative skills would be linked to literacy in ways that enhance students' abilities to communicate about technical subjects.

In terms of vocational mathematics, Wake and Williams (2001) identified seven general mathematics competences for vocational students. These are costing a project, handling experimental data graphically, interpreting large data sets, using mathematical diagrams (including plans or scale drawings), using models of direct proportion, using formulae and measuring. In order to better prepare pre-vocational students as future workers, they make the following observations and suggestions:

1. Given the noticeable use of relatively 'low level' mathematics used in quite complex situations and contexts, formal education curricula should emphasise the development of these skills.
2. Given the historical development of mathematics curriculum and assessment, students are generally unaware of 'non-standard' uses of mathematics. Curriculum and assessment in formal education should encourage experiences of a diversity of conventions and methods.
3. Given that the whole process of workplace activity shapes the process and meaning of the mathematics, students in formal classrooms should be able to experience activities where the mathematics is embodied in context and to use artefacts with which they have become familiar.
4. Given that students are required to transform their existing mathematical knowledge to make sense of activities in unfamiliar workplace situations, they should be prepared for this process in formal education.
5. Given that many workers actually design spreadsheet programmes in the workplace for modelling and for the recording, processing and analysis of data, students should have experience of this in formal education.
6. Given that the mathematical activity in the workplace is often addressed and solved successfully by a range of methods, including 'non-standard' methods, students in formal education should be aware that there are many and varied ways to solve any problem.

Wake and Williams (2001) concluded that vocational education students should be set 'more challenging tasks which require them to 'inquire', to work out how others use mathematics (e.g. in work contexts) and to develop problem solving skills as well as mathematical resources and confidence' (p.41).

Appelrath (1985 translated by Straesser, and cited in Sträßer & Zevenbergen 1996) quote a VET teacher trainer who identifies the critical function of mathematics in vocational education:

> mathematics in vocational education serves more as background knowledge for explaining and avoiding mistakes, recognizing safety risks, judicious measurement and various forms of estimation…. Not practice at the workplace but deepening of the professional knowledge, education for a responsible use of tools and machines and the understanding of and coping with everyday mathematical problems legitimizes mathematics in vocational education. (p.606)

In summary, school and VET sector mathematical and numeracy curricula are laying crucial groundwork for the future attitudes and confidence that workers will display towards the numeracy demands of their jobs and need to be developed with this in mind.

Research on workplace learning

Onstenk (1999) differentiates between learning on the job and on-the-job training. The former is not structured by specific pedagogical activities but by characteristics of the work itself, affording opportunities (or not) for learning dependent on whether the work situation constitutes a learning environment. He asserts that the likelihood of learning processes occurring in a particular job situation will depend upon: (a) the available skills and learning abilities of the employee, (b) the employee's willingness to learn, (c) the on-the-job learning opportunities, (d) the availability of on-the-job training, and (e) the relationships and mutual influences of all of these. Both the job content and the work environment can open up learning possibilities, according to Onstenk, however tensions may be experienced between work objectives and the achievement of qualifications and learning by workers. He notes that 'management often still lacks an imagination for an integration of work and learning' (p.14).

Billett, Cooper, Hayes, and Parker (1997) consider the issues of workplace learning as an alternative or complement to learning in institutional settings, noting that the changing nature of work is demanding the ability to go beyond the routine and predictable. According to Billett et al., the strengths of workplace participation, in offering the possibility of authentic vocational experiences, include 'goal-directed activities that press workers into learning which extends and reinforces their knowledge' (p.9) as well as experiences which offer engagement in routine problem-solving. The limitations of workplace participation are that:

- not all forms of knowledge accessed in workplaces are desirable [or appropriate]
- access to authentic problem solving of an increasingly complex nature is not always available
- access to expert others is limited by availability and credibility and reluctance
- expertise is sometimes absent
- knowledge is possibly hidden (opaqueness)
- [there could be an] over-reliance on instructional media. (p.48)

Regardless of how authentic institutional education tries to be it is always removed to some degree from the exigencies of the workplace. Workplace learning, however, often requires considerable time as the knowledge and skills to be acquired are significant. As Billett et al. note, both trades and professions have mandated extensive periods of workplace experience as a requirement to develop vocational knowledge.

O'Connor (1994) recommends that the designers of educational programmes consult with those worker/learners who know most about the detailed and intimate workings and requirements of the particular context layer. The notion of workers as 'unskilled' needs to be consciously and explicitly rejected and according to O'Connor:

> educational interventions need to start from a premise of existing skills, knowledge and ability, if they are to use those skills to assist in the development and the acquisition of new skills and knowledge. There is an increasing body of research which acknowledges and respects the fact that everyday or routine tasks or job performance reveal a deeper set of understandings of the complexity (physically or cognitively) of skills and knowledge brought to bear in the performance of work. (p.278)

He continues that ethnographic studies 'emphasise that the nature of work itself is collective, and almost always requires the informal collective interaction and action among individuals' (pp.281-282). The communal model which operates has greater depth than any individual knowledge base; the group develops a communal memory of problems and solutions, and provides assistance to individuals — a valuable and relevant learning asset.

Brown (1998) includes among critical learning processes the encouragement of workers to reflect upon their own learning, to see beyond the surface level, and to see their own practice as continually developing rather than 'the acquisition of a fixed body of knowledge or a set of immutable competencies' (p.169). He recommends techniques to develop thinking skills, while noting the barriers imposed by the failure of other workplace personnel (in the UK, at least) to value these new techniques and problem solving skills. He also stresses the importance of learner independence, teamwork and other collaborative learning, the linking of learning and assessment practices, and the development of a substantive knowledge base. The latter is fundamental to high level expertise and goes beyond the current requirements underpinning current occupational competence in order to inform future learning.

For effective work-based learning, Brown (1998) supports Billett et al.'s (1997) claim that there is no one best context of learning, nor an optimal mix between specialist expertise and broader vocationally oriented knowledge or on the job versus off the job training. The environment needs to be challenging and varied, and a balance needs to be struck between learning for work and learning through work — especially when the work is undemanding. One positive aspect suggested by Brown is that work-based learning has the potential, especially through group projects, to address a range of issues (including quality control) not currently carried out due to limitations such as time and money). There are documented case studies of these theories in practice in the Australian automotive industry (e.g., Sefton, Waterhouse, & Deakin 1994; Sefton, Waterhouse, & Cooney 1995; Waterhouse 1996). Mathematical knowledge and skills are totally integrated into the programme of work-based learning, with successful outcomes for a range of workers including workers from non-English speaking backgrounds.

Loo (2004) argues that much has been written about the relationships between learning styles and learning preferences with the aim of tailoring teaching methods to the ways that students prefer to learn. However, in a study examining the relationships between Kolb's (1984) four learning styles and four learning types, and twelve different learning preferences, only three significant relationships were found. Overall, there appeared to be only weak linkages between learning styles and learning preferences. Loo therefore recommended that educators use a variety of learning methods and encourage students to be receptive to different learning methods, rather than try to link specific learning methods to specific learning styles.

Transfer of skills between contexts

There has been considerable discussion and research on how easily learners can transfer skills learned and used in one context to another context. As argued above, mathematical skill underpins but does not equate to numeracy in the workplace. Consequently, this issue of skill transfer has significant implications for educators in relation to assumptions made both about the transfer of mathematical skills into workplace numeracy and about the ability of workers to deal with the different numeracy demands of different roles or tasks. Skill transfer is of particular relevance in the competency based training environment, in which such transfer tends to be represented as relatively unproblematic.

Discussing transfer of mathematical skills between contexts from an empirical perspective involving a study of year 10 students, Misko (1998) notes that:

> The major finding in this study is that transfer can generally occur if the skill has been learnt to a proficient level in the first place. That is, transfer is produced by better skill acquisition. This is a heartening finding for teacher and trainers. … (p.298)

Discussing the issue of transfer from a sociocultural perspective, Billett (1998) suggests that:

> vocational knowledge has its genesis in different levels of social development, each with its own characteristics and potential for transfer. In current vocational curriculum frameworks, goals for vocational education often relate to the disembedded socio-cultural level of knowledge, yet there is an expectation of that knowledge being transferable across communities of practice, such as workplaces with their own sets of embedded norms and values. Yet, not only are these communities distinct, but that transfer is from one type of community of practice to another (e.g., a workplace to a particular classroom). This makes the prospect of transfer across different kinds of settings 'far' (transfer to circumstances which are novel), something which does not readily happen. (p.1)

Billett (1996) makes a series of general recommendations for educators to aid in transfer, including: enhancing connections, assisting students to embed and disembed knowledge, encouraging reflective learning, and utilising authentic experiences.

Collins and Coleman (2002) suggest that problems with transfer may arise from the situated learning perspective which holds that training should occur in a particular context in order to be transferable — for example, through apprenticeship or practicum models. They draw attention to criticisms that situated learning may fail to help learners develop critical thinking abilities and to take account of mastery. To overcome these criticisms as well as issues of disruption to work routines and productivity, including the dangers of placing inexperienced workers in unsuitable situations, they recommend the use of simulation techniques. Ideally, such training would prepare students to be flexible and to be aware that variability will be present in the real workplace (pp.9-10).

Drawing on activity theory (Engeström, 1987, 2001) Kanes (2002) observes that 'numerical knowledge is 'generic' in so far as it is an outcome of [the] activity system of numeracy. However, it is 'site-specific' to the extent that it affords the construction of numerical tools within a site-specific activity' (p.40). Rather than numerical knowledge flowing between different activities, Kanes concludes that this projection of numerical tools into the site-specific activity leads to the 'transformation' of generic numeracy and the 'generation' of site-specific numeracy.

In line with Engeström's (1987, 2001) concept of expansive learning, Griffiths and Guile (2003) express the following ideas about learning associated with work:

1. … context (i.e. the historical organisation of curricula and work), and therefore the access provided in different contexts to artefacts and people, influences learning.
2. … learning through work experience involves mediating the relationship between different kinds of knowledge and experience developed in school and work (i.e. theoretical and everyday).
3. …opportunities to participate in forms of social practice, for example, using context-specific language to clarify understanding and resolve problems associated with different workplace 'communities of practice' are central to learning through work experience.
4. … work experience should assist learners and educators to create new knowledge and new educational and workplace practices. (pp.58-59)

They also raise questions as to whether learners in work experience programmes are supported to:

1. Understand and use the potential of subjects as conceptual tools for seeing the relationship between their workplace experience and their programmes of study as part of a whole?
2. Develop an intellectual basis for criticising existing work practices and taking responsibility for working with others to conceive, and implement where possible, alternatives?
3. Develop the capability of resituating existing knowledge and skill in new contexts as well as being able to contribute to the development of new knowledge, new social practices and new intellectual debates?
4. Become confident about crossing organisational boundaries or the boundaries between different, and often distributed, communities of practice?
5. Connect their knowledge to the knowledge of other specialists, whether in educational institutions, workplaces or the wider community? (p.59)

Griffiths and Guile (p.61) elaborate on one of the main characteristics of boundary crossing as involving a process of 'horizontal development'. 'Learners have to develop the capability to mediate between different forms of expertise and the demands of different contexts, rather than simply bringing their accumulated vertical knowledge and skill to bear on the new situation.' Following the work of Engeström, Griffiths and Guile distinguish between different types of boundary crossing: (a) carrying out a known activity in a new context; (b) 'individuals and groups using the problems which arise while undertaking a task as the basis for developing a new pattern of activity and new knowledge, polycontextual knowledge, in a new context' (p.61).

In summary, there is no definitive statement on the optimal site of learning for work, nor on whether specialist or generalist expertise is needed. Linear, hierarchical models of curriculum, unrelated to students' lives, do not appear satisfactory. The research points to integrated curricula, problem-based pedagogies, and the need for the development of skills of communication and reflection, as well as thinking and transfer skills. Workplace learning may be intended to enhance the knowing of workers both subjectively and objectively, so that as individuals they may be empowered as 'knowledge producers' as well as 'knowledge consumers' — that is, to be technologically, socially, and/or democratically numerate (in the broadest sense of the term, cf., 'literate').

Mathematics and numeracy education in the workplace

Noss, Hoyles, and Pozzi (2000) identify an assortment of methods and algorithms used in three diverse professions (banking, commercial aviation, and nursing), including 'tricks of the trade,' which were quick and efficient at achieving particular workplace goals. Some of the practices match with their recognised professional textbook methods, others differ. In increasingly computerised workplaces, Noss (1997) asserts that people need to gain access to underlying models; for this they need tools (e.g., graphs, variables, parameters) and means of expression (e.g., numerical, algebraic, geometric tools). He concludes that new cultures of work are redefining the boundaries for mathematics education towards holistic approaches rather than teaching sets of isolated skills.

While on the surface it appears that fewer and fewer mathematical skills are needed in a technological society, the ability to critically evaluate their uses requires greater sophistication. Modern computer technology plays a dual role in the process of using mathematics in the workplace (Noss 1997; Straesser 1998). The use of sophisticated software hides the mathematics and speeds up its disappearance, yet 'the very same technology can be used to foster understanding of the professional use of mathematics by explicitly modelling the hidden mathematical relations and offering software tools to explore and better understand the underlying mathematical models' (Straesser 1998, p.434).

Noss (2002) believes that in the knowledge economy of the 21st century the competence in constructing, interpreting and critiquing models has become a core part of social and professional life. His (and his colleagues') research has shown that:

> a person's mathematical knowledge is not invariant across time and space; it is transformed into different guises, different epistemologies, more or less visible as mathematics. This transformation seems much more powerful than the traditional notion of "application" or "use" that is often employed as a metaphor to describe the process. (p.59)

Noss also stresses the importance of mathematical models in relation to the increased number of people who need to understand the system they are using (cf., Engeström 1987). He concludes that 'the analysis of mathematics in work concerns the transformation of knowledge as it is recontextualized across settings' (p.59). Of course, this requires the mathematical knowledge or the opportunity for learning it to be present. It cannot be assumed that any worker, even with Year 12 mathematics has developed useable mathematics in school. Personal experiences over twenty years of vocational teaching suggests that, for many, the skills may have been learned in isolation, making transfer problematic. The end result is that common sense in relation to realistic answers, or even the production of reasonable estimates, is frequently lacking.

Reflective thinking is required for numeracy. To develop such reflective thinking, Keitel, Kotzmann, and Skovsmose (1993) propose starting from a meaningful problem context, where 'mathematical concepts, theoretical frameworks and modelling activities should be used to become able to understand the problem, formulate alternative solutions and negotiate with others about their acceptability' (p.275). This starting point accords well with Onstenk's (2001) problem-based model of developing broad occupational competence. Although their work was not focused on the workplace but the school classroom, the following summary by Keitel, Kotzmann, and Skovsmose (1993) may be closely compared with findings about mathematics in, and for, the workplace. For example, it shows strong resonance with the work of Kanes (1997b, p.269), in terms of contingency, specificity, and creativity of knowledge — also with Bernstein's (2000) conception of horizontal discourse in the form of workplace numeracy.

> The knowledge produced within and for the local environment is not only a reconstruction of existing knowledge but is partly and potentially "new" knowledge. It may provide information on issues which were not available so far. This gives a special and additional value to this produced knowledge.
>
> The knowledge is specific knowledge generated in specific contexts. It is potentially valid in this context but not necessarily in other contexts. . . . It could have a generalising potential which should be explicated and evaluated.
>
> The knowledge is potentially useful for a specific audience. If access is provided to others it may increase their ability to understand their social situations and to cope with certain demands as well.
>
> For the students the generation of locally useful knowledge implies an integration of experience-based judgement with generally available and other forms of socially valuable knowledge. (pp.275-276)

In the quotation above the emphasis is on learners (or workers in our case) as knowledge producers — a far cry from the experience of many people in school and vocational mathematics classes merely as knowledge consumers.

According to Coben (2003), the nature of adults' contexts — their possibilities and constraints — needs to be made prominent and integral to the process of teaching; adult numeracy teacher education needs to be informed by a broader concept of numeracy which connects adults' numerate practices with their thoughts and feelings about mathematics — its nature, purpose, and meaning. In FitzSimons (2001a) I draw upon the work of Giroux to work towards enabling adult and vocational education students and educators to address representational practices that have the discursive power to construct common sense and textual authority in mathematics education. Wedege (1999) explores adults' blocks and resistances to learning mathematics, arguing that adults' perceptions that they have managed their lives up until now quite adequately could cause resistance to the idea of further mathematical education. This is clearly a major issue in workplaces where occupational health and safety issues are at stake.

In FitzSimons (2001b) an attempt to integrate mathematics, statistics, and technology in vocational and workplace education is outlined. In the workplace mathematics and statistics are essential for communication and decision-making, and process workers at lower classifications of skill levels are likely to be confronted with statistical charts and warnings about non-conformity. Some ways in which to address the challenge of making mathematics, statistics, and technology education take on real meaning within the context of the workplace are described and highlighted that show how it is possible for mathematics educators to work in co-operation with industry, particularly at the local level, in a way that will encourage and support lifelong learning yet remain critical of the uses to which mathematics, statistics, and technology are put.

Van Groenestijn (2002, p.303) uses seven generally accepted andragogical starting points for adult education to conclude that 'learning mathematics in ABE (Adult Basic Education) must focus on math-as-a-tool and hence on learning-for-doing and learning-by-doing, i.e., learning –in-action.' However, she cautions against total reliance on these methods 'because of the risk that such functional knowledge and skills may also yield context-bound and partial knowledge and skills.'

Van Groenestijn identifies six steps in problem solving which also enable adults to analyse their own ways of learning. She distinguishes three elements:

1. Through problem solving learners become aware of [the] *learning process* itself *(what)*
2. During problem solving learners may want to emphasize the *quality* of their learning *(why)*
3. When doing problem solving learners learn how to *organize* the learning process. *(how)* (p.304)

She argues that problem-based learning offers the possibility of creating learning situations in which mathematical concepts and actions are integrated. Adults are encouraged to create their own ways of solving problems as well as developing their own notational systems.

Finally, Lloyd and Mikulecky (1998b) adopt a functional analytical approach to numeracy education for the workplace. They recommend task analysis, including interviewing relevant personnel, observation of workers performing the relevant tasks (especially where there are difficulties), collection of artefacts, and custom-design of curriculum around those analyses. This, they claim, should ideally be followed by custom-designed evaluation—although their suggestion of pre- and post-tests is problematic—as discussed above—and likely to alienate workers, even contributing to any mathematics anxiety (see Coben 2003).

In summary, workplace numeracy education cannot be approached from a traditional 'school-mathematics'. Workplace numeracy education requires a fundamentally different curriculum and pedagogy from that of school mathematics. Such learning needs, however, to encompass underpinning mathematical knowledges and skills in ways that enable the generation of 'new' knowledge in order to solve problems which cannot always be known in advance.

Conclusion

In the first section of this literature review *Numeracy and its Relationship to Mathematics*, the contested concept of numeracy was explored by situating it in the Australian context, and then comparing various international definitions, surveys, and curricular expectations for adult learners. Coben's (2003) definition of numerate behaviour was nominated as being the most relevant to the topic at hand. However, it was recognised that the concept of numeracy can never be culture- or value-free.

The following section *Mathematics and Numeracy in the Workplace* reviewed a selection of recent studies into how mathematics and numeracy are used in the workplace, and identified the kinds of skills needed in different workplaces. The conditions of knowledge production are very different in formal sites of education and workplaces, and suggestions were made as to how teachers in formal educational settings may support workplace numerical practices.

The final section *Curricular and Pedagogical Implications* briefly reviewed a selection of the literature on research into workplace learning and participation and argued that the issue of transfer of skills is by no means unproblematic. The differences between the workplace and the institutional classroom which take the form of different activity systems were highlighted. In the former, the object is to complete a task as efficiently and effectively as possible. In the latter, the intended outcome is often to learn more about the subject itself. Clearly the conditions for teaching and learning numeracy are very different in these respective sites — even when a classroom lesson is designed to simulate the workplace, it can never completely capture the exigencies of actual practice. The analysis of the data collected from the chemical handling and spraying research project identifies some of these exigencies.

References

Australian Association of Mathematics Teachers [AAMT] 1997, *Final report of the Rich Interpretation of Using Mathematical Ideas and Techniques Key Competency Project*, Author, Adelaide.

Australian National Training Authority 2000, *Built in not bolted on* (revised ed.) [Available from the World Wide Web: http://www.anta.gov.au/]

Baker, D 1998, 'Numeracy as social practice', *Literacy & Numeracy Studies: An International Journal in the Education and Training of Adults*, vol.8, no.1, pp.37-50.

Bernstein, B 2000, *Pedagogy, symbolic control and identity: Theory, research, critique* (Rev. ed.). Lanham, MD: Rowman & Littlefield.

Billett, S 1996, 'The transfer problem: Distinguishing between sociocultural and community of practice', in *Learning and work: The challenges: 4th Annual International Conference on Post-Compulsory Education and Training Vol. 4*, Centre for Learning and Work Research, Griffith University, Brisbane, pp.21-36.

Billett, S 1998, 'Transfer and social practice', *Australian & New Zealand Journal of Vocational Education Research*, vol.61, pp.1-25.

Billett, S, Cooper, M, Hayes, S & Parker, H 1997, *VET policy and research: Emerging issues and changing relationships. A report for the Office of Training and Further Education, Victoria*, Office of Training and Further Education, Melbourne.

Bishop, AJ 1988, *Mathematical enculturation: A cultural perspective on mathematics education*, Kluwer Academic Publishers, Dordrecht.

Brown, A 1998, 'Designing effective learning programs for the development of a broad occupational competence', in *Key qualifications in work and education*, eds WM Nijhof and JN Streumer, Kluwer Academic Publishers, Dordrecht, pp.165-186.

Buckingham, EA 1997, *Specific and generic numeracies of the workplace: How is numeracy learnt and used by workers in production industries, and what learning/working environments promote this?* Centre for Studies in Mathematics, Science, and Environmental Education, Deakin University, Burwood, Vic.

Clements, MA (Ken) 2001, 'Forging links for more equitable and widespread mathematics education: The roles of schools and universities', in *Adult and life-long education in mathematics: Papers from Working Group for Action 6, 9th International Congress on Mathematical Education, ICME 9*, eds GE FitzSimons, J O'Donoghue, and D Coben, Language Australia in association with Adults Learning Mathematics – A Research Forum (ALM), Melbourne, pp.47-68.

Coates, S, Fitzpatrick, L, McKenna, A, & Makin, A 1995, *National reporting system*, Department of Employment, Education and Training, Canberra.

Coben, D 2001, 'Fact, fiction and moral panic: The changing adult numeracy curriculum in England', in *Adult and life-long education in mathematics: Papers from Working Group for Action 6, 9th International Congress on Mathematical Education, ICME 9*, eds GE FitzSimons, J O'Donoghue, and D Coben, Language Australia in association with Adults Learning Mathematics – A Research Forum (ALM), Melbourne, pp.125-153.

Coben, D 2002, 'Use and exchange value in discursive domains of adult numeracy teaching', *Literacy & Numeracy Studies*, vol.11, no.2, pp.25-35.

Coben, D (with Colwell, D, Macrae, S, Boaler, J, Brown, M and Rhodes, V), 2003, *Adult numeracy: Review of research and related literature*, National Research and Development Centre for Adult Literacy and Numeracy, London. [Available as PDF from www.nrdc.org.uk]

Cockcroft, WH (Chairman) 1982, *Mathematics counts: Report of the Committee of Inquiry into the Teaching of Mathematics in Schools*, Her Majesty's Stationery Office, London.

Collins, D & Coleman, H 2002, 'Transfer of learning', in *Learning for the future, proceedings of the Learning Conference 2001*, eds B Cope & M Kalantzis, Common Ground Publishing, Australia. Available at http://LearningConference.Publisher-Site.com/

Dawe, S 2002, *Focussing on generic skills in training packages*, National Centre for Vocational Education Research, Adelaide.

Department for Education and Employment [DfEE] 1999, *Improving literacy and numeracy: A fresh start*, DfEE, London. [Retrieved August 17, 1999 from the World Wide Web: http://www.lifelonglearning.co.uk/mosergroup.front.htm]

Department of Education and Science [DES] 2000, *Learning for Life: White Paper on Adult Education*, The Stationery Office, Dublin.

Department of Education, Training and Youth Affairs [DETYA] 2000, *Numeracy, a priority for all: Challenges for Australian schools*. [Retrieved March 15 2001 from the World Wide Web: http://www.detya.gov.au/schools/publications/numeracy.pdf]

Department of Employment, Education, Training and Youth Affairs [DEETYA] 1998, February, *Literacy and numeracy training for unemployed job seekers aged 18 to 24 years: A consultation paper.* [Retrieved August 24, 1998 from the World Wide Web: http://www.deetya.gov.au/mot/litnum.htm, last updated November 2, 1998.]

Ellström, P-E 1998, 'The many meanings of occupational competence and qualification', in *Key qualifications in work and education*, edsWM Nijhof and JN Streumer, Kluwer Academic Publishers, Dordrecht, pp.39-50.
Engeström, Y 1987, *Learning by expanding An activity-theoretical approach to developmental research*, Orienta-Konsultit, Helsinki. [Retrieved February 20, 2003, from the World Wide Web http//lchc.ucsd.edu/MCA/Paper/Engeström/expanding/toc.htm]
Engeström, Y 2001, 'Expansive learning at work: Toward an activity-theoretical reconceptualization', *Journal of Education and Work*, vol.14, no.1, pp.133-156.
Evans, J 2000, *Adults' mathematical thinking and emotions: A study of numerate practices*, Routledge Falmer, London.
Fairclough, N 2000, *New Labour, new language?* Routledge, London.
Falk, I & Millar, P 2001, *Review of research: Literacy and numeracy in vocational education and training*, National Centre for Vocational Education Research, Adelaide.
FitzSimons, GE 2000, 'Lifelong learning: Practice and possibility in the pharmaceutical manufacturing industry', *Education & Training*, vol.42, no.3, pp.170-181.
FitzSimons, GE 2001a, 'Generating notions of democratic citizenship in adult and vocational education', in *Knowledge demands for the new economy Proceedings of the 9th Annual International Conference on Post-Compulsory Education and Training, Vol 1*, eds F Beven, C Kanes, and D Roebuck, Centre for Learning and Work Research, Griffith University, Brisbane, pp.231-238.
FitzSimons, GE 2001b, 'Integrating mathematics, statistics, and technology vocational and workplace education', *International Journal of Mathematics, Science, and Technology Education*, vol.32, no.3, pp.375-383.
FitzSimons, GE 2002, *What counts as mathematics? Technologies of power in adult and vocational education*, Kluwer Academic Publishers, Dordrecht.
FitzSimons, GE, Coben, D & O'Donoghue, J 2003, 'Lifelong mathematics education', in *Second international handbook of mathematics education*, eds AJ Bishop, MA Clements, C Keitel, J Kilpatrick, and F Leung, Kluwer Academic Publishers, Dordrecht, pp.103-142.
FitzSimons, GE, Jungwirth, H, Maaß, J & Schloeglmann, W 1996, 'Adults and mathematics (Adult numeracy)', in *International handbook of mathematics education*, eds AJ Bishop, MA Clements, C Keitel, J Kilpatrick, and C Laborde, Kluwer Academic Publishers, Dordrecht, pp.755-784.
Forman, SL & Steen, LA 1999, *Beyond eighth grade: Functional mathematics for life and work.* (Research Report MDS-1241), University of California at Berkeley, National Center for Research in Vocational Education, Berkeley, CA.
Gal, I, Tout, D, van Groenestijn, M, Schmitt, MJ & Manly, M 1999, *Numeracy (working draft).* [Available http://www.alm-online.org/all Accessed 14 January, 2004]
Gillespie, J 2003, 'The national survey of numeracy in England. Findings, insights, reflection and implications' in *Learning mathematics to live and work in our world. Proceedings of the 10th International Conference on Adults Learning Mathematics*, eds J Maasz & W Schlöglmann, Universitätsverlag Rudolf Trauner, Linz, pp.102-109.
Griffin, P & Forwood, A 1991, *Adult literacy and numeracy competency scales: An International Literacy Year project,* Phillip Institute of Technology, The Assessment Research Centre, Melbourne.
Griffiths, T & Guile, D 2003, 'A connective model of learning The implications for work process knowledge', *European Educational Research Journal* vol.2, no.1, pp.56-73.
Habermas, J 1974) *Theory and practice*, J Viertel, Trans., Heinemann, London. (Original work published 1963)
Harris, M 1991, 'Looking for the maths in work', in *Schools, mathematics and work*, ed M Harris, Falmer Press, London, pp.132-144.
Hoyles, C, Wolf, A, Molyneux-Hodson, S, & Kent, P 2002, *Mathematical skills in the workplace. Final report to the Science, Technology and Mathematics Council. Foreword and executive summary*, Institute of Education, University of London: Science, Technology and Mathematics Council, London. [Retrieved January 27, 2004, from the World Wide Web: http://www.basic-skills-observatory.co.uk/uploads/doc_uploads/522.pdf]
Jablonka, E 2003, 'Mathematical literacy', in *Second international handbook of mathematics*, eds AJ Bishop, K Clements, C Keitel, J Kilpatrick, and F Leung, Kluwer Academic Publishers, Dordrecht, pp.75-102.
Kahane, J-P.1998, 'Mathematics and higher education between Utopia and realism', in *Justification and enrolment problems in education involving mathematics or physics*, eds J Højgaard Jensen, M Niss and T Wedege, Roskilde University Press, Roskilde, pp.75-87.
Kanes, C 1997a, 'An investigation of artifact mediation and task organisation involving numerical workplace knowledge', in *Good thinking — Good practice: Research perspectives on learning and work Proceedings of the 5th Annual International Conference on Post-Compulsory Education and Training Vol. 1*, Centre for Learning and Work Research, Griffith University, Brisbane, pp.79-91.

Kanes, C 1997b, 'Towards an understanding of numerical knowledge in the workplace', in *People in mathematics education Vol. 1*, eds F Biddulph and K Carr, Mathematics Education Research Group of Australasia, University of Waikato, NZ, pp.263-270.

Kanes, C 2002, 'Delimiting numerical knowledge' *International Journal of Educational Research*, vol.37, pp.29-42.

Kanes, C 2003, 'Developing numeracy', in *Developing vocational expertise: Principles and issues in vocational education*, ed J. Stevenson, Allen & Unwin, Sydney, pp.81-109.

Kearns, P 2001, *Review of research: Generic skills for the new economy*, National Centre for Vocational Education Research, Adelaide.

Keitel, C Kotzmann, E & Skovsmose, O 1993, 'Beyond the tunnel vision: Analysing the relationships between mathematics, society and technology', in *Learning from computers: Mathematics education and technology*, eds C Keitel and K Ruthven, Springer Verlag, Berlin, pp.243-279.

Klein, M 1998, 'New knowledge/new teachers/new times: How processes of subjectification undermine the implementation of investigatory approaches to teaching mathematics', in *Teaching mathematics in new times, Vol 1*, eds C Kanes, M Goos and E Warren, Mathematics Education Research Group of Australasia, Griffith University, Brisbane, pp.295-302.

Klein, M 2000, 'Is there more to numeracy than meets the eye? Stories of socialisation and subjectification in school mathematics', in *Mathematics education beyond 2000. Proceedings of the 23rd Annual Conference of the Mathematics Education Research Group of Australasia, Vol. 1*, eds J Bana and A Chapman, Mathematics Education Research Group of Australasia, Perth., pp.72-78.

Klein, P D 2003, 'Rethinking the multiplicity of cognitive resources and curricular representations: Alternatives to 'learning styles' and 'multiple intelligences'', *Journal of Curriculum Studies, vol.* 35, no. 1, pp.45-81.

Knijnik, G 1997 'Mathematics education and the struggle for land in Brazil', in *Adults returning to study mathematics: Papers from Working Group 18, 8th International Congress on Mathematical Education, ICME 8*, ed GE FitzSimons, Australian Association of Mathematics Teachers, Adelaide, pp.87-91.

Knijnik, G 1998, 'Ethnomathematics and political struggles' *Zentralblatt für Didaktik der Mathematik*, vol.5/98, pp.186-192.

Kolb, D A 1984, *Experiential learning*, Prentice-Hall, NJ.

Lave, J 1988, *Cognition in practice: Mind, mathematics and culture in every day life*, Cambridge University Press, Cambridge.

Lesh, R 2000, 'Beyond constructivism: Identifying mathematical abilities that are most needed for success beyond school in an age of information', *Mathematics Education Research Journal*, vol. 12, no. 3, pp.177-195.

Lindenskov, L & Wedege, T 2001, *Numeracy as an analytical tool in mathematics education and research*, Roskilde University, Centre for Research in Learning Mathematics, Roskilde.

Lloyd, P & Mikulecky, L 1998a, *Numeracy in the workplace. A comparison of skill demands and skill levels.* [Available from ERIC online database, ED 431 107.]

Lloyd, P & Mikulecky, L 1998b, *Numeracy in the workplace. Numeracy skills for workplace needs.* [Available from ERIC online database, ED 431 107.]

Loo, R 2004, 'Kolb's learning styles and learning preferences: Is there a linkage?', *Educational Psychology*, vol. 24, no. 1, pp.99-108.

Magajna, Z & Monaghan, J 2003, 'Advanced mathematical thinking in a technological workplace', *Educational Studies in Mathematics*, vol.52, no.2, pp.101-122.

Masingila, J 1993, 'Learning from mathematics practice in out-of-school situations', *For the Learning of Mathematics*, vol.13, no.2, pp.18-22.

Mayer, E Chair 1992, *Report of the Committee to advise the Australian Education Council and Ministers of Vocational Education, Employment and Training on employment-related Key Competencies for post-compulsory education and training*, AEC & MOVEET, Melbourne.

Misko, J 1998, 'Do skills transfer? An empirical study', in *VET research: Influencing policy and practice. Proceedings of the first national conference of the Australian Vocational Education and Training Research Association*, eds J McIntyre & M Barrett, Australian Vocational Education and Training Research Association, Sydney, pp. 289-300.

National Board of Employment, Education and Training/Employment and Skills Council 1996, *Education and technology convergence: A survey of technological infrastructure in education and the professional development and support of educators and trainers in information and communications technologies, Commissioned Report No. 43*, Australian Government Publishing Service, Canberra.

Niss, M 1994 'Mathematics in society', in *Didactics of mathematics as a scientific discipline*, eds R Biehler, RW Scholz, R Strässer and B Winkelmann, Kluwer Academic Publishers, Dordrecht, pp.367-378.

Norton Grubb, W 2002, *Exploring "multiple mathematics".* [Retrieved August 9, 2002, from the World Wide Web: http://www.stolaf.edu/other/extend/Expectations/grubb.html]

Noss, R Hoyles, C & Pozzi, S 1998, *ESRC end of award report: Towards a mathematical orientation through computational modelling project*, Mathematical Sciences Group, Institute of Education, University of London, London.
Noss, R 1997, *New cultures, new numeracies,* Inaugural professorial lecture, Institute of Education, University of London, London.
Noss, R 2002, 'Mathematical epistemologies at work', Plenary Lecture in *Proceedings of the 26th conference of the International Group for the Psychology of Mathematics Education Vol. 1*, eds AD Cockburn and E Nardi, University of East Anglia, School of Education and Professional Development, Norwich, pp.47-63.
Noss, R & Hoyles, C 1996a, 'The visibility of meanings: Modelling the mathematics of banking', *International Journal of Computers for Mathematical Learning*, vol.1, no.1, pp.3-31.
Noss, R & Hoyles, C 1996b, *Windows on mathematical meanings: Learning cultures and computers*, Kluwer Academic Publishers, Dordrecht.
Noss, R, Hoyles, C & Pozzi, S 2000, 'Working knowledge: Mathematics in use', in *Education for mathematics in the workplace*, eds A Bessot and J Ridgway, Kluwer Academic Publishers, Dordrecht, pp.17-35.
Noss, R, Pozzi, S & Hoyles, C 1999, 'Touching epistemologies: Meanings of average and variation in nursing practice', *Educational Studies in Mathematics*, vol.40, no.1, pp.25-51.
Numeracy Working Group 1999, 'Numeracy and the International Life Skills Survey', *Adults Learning Mathematics Newsletter*, vol.6, pp.1-3.
O'Connor, P 1994, 'Workplaces as sites of learning', in *Thinking Work: Vol 1 Theoretical perspectives on workers' literacies*, ed P O'Connor, ALBSAC, Sydney, pp.257-295.
O'Donoghue, J 2000, 'Assessing numeracy', in *Perspectives on adults learning mathematics: Research and practice*, eds D Coben, J O'Donoghue and GE FitzSimons, Kluwer Academic Publishers, Dordrecht, pp.271-287.
OECD/PISA 2002, *Programme for International Student Assessment.* [Retrieved April 15, 2002, from the World Wide Web: http://www.pisa.oecd.org/math/def.htm]
Onstenk, J 1998, 'New structures and new contents in Dutch vocational education', in *Key qualifications in work and education*, eds WJ Nijhof and JN Streumer Kluwer Academic Publishers, Dordrecht, pp.117-132.
Onstenk, J 1999, August, *Competence development and learning at work.* Paper contributed to the European Association for Research in Learning and Instruction (EARLI 1999) symposium, Learning and Working, Göteborg, Sweden.
Onstenk, J 2001, 'Broad occupational competence and reforms in vocational education in the Netherlands', *Australian and New Zealand Journal of Vocational Education Research*, vol.9, no.2, pp.23-45.
Pozzi, S, Noss, R & Hoyles, C 1998, 'Tools in practice, mathematics in use', *Educational Studies in Mathematics*, vol.36, no.2, pp.105-122.
Ritter, J 1989, Nov, 'Ancient Egypt and Mesopotamia: Prime numbers', *The UNESCO Courier,* vol.11 (A mathematical mystery tour), pp.12-17.
Sanguinetti, J, & Hartley, R 2000, *Building literacy and numeracy into training A synthesis of recent research into the effects of integrating literacy and numeracy into training packages*, Adult Literacy and Numeracy Australian Research Consortium, Melbourne.
Sefton, R, Waterhouse, P & Cooney, R 1995, *Workplace learning & change: The workplace as a learning environment*, Automotive Training Australia, Melbourne.
Sefton, R, Waterhouse, P & Deakin, R eds 1994, *Breathing life into training: A model of integrated training*, National Automotive Industry Training Board, Melbourne.
Smith, JP,III 1999, 'Preparing students for modern work: Lessons from automobile manufacturing', *The Mathematics Teacher*, vol.92, no.3, pp.254-258.
Steen, LA 2001, 'Mathematics and numeracy: two literacies, one language', *The Mathematic Teacher*, Singapore. [Retrieved January 6, 2004, from the World Wide Web: http://www.stolaf.edu/people/steen/Papers/twolits.html]
Straesser, R 1998, 'Mathematics for work: A didactical perspective', in *8th International Congress on Mathematics Education: Selected lectures*, eds C Alsina, JM Alvarez, B Hodgson, C Laborde, and A Pérez, SAEM 'THALES', Sevilla, pp.427-441.
Sträßer, R, & Zevenbergen, R 1996, 'Further mathematics education', in *International handbook of mathematics education*, eds AJ Bishop, K Clements, C Keitel, J Kilpatrick & C Laborde, Kluwer Academic Publishers, Dordrecht, pp.647-674.
Teese, R 2000, *Academic success and social power*, Melbourne University Press, Melbourne.
Van Groenestijn, M 2002, A *gateway to numeracy. A study of numeracy in adult basic education*, CD β Press, Universiteit Utrecht, Utrecht.
Virgona, C, Waterhouse, P, Sefton, R & Sanguinetti, J 2003, *Making experience work: Generic skills through the eyes of displaced workers* (Vols. 1 & 2), National Centre for Vocational Education Research, Adelaide.

Wake, G & Williams, J 2001, *Using college mathematics in understanding workplace practice: Summative report of research project funded by the Leverhulme Trust*, The University of Manchester, Manchester. [Available as PDF from http://www.education.man.ac.uk/lta/publications/index.shtml]

Wake, GD, Williams, JS & Haighton, J 2000, 'Spreadsheet mathematics in college and in the workplace: A mediating instrument?', in *Proceedings of the 24th conference of the International Group for the Psychology of Mathematics Education Vol. 4*, eds T Nakahara and M Koyama, Hiroshima University, Hiroshima, pp.265-272.

Waterhouse, P 1996, 'Multiple tales for training', *Education Links*, vol.53, pp.4-8.

Watson, M, Nicholson, L & Sharplin, E 2001, *Review of research: Vocational education and training: Literacy and numeracy*, National Centre for Vocational Education Research, Adelaide.

Wedege, T 1999, 'To know — or not to know — mathematics, that is a question of context', *Educational Studies in Mathematics*, vol. 39, nos.1-3, pp.205-227.

Wedege, T 2000a, 'Mathematics knowledge as a vocational qualification', in *Education for mathematics in the workplace*, eds A Bessot and J Ridgway, Kluwer Academic Publishers, Dordrecht, pp.127-136.

Wedege, T 2000, 'Technology, competences and mathematics', in *Perspectives on adults learning mathematics: Research and practice*, eds D Coben, J O'Donoghue and GE FitzSimons, Kluwer Academic Publishers, Dordrecht, pp.191-207.

Wedege, T 2002, 'Numeracy as a basic qualification in semi-skilled jobs', *For the Learning of Mathematics*, vol.22, no.3, pp.23-28.

Wenger,E, McDermott, R & Snyder, W 2002, *Cultivating communities of practice: A guide to managing knowledge*, Harvard Business School Press, Boston Massachusetts.

Yasukawa, K, Johnston, B & Yates, W 1995, 'Numeracy as a critical constructivist awareness of Maths — Case studies from Engineering and Adult Basic Education' in *Regional collaboration in mathematics education 1995*, eds RP Hunting, GE FitzSimons, PC Clarkson, and AJ Bishop, Monash University, Melbourne, pp.815-825.

Zevenbergen, R 1996, 'The situated numeracy of pool builders', *Critical Forum*, vol.4, no.2, 34-46.

Analysis of rural/conservation common units of competency against the National Reporting System

An analysis of the numeracy demands of the Rural/Conservation common units of competency (developed by the Rural Training Council of Australia for the Australian National Training Authority) that relate to chemical spraying and handling at Australian Qualification Framework levels I, II and III was undertaken. Some additional units relating to chemical spraying and handling were also analysed. Numeracy demands are implied within the 'performance criteria' of these common units (directly stated in two 'performance criteria') and appear within 'range statements' and 'evidence Guides, specific knowledge and specific skills.' The analysis involved the identification of numeracy tasks and a mapping against the National Reporting System (NRS).

Common unit: *RTC 1701A Follow basic chemical safety rules*

This unit outlines the skills and knowledge required of a person working in an enterprise which uses chemicals. The worker needs to be aware of how chemicals are handled, stored and transported, the use of personal protection equipment and safety issues around chemical use.

A worker meeting the numeracy demands of this standard would be able to:

- locate and discuss specific numerical information from chemical labels (**NRS 1 - 2**)
- estimate sizes and use language of space for transport and storage of chemicals (**NRS 1)**
- count and record quantities (**NRS 1).**

AQF II

Common unit*: RTC 2706A Apply chemicals under supervision*

This unit outlines the skills and knowledge required of a person applying chemicals under supervision, to control weeds, pests and diseases, using application equipment specific to the workplace.

A worker meeting the numeracy demands of this standard would be able to:

- locate and select relevant numerical information from chemical labels and MSDS (**NRS 3)**
- measure metric quantities using simple measuring instruments **(NRS 2)**
- correctly measure volume of chemical to apply using jugs, scales etc (**NRS 3)**
- check settings and output of equipment eg nozzles, hoses, gauges, respirators, drench guns (**NRS 3 – 4 depending on equipment**)
- calculate time periods before work can continue in the area **(NRS 3)**
- record information including date, time, rates of application (**NRS 3)**
- use symbolism and conventions relevant to the task eg L/ha (**NRS 3)**

Additional units:

RTC 2401A Treat weeds

RTC 2404A Treat plant pests, diseases and disorders

These units of competency apply to a wider range of treatments which include both chemical and non-chemical solutions as part of an Integrated Pest Management (IPM) program. For the parts relating to chemical solutions, these units have the same numeracy demands as the core unit *RTC 2706A*.

AQF III

Common unit*: RTC 3704A Prepare and apply chemicals*

This unit of competency outlines the process of preparing and applying chemicals for the control of weeds, pests and diseases. A worker demonstrating competency against this unit would be able to prepare, apply and handle chemicals safely while working unsupervised within enterprise guidelines.

A worker meeting the numeracy demands of this standard would be able to:

- ♦ Read and interpret numerical information on chemical labels and MSDS (**NRS 3)**
- ♦ Calibrate equipment
  - -calculate metric quantities (**NRS 3)**
  - -use ratio and proportions to calculate mixing rates (**NRS 4)**
  - -convert between metric units (**NRS 4)**
  - -develop and use formulae which describe relationships between variables in familiar contexts (NRS 4)
  - -use a calculator to calculate amounts, rates etc (NRS 4)
  - -use developing estimation skills (**NRS 4)**
  - -interpret and apply test results (**NRS 4)**
  - -calculate output from particular machines/equipment (**NRS 4)**
  - -use area to calculate amount of chemical/ cost of required chemical (**NRS 4)**
  - -gather necessary information from external sources eg wind speed, humidity (**NRS 4)**
  - -examine and question the appropriateness of mathematical actions (**NRS 4)**
  - -compare results of anticipated outcomes to confirm results (**NRS 4)**
- ♦ Complete records eg date, time, amounts, rate, cost etc (**NRS 3)**

RTC 3705A Transport, handle and store chemicals

This unit of competency outlines the process of transporting, handling and storing chemicals safely without supervision.

A worker meeting the numeracy demands of this standard would be able to:

- ♦ Read and interpret numerical information on chemical labels and MSDS **(NRS 3)**
- ♦ Calculate the amount of chemical that can safely be transported in one load **(NRS 2)**

Additional units:

RTC 3401A Control weeds

RTC 3404A Control plant pests, diseases and disorders

These units of competency apply to a wider range of controls which include both chemical and non-chemical solutions as part of an Integrated Pest Management (IPM) program. For the parts relating to chemical solutions, these standards have the same numeracy demands as the common unit *RTC 3704A*, as well as further demands relating to the supervisory role.

The additional numeracy demands of this unit are:

- implement the spatial, logistical and quantitative requirements of the IPM program (**NRS 5)**
- calculate and record economic thresholds (**NRS 5).**

References

Coates, S, Fitzpatrick, L, McKenna, A, & Makin, A 1995, *National reporting system*, Department of Employment, Education and Training, Canberra.

Case studies

The case studies reported here constitute, in summary form, the empirical research for the study *Learning numeracy on the job for chemical sprayers*. The researchers visited 13 workplaces in the plant production, wine growing, outdoor recreation, chemical warehousing and local government industries at various times between 2003 and 2004.

Worksites/enterprises were chosen with the assistance of a project reference committee made up of industry representatives and numeracy education experts. The studies involved recording interviews (either by audio-tape or through rich note taking as the participants preferred), observing workplace spraying practices where possible, and collecting artefacts, in the form of records, measuring instruments, charts, ready-reckoners and tables.

Interview transcripts were signed off by participants.

Case study A

The enterprise

The workplace is an example of NSW rural production, a large single site orchard consisting of 700 acres of stone fruit cultivation. Overall, the orchard employs 18 permanent staff across areas such as packing, orchard maintenance, human resources, and marketing. The team that looks after the orchards and is involved in handling chemicals is made up of eight male workers. There are two owners, a male owner/manager with engineering mathematics skills, who finds the calculations 'simple' and 'logically thinking out a process', and his female partner, a pharmacist, who regards the maths used by workers as 'difficult'.

Total responsibility for day to day calculations is left to the chemical supervisor, although the initial workplace methods of calibration and calculation had been worked out by the owner/manager.

The study

The site visit took place at a time of severe weather conditions which precluded spraying operations and hence observation and which limited interviews to the two owners. Artefacts collected to support the interview process included a Calibration Record Sheet (which workers also date and file for future reference) and an example of a spray diary provided to the orchardist by a consortium of chemical producers and suppliers.

Critical tasks

The work undertaken at this large orchard is consistent with an enterprise that is very familiar with strict reporting procedures and adherence to quality assurance guidelines as stipulated by its main customer, which is one of the country's leading retail fruit and vegetable outlets. Therefore, posting accurate reports concerning calibration for chemical usage, plus individual daily work sheets, is not seen as an onerous task, but as a necessary part of everyone's day. The workers all follow the supervisor's calibration calculations, and these differ not just with the chemical used, but the area to be sprayed as well as the equipment used.

Using mathematics

An example from a workplace calibration record sheet has the following calibration table worked out by the supervisor, for workers to follow:

Table 1: Calibration

Tornado 3000L Sprayer	—	Kubota 8030 (tractor)
Nozzle output per 100m	—	66 Litres
Speed per 100m – 56 seconds	=	6.43km/hr
Volume rate	—	66 x 100 6m (row width)
Use 1ST gear high range (1700 revs)		
Use – Litres per Hectare	=	1100L

How numeracy is taught and learned in the workplace

The manager supports training for his workforce, all of whom have completed formal chemical use training, although only the supervisor works out calibration of chemical usage. Workers need to be able to interpret formulae and understand that the calibrations developed (for example Table 1) only relate to a specific situation. If any variable changes for example the tractor speed because of a change in the terrain, or nozzle output because of nozzle wear, then the calculations in the table would need to be re-done.

Case study B

The enterprise

A vineyard in rural Victoria. There is a spraying supervisor with one assistant, but the vineyard employs about 50 people on contract at vintage time.

The study

There was a semi-structured interview with the supervisor.

Critical tasks

The vineyard sprays for fungus, light brown apple moth, downy and powdery mildew, bunch rot, berry splitting and botrytis. Spraying takes place from October until the end of February, using 600L [air blaster] or 400L [boom sprayer] tanks, with boom sprayers for herbicides and air blasters for fungus.

Spraying tasks differ from broad acre because it is necessary to work out how many hectares are actually covered – the spray is applied only on vines, not broad areas such as pathways. There is a procedure in place 'a spray order' which gives information on the chemical/s used, the rate of spray, and the recommended dilution.

Each block of vines is coded according to grape variety and location with 2 alpha- and 2 numeric ciphers for easy identification. Some blocks are 6.75ha and others are 5.26ha. Each block has known hectares, number of vines, linear metres of vine length listed. A scaled map of the vineyard is used to work out the hectares, the linear measures and the row spaces; it also shows irrigation points. This is useful for contractors to work out 'per vine' ratios.

A linear metre is how long the row-length is. Vine rate is different from the label rate on sprays.

Using mathematics

As described by the supervisor, the basic unit of measurement is the tank size. This is an easy way to eliminate over-spraying as some of these chemicals can cost up to $150 per hectare.

> Calculations follow formula on sheet, based on tank size. Calibration involves speed of tractor, work out output per nozzle, do this over 100m, know that roughly this nozzle sprays _ metre this way and _ metre that way under vine. Can work out how many hectares per 100m of row are going out. We work out how many linear metres — and we know that there are 33 vine rows in a hectare — are going out. The space is 100m across divided by the number of vine rows. Here they are 3.6 m apart. If vines were closer then there would be more vine rows.
>
> In weedicide applications the labels give a broad hectare rate not the vine hectare rate — for spraying the whole paddock. If you put a broad hectare rate into the tank it's probably three times the amount, with the danger of over-spraying.
>
> One hectare is 100m x 100m and we just divide how many rows are going in there … On a boom spray the 2 sprays each cover 0.5m, but there is a distance of 1m between the vines not sprayed. There are 33 rows, if producing 2 litres per nozzle, and we might have 2 nozzles, or 4 nozzles running, so we're running 8 litres per 100 m, then we can work out how much is actually coming out of the tank. So if we divide the 8 litres into the size of the tank, 400 litres, then we can work out …50
>
> If we know we've got 33 rows, we can multiply that figure, litres, by 33, then that will give us a rough figure of vine hectare spray. Then we have to work out how much that whole tank will spray. It will probably be roughly a third, in our case, could be more. For calibration, use measuring buckets placed underneath nozzles for one minute to calculate total water [spray], then multiply it by the speed of the tractor, to get the rate per hectare.

An example of a calculation:

1 ha = 100m x 100m

row spacing = 3.66

100/3.66 = 27 rows/ha

27 rows x 3 litre/100m = 81 litres/vine hectare

400 litre tank / 81 litres = 4.9 vine hectares [approx. 5]

normally spray 1/3 of ground under boom spray

5 vine ha x 1/3 == 1.66 broad ha equivalent

If the label rate is 2 litres/ha, 2 x 1.66 = 3.32 litres of actual chemical per 400 litre tank.

Table 2: Equipment Set Up and Calibration table

Date		Tractor			RPM			
Gear		Spray plant			Pressure			
Size, number & arrangement of jets								
Calculate speed in kilometres per hour								
3.6	X	Distance in metres	÷	Time in seconds	=	Km/hr		
3.6	X		÷		=			
Calculate output in litres per hectare								
600	X	Nozzle output	÷	Nozzle spacing	÷	speed	=	L/ha
600	X		÷		÷		=	
Calculate chemical to add to tank								
Tank capacity (in litres)	x	Chemical rate (in litres or kg/ha)	÷	Output (L/ha)	=	Chemical in tank		
	x		÷		=			

Distance: Measure 50 or 100 metres to time the tractor

Time: Time the tractor over the measured distance in seconds

How numeracy is taught and learned in the workplace

The supervisor and his assistant have the relevant formal chemical use training and there is a rule that all people engaged in spraying must have this training. The supervisor does all the training of new workers for chemical handling and spraying. He follows guidelines which determine who can be authorised to spray.

New workers are supported and mentored by the supervisor and his assistant. For example:

- ✧ Nozzle output (of sprayers) is a crucial step in calibration. To work out nozzle output, water is collected from nozzles in a bucket with a measuring scale on the side. The measuring bucket indicates nozzle output which is required for the calibration formula.
- ✧ Workers are assigned to particular work contexts where calibration is easier for example using herbicides; spraying in paddocks that are exactly 2 hectare which allows errors in spraying to be identified.
- ✧ Observation by the supervisor and his assistant of spraying highlights any issues. For example faulty equipment 'nozzles have packed up'; errors such as not putting out the spray at the right pressure or speed.

> New people — we run them through the whole procedure. Get them to do calibrations, etc. We usually start them off on weedicides, because it's the easiest way of calculating, then we go to broad spraying on the mist blaster. There are certain paddocks that we put them in.
>
> We've got a few paddocks exactly 2 hectares, and if they've still got spray at the end of it, or they haven't put enough on, or they haven't done it at the right speed or they haven't put it out at the right pressure, so there's some check spots that we do.
>
> We then try to ascertain where the problem was. And if we have problems with it, it goes in the comments sheet of the sprayer. And it might not be their fault — it could be that one of the nozzles has packed up. … We usually find out what the problem is, if it's the operator's problem or the machine problem. And then we try and correct it. If it is the operator's mistake, we then have to go back through the learning process.

> We usually go out; I make sure that what they are doing is correct. I watch each step. And I usually go out in the paddock with them. They do a few rows, and they might not be turning it off at the end of the row and turning into the new row and turning it on again [correctly]. There's a whole heap of things.

Case study C

The enterprise

A metropolitan local government in NSW, in outer Sydney. The 'noxious weed team' is responsible for noxious care, bush regeneration, bush care and fire mitigation. There are four teams adding up to nineteen people, including the five team leaders responsible to the manager in charge of weed management. There are two spray vehicles, mobile units on utilities and some hand spraying. Bush care responsibilities involve large numbers of volunteers. The manager coordinates 46 bush care groups and 7 Landcare groups.

The study

The manager was interviewed by phone and on-site; recording was by rich note-taking.

Critical tasks

While the task is essentially weed control and bush regeneration, the manager also emphasised the functions of bush recovery, Landcare and fire mitigation. There is an integrated management plan and budget which might entail, for example, cutting back woody plants to the ground and then applying Round-up. Work is undertaken within the scope allowed by the, national registration aligned to the Pesticide Acts. Use of the boom spray may lead to off-target damage, although the legislation prescribes that this is unacceptable; it certainly generates complaints from the public.

Teams are constantly trying to avoid large scale spraying but rather treat plants that are close to the ground or 'slash and spray'.

Using mathematics

According to the manager, calibration is not a daily task because the teams are mostly not spraying litres/ha. Teams mix concentrations as per the chemical label. The technical component relates to the use of pressure (which is seen as a variable) from the pump used to give pressure to a certain nozzle (nozzle output is another variable). Spraying of ovals for weed eradication is done to a calibration formula. Some workers find calibration charts useful but 'people have different methods and ways of doing things'.

How numeracy is taught and learned in the workplace

There is a range of formal training:

- To be employed, workers must have mandatory training – relevant chemical training or 'old' training.
- Mandatory training is minimum – the teams require people with higher levels of understanding relating to chemicals, for example, someone on a spray truck requires Australian Qualification Framework (AQF) level II, whereas the council wants them to have at least AQF Level III or IV, in order for them to take on the wider connotations of roles, and to have a better understanding of what they are supposed to be doing.

- In addition, all people in the bush regeneration and bush care team are required to have Certificate II in Bush Regeneration, or equivalent.
- All team leaders have at least formal chemical use training to AQF Level III.
- The manager's own qualifications include Certificate II in Bush Regeneration, Certificate IV in Conservation and Land Management, Bachelor of Applied Science in Horticulture, and formal chemical use training AQF Level IV (which is upgraded through work).

In talking about his perspective on how learning/teaching of numeracy/mathematics is occurring in his workplace, the manager revealed the following insights:

- Learning is done within the social context of a team. Formal chemical use training is conducted on site by a Registered Training Organisation (in this instance TAFE NSW). The formal chemical training 'works' because it is related to the particular context of the enterprise, using the specific equipment, situation and chemicals. The theory is taught and applied immediately on the job. 'The best training in the world – if it doesn't have that practical application –will not get the worker where they need to be'. The training organisation being on site also provides 'a critique of our systems and some improvements made as a result of training'.
- In terms of the formal training arrangements and informal learning processes that relate to spraying and handling chemicals, it was the role of the team leader to reinforce what would be done in training. The training is 'done as it is needed – others come into the role – they need training in the use of the equipment – they go over how things are measured and how to come to conclusions. The team leader is more there to observe how things are done and if things are done right'.
- Team leaders further support teams by completing relevant checklists and forms relating to chemical recording.

Case study D

The enterprise

A small golf course in the outer western regions of NSW. The course maintains 0.85 ha of greens with a team of four people.

The study

A semi-structured interview with the manager/team leader of the maintenance area. . Observation of simulation exercises in the use and importance of the customised machinery that is used in spraying the greens, which includes the workplace designed three-sectional boom that can be mounted onto a tractor.

Critical tasks

The manager saw work as 'more curative here, not preventative', so this work practice has an impact on the chemicals used. Cost of chemicals is a defining factor in what and how chemicals are used.

There are some critical aspects of the work of chemical spraying, including the manager's 'main three':

1. pressure -which relates to the output from the type of nozzle used
2. spray width - relates to the nozzle used
3. ground speed.

The 'main three' critical aspects are linked to particular workplace contexts. For example some of the terrain at the golf course is quite hilly and this impacts on the ground speed of the vehicle. Calibration of chemical use would need to take into account any change in ground speed.

Within the social context of the team, variables such as weather temperature are checked by experienced workers using equipment 'individual weather stations' to check against 'which chemicals can be used over 25º C'. Based on readings, workers also 'roughly estimate' times for watering the greens (after chemicals have been applied in certain circumstances)

Critical tasks also relate to occupational health and safety issues. For example a 400 litre tank is used. The tank is not to be filled beyond 270 litres of liquid ('6 litres/ha of chemical product is calibrated within that 270 litre') because of the weight...

Using mathematics

The manager stated some spraying is based on his calculations but overall he encourages a holistic, integrative approach to mathematical calculations and if workers are 'not sure then double check' with the whole team.

How numeracy is taught and learned in the workplace

Three of the four workers have completed formal chemical use training. Most of the calculations are worked out together in a community of practice by the manager with his team. Simulation activities are constantly held in the concrete yard beside the machine shed to ensure that everyone is comfortable with what they have to do. The manager gave one example whereby the workers needed to double check the use of a hand-held nozzle applicator, so he got them to 'mark out 25 metres on the concrete and work out how many litres/minute' calculations. Use of chemicals is decided by the manager based on information from the chemical label relating to practices that 'rotate chemicals, have favourites, and use lower schedule that does the job (no schedule 7 poison here)'.

Case study E

The enterprise

The enterprise is a golf resort in Victoria. In this area are three apprentices and five qualified staff. Spraying is used to maintain greens which suffer from a magnesium deficiency and, after testing, may require addition of fertiliser. There are 18 greens covering 2ha in total and spraying is year round. Normal weed control measures, mostly Round-up, are applied.

The study

A semi-structured interview with the supervisor. No spraying could be observed on the day of the interview because of adverse weather conditions.

Critical tasks

There are about 6-7 applications of fertiliser over a six month period, followed by testing and if necessary further applications. Spraying uses knapsacks, with which workers are started. Inexperienced workers spray on the roughs initially, greens are more complex with bunkers and players to consider. While nothing chemically or environmentally damaging is used on fairways, chemicals on greens are potentially more toxic, but workers have considerable experience by the time they are involved at this level.

Use of mathematics

According to the supervisor, all that is required is a knowledge of basic ratios. The supervisor provided an example of a calculation:

5 litres/10000 square metres. What is the rate for for .65 ha? [6.5 greens]

450 litre tank does 0.65 hectare.

5/10000 = x/ 6500

x = 5 litres x 6500 sq. m / 10000 sq. m

= 3.2 litres of chemical per 450 litre tank of water, (maybe 447 litres, but the accuracy here is not that important).

The calculation example above of chemical spraying within a context of green spraying, involves a knowledge of proportions, familiarity with context -specific formulae, solving equations that involve area to be sprayed.

How numeracy is taught and learned in the workplace

All workers engaged in spraying must have completed the relevant formal chemical use training but an ability to estimate realistically is important – unfortunately, the supervisor believes, that those with a school based mathematics education do not have a sense of what would be a realistic answer. The supervisor does the basic calculations and encourages staff to check their computations with him.

Inexperienced workers are started on knapsacks where they are given rates of spray and use measuring cups, eg 100ml of Round-up with 10L water. On their first task they are accompanied by a more experienced worker.

Yearly, or if there is a problem, tanks need to be calibrated, with the results recorded in the Boom Sprayer Calibration Worksheet. Measures are all specified in the Sports Turf Protection Manual. Workers use a measuring jug to collect water from all of the spray nozzles, to find what the output from each nozzle is per minute, which is introduced into a standard formula. The supervisor instructs the workers on the required bar pressure and the nozzle type. The workers collect the data and measure the tractor speed, recording details in the completed worksheet.

Case study F

The enterprise

The enterprise is a large nursery in the Blue Mountains of NSW, to the west of the Sydney metropolitan area. The nursery is considered a large one occupying 110 acres with five separate areas that allows it to create products for both the national and international marketplaces. Each area has its own supervisor who is responsible for the combined supervision of some thirteen apprentices for the whole nursery.

An indication of the sophistication of this nursery is that it has an on-site laboratory that is concerned with the balance of the use of chemicals in pest control, through an etymological engagement with the environment. Because of the export nature of this enterprise's business, for 'certain pests and diseases there is zero tolerance'.

In terms of the storage of chemicals for this nursery enterprise, large quantities are kept under strict compliance with legal regulations. Observation included noting that chemicals are warehoused in a separate building, with appropriate signage and fans running for adequate ventilation.

The study

An enterprise visit was conducted. Interviews were conducted with the manager, laboratory technician and area supervisor. As requested by the manager, recording was by note-taking rather than tape. A semi-structured interview format was followed in a variety of workplace locations.

Critical tasks

A key role of the manager is to oversee the implementation of an Integrated Pest Management (IPM) plan. The success of this plan is manifested through the 'identification and monitoring of pest populations that can lead to a decision to begin spraying'. The manager confirmed what the laboratory specialist noted, that apprentices are an integral part of the identification process.

As part of the IPM for this enterprise, there is the use of a particular 'spray model' that includes 'about five (main) chemicals with different modes of action'. The area supervisor has a clear, strong relationship with his apprentices; they work with him generally on the job for at least six months, and then spray under supervision. What this supervisor says in terms of practice and reporting information is that they all need to be 'singing from the same song-sheet'. There is a serious economical threshold to be considered especially in relation to the identification of pests and diseases and how 'hot spots will be monitored two times a week (as opposed to just the once)', and the need to ensure the proper rotation of chemicals.

The consideration of these factors may be the difference between low and huge upfront costs.

Workers must be 'suited up' and Chemical Usage Charts must be signed by all at the mixing stage, when chemicals are mixed in a motorised machine that has been customised to this particular workplace and mounted /pulled by a tractor (the speed/gear has already been set on the machine). Apprentices line up with their tractors that are already mounted with a container suitable to hold the chemical mixture. The containers have already been filled with water to the required pre-determined level when chemicals are added, then mixed with the aid of the motorisation option. Before any worker can access any chemical they must enter appropriate and required information on a Material Safety Data (MSD) sheet.

Using mathematics

There are a 'huge number of chemicals used', or that could be used, and most of these come with rates already on the labels.

If they are attentive, apprentices can by the second year, start to link pests to what chemicals could be used against them, 'but not necessarily the correct dosages'. Apprentices are taught about 'cycles' in pest management, for example, for western flower thrip the different levels of spray will relate to the different chemicals used at different parts of the 'cycle' (1^{st} phase =Avid [chemical] = 50 ml/100 L, to 5^{th} phase =Mavrik[chemical] = 40 ml/100 L). The use of Spray Record Sheets is critical to this process; they 'can be a bit monotonous, (but) need to check for resistance (re-overuse of a chemical)'.

Although the supervisor often prompts his apprentices to do 'what you learned in TAFE', he also emphasised that everyone worked calculations out together as a team ('…if I don't know it, someone else will'.), although he had some example worksheets from his own workbooks that provide tried and true reference material to follow.

How numeracy is taught and learned in the workplace

The manager has been in this workplace for 14 years, and has qualifications in horticulture. The area supervisor has been in this particular workplace for 7 years, having begun in the industry working from 16 years of age. He and some of his area team are due for a renewal of their chemical use training – and this will most probably be conducted on site because of the large number. His apprentices have completed formal chemical use training. At present, all 13 apprentices are male, but female apprentices have previously been employed.

A typical enterprise specific training program for apprentices would begin with intensive and ongoing on site training, and the emphasis on safety first. The supervisor stated that there is information on pesticide absorption rates (as per body exposure), safe handling, spraying and equipment guidance 'before touching chemicals' (there was emphasis on this point). Apprentices 'do' calibration at TAFE, but 'once done though (it is) still problematic'. As part of their training, and the application of their skills to the job, a senior worker will allow apprentices to have a go depending on the different types of chemicals, pests, et cetera.

The supervisor, who is 'no slouch at maths', finds calibration difficult at times as well – '(it's) an individual thing but at the end of the day, experience plays a major role'. An applicable example was given, where if three different plants are situated together, and theoretically, they each need a different chemical, then ('what to do in this situation?') the solution is 'worked out in-house – to save mixing three batches of chemicals'.

Case study G

The enterprise

This study was of a small amenity horticulture enterprise, a vegetable grower from Cabramatta in Sydney's inner west. He conducts a greengrocer outlet, where the interview took place. The horticulture holding is small, about one hectare, and is run by the owner/manager with one helper.

The study

This was a single interview with the grower at his retail outlet. He did not agree to a request to observe his work practices.

Critical tasks

The grower's holding is small. He has one other helper who works with him on his holding. They spray using hand-held sprayers early morning or dark, when wind is negligible. The grower only uses 'two kinds of spray (with) non-power equipment'. This latter circumstance he noted as being the same for most small growers.

Using mathematics

The grower works in a social context with his one helper particularly in relation to working out the correct walking speed. Mathematical calculations that this grower uses relate to the four basic mathematics skills of multiplication, adding, subtraction and division These mathematical skills are embedded in: estimation and calculation of litres of water to chemical concentrate; litres of chemical mixture to hectares; litres dispensed over a particular area, at a particular walking speed, and effective width of spray. The grower's understanding of the underpinning calculations relating to effective and quality work practices come from the stages of the basic formula for calibrating used in the [relevant formal chemical use training]: 'total spray output – litres/minute; effective spray width – metres; actual ground speed – km/hr, and water application rate – litres/ha'.

How numeracy is taught and learned in the workplace

The grower is originally from Vietnam, and was a 'teacher thirty years ago – a deputy principal of a high school back in Vietnam'. His level of English language and mathematical abstraction is extremely high. Because his underlying mathematics is very well developed he has been able to utilise these skills within the formal chemical use training and in applying the formulae utilised in training in a way that is relevant to this particular holding.

Case study H

The enterprise

The enterprise is in the amenity horticulture industry, a large nursery in Victoria with 180 staff in total, 8 involved in spraying.

The enterprise extensively documents its past history as a mechanism for learning from mistakes. It also shares knowledge with a sister operation in Sydney and makes use of expertise from state government departments.

The study

Semi-structured interviews were conducted with a male and a female supervisor and an unstructured interview with a TAFE teacher who delivers formal chemical use training who was visiting the nursery.

Critical tasks

Regular spraying to prevent pests and diseases, e.g. fungal diseases, western flower thrip, broad spectrum against other insects, systemic herbicides. Spraying occurs around perimeters and growing areas, generally every second day somewhere on site.

Wind is a problem in the area, as the spray can travel maybe 4 or 5 igloos down. Spraying is usually done when everyone else has gone home, late in the afternoon or very early in the morning. If there is a new chemical [e.g. fungicide] it is trialed before use. For example, they select 200 pots: 100 pots are sprayed and 100 are used as a control for observation.

Using mathematics

Mathematical processes arise in mixing chemicals and following the rate prescribed by suppliers. There is a spray list, giving rate per litre or gram per litre, to be applied to all igloos with the relevant plants. Although individuals do the actual calculations for their spraying, the supervisors know from experience that they generally go through about 20 litres per igloo. For example, if there are 15 areas to spray, they should use around 300 litres. If it is 'spray-to-runoff' there is usually a little bit more used.

Errors which occur include insufficient mixing, incorrect mixing, incorrect weighing of the chemical, two chemicals mixed together can curdle — a common problem for beginners. Order of mixing is important. For example mixing powder with water rather than water with powder.

How numeracy is taught and learned in the workplace

The TAFE teacher indicated that students varied considerably in confidence and that :

> emphasis was on practical exercises. For example, they have a practical exercise on calibration. They do theoretical calculations from the formula, then practical demonstrations, with area calculations, using water instead of chemicals, checking that the equipment works, gathering information and recording it on a sheet. After spraying, they refill the tank to 'start level', or measure the nozzle output with a measuring cylinder, comparing the theoretical and actual figure with a ±5% tolerance. If the results are not close, they ask why not. Explain the reason. Errors could be with the operator, e.g. measurement, timing, or with the nozzles [wrong or faulty nozzles]. Demonstrate different outputs with a change in pressure
> In general, workers have:

- a lack of tertiary education
- no career paths beyond a Nursery Hand
- lack of foundations, not having seen the purpose of learning mathematics at school
- a strong sense of the importance of record keeping
- a need for literacy to read and extract knowledge
- a need for good communication skills
- a need for the ability to think outside the square.

On the job, new workers are given the chemical users book provided by the company (currently being updated). They are given an opportunity to ask questions. Then, after being issued with normal regulation safety clothing, the process is demonstrated: location of chemicals, where and how to mix. They go through the different machines one by one. They usually start on the little pump spray [8 litres] and progress up to the 200 litre, then up to the 400 litre. They are always partnered — they never go out by themselves on the unit. The supervisor goes out and assesses their work, pulling them out if there seems to be a mistake.

New workers normally work with an experienced person with relevant formal chemical use training. At first, the experienced person would be doing the mixing, with the new worker doing the observing. The next time it could be that the new worker does the mixing with the experienced person observing — until they are competent. If the new worker makes a mistake the experienced person would question them as to whether they thought it was right. Mistakes do happen. For example to minimise the amount of time in spraying, sometimes pesticides and fungicides are mixed together. These need certain methods to mix correctly. They may need to add an extra agent in order to prevent unwanted side effects.

Newcomers are also reminded to take care of themselves and the other staff in terms of personal safety. The staff will do whatever it takes to avoid mistakes.

Case study I

The enterprise

A large Victorian company with 300 workers involved in the production of commercial chemicals and the handling of raw materials and finished products. Ninety percent is bulk-handled and computer controlled.

Chemicals are delivered by trucks, which require measuring through a weighbridge, or from ships, downloaded through pipes: 200 tonnes/day can be handled on site, the rest stored at Coode island.

Chemicals are kept in a number of locations on site:

- 3 shade stores for flammable liquids, with bungs
- a cool store kept below 7° C [4°-7°]
- organic products in the quarry, isolated under lock and key
- main dry goods store [only powders].

There is a pipeline from Esso/BHP at Hastings which brings ethane [200 tonnes per day] to be converted to ethylene; also BTX from BHP [liquid] at Pt Kembla which contains 85% - 90% benzene. These are combined to make ethyl-benzene which is the basis for the production of styrene monomer, producing 9000 tonnes per month.

The study

Semi-structured interviews with an inventory clerk, a cycle operator and two raw materials controllers.

Critical tasks

The inventory clerk is required to:

- calculate production inventories of finished products, usages of raw materials
- procure bulk raw materials from purchase orders
- work out delivery timetables
- make labels for drumming-out [30 000 drums of acetone per year] using a batch number system of 9 digits:
  - Department [3 digits e.g. 105] year [1 digit e.g. 4] week [2 digits e.g. 16] day [1 digit e.g. 6 = Friday] product [1 digit e.g. 5 = styrene] tank [1 digit e.g. 0 = tank A]

The work of the cycle operator involves loading and unloading chemicals and making up of batches to go into the manufacturing process. Operators need to know chemical properties; also to make sure that there is enough room in the storage tank. To do this they monitor a gauge that gives the percentage full for liquids or gases; also knowing the capacity of tanks means that as they reach capacity, a new tank is chosen to avoid over-filling. A road-tanker holds about 8000 litres in one compartment. The driver and the operator work together to make sure that the transfer is carried out safely, based on a Bulk Tanker Order Form.

The raw materials controllers store chemicals of various kinds (but not the most dangerous) and these need to be segregated in accordance with legislation. Picking slips are coded with 4-digits to give the location of store and aisle numbers. Then the 9-digit batch numbers are used to locate the particular order. There are universal world standards for identification of chemicals. After the load is picked [and checked] it is re-checked and re-signed by loading person who puts it on truck. Customers receive a computer-generated Certificate of Analysis, through the laboratory.

The on site contractor transport supervisor makes up the loads, segregating loads into classes. The loaders make up the load on the truck in accordance with the driver's requirements.

Using mathematics

The inventory clerk uses *Excel* spreadsheets to keep records of raw materials and production; kilograms are the basic unit [litres are transformed into kg]. This includes the pipeline flow and truck and ship delivered chemicals.

For the operator, the task is the conversion of an order in kilograms to the operator's meter in litres, so there needs to be a conversion by the loader. The rough conversion is: 1000 kg converts to 1100 litres [i.e., add 10%] to allow for the specific gravity of the chemicals. 'I move the 1 across to make 11'. Interstate transport has a mass loading sheet, subject to standards. If the order for bulk transport is 25 tonnes, it could be rounded off to 24.5 – 25.5; better 24.8 - 25.2; 'it's not critical'.

For the raw materials controllers the task is primarily one of identification of chemicals.

How numeracy is taught and learned in the workplace

The inventory clerk argues that all people handling chemicals are well trained: 'I've noticed that any one of them that's got a query, they ask.' On a noticeboard: 'Asking a dumb question is better than making a silly mistake.'

New workers in the operations area are trained by working with the driver and the cycle operator. Drivers must have completed Inflammable Liquids training in order to get an endorsed licence; knowing chemical codes and requirements for disposal of spillages. Loaders also need to complete similar training and work with the operator on site.

In raw materials control, a new person, on trial for 3 months [entry-level], is always accompanied by an experienced worker; they have to know the chemical codes first, and have a fork-lift licence. After 3 months their skill levels are tested as pay structures are tied to learning.

Problems may arise according in production departments if too many or too few ingredients are added, causing batches to go hard. With raw materials, drums may be pierced by the forklift [maybe driver error or faulty pallet]. Mistakes can occur in the selection of chemicals. Such mistakes are usually noticed by checking [3 checks], but even still the wrong order may go through, with the risk of legal action from client. This may even lead to an illegal declaration on export documents.

Case study J

The enterprise

The enterprise is a large warehouse located north of Sydney, NSW. The warehouse is simply for storage and chemicals are regarded as 'just another box' to store. Only distribution is conducted with no decanting or mixing of chemicals. There are 20 staff working as pickers (who 'pick and pack') and a further 8 involved in packaging.

The study

A semi-structured interview with the manager and observation of operations.

Critical tasks

- ✧ There is pallet work using a forklift, but the pickers spend about '75% of their time walking, and approximately 20% picking and checking'.
- ✧ There are almost no accidents with products that are palleted.
- ✧ The warehouse benchmark relates to outputs. Workers' performance is continuously being measured through their outputs relating to the number of 'lines' they are given to pick and pack. Some of the considerations for workers are their need to maintain their 'line output', which relate to adhering to certain processes that require initials and the corresponding weight of products to be keyed into the database .A weakness in the level of output could then be detected and further monitored by a supervisor.

Use of mathematics

When asked how critical mathematics was to the warehouse, the manager stated that 'maths in distribution is very important – the product numbering, quantities, alpha numerics (relating to the distribution system), the floor setup in coordinates'. Workers know where the products are based on the product location that is already entered into the database. From the technical bulletin the identification labels are then determined and computer-generated. The workers need to be aware of where the products are in relation to the whole warehouse, but the criticality is taken out of the equation – 'not meaning to be disrespectful, but we've taken the thinking out for them – (it's) like driving down the street'. Aisles numbers are from 1-10, there are 2-digit numbers for identifying bays ('like a street, with odds on one side and evens on the other'), and the idea is to give workers the shortest route to 'pick and pack'. With regards to storage of chemicals, these are in an area called the 'bunded area'. If there is a spill, this area has been setup to cope with that occurrence though as the manager pointed out, 'the spill annually is no more than 10 litres maximum' because the 'pain to go through cleaning up the mess – the guys are very careful'.

How numeracy is taught and learned in the workplace

Training of workers involves doing the 'Terry' Course, which relates to an RTO trainer, Terry, coming on-site to conduct training as required, from the Transport & Distribution Training Package. This type of training is premised with an involved induction process". It is a 'fairly standard, two-fold exercise that includes all tools and training (is) upfront, and the second part uses measuring tools to give feedback about being up-to-speed'.

The manager's view was that knowledge to do the work came from the ability to read, understand and interpret technical bulletins associated with those products. 'There used to be a time when the enterprise conducted pre-tests, for example numeracy skills – no more. We found that out of a group of for example 10, maybe we'd pick two that in the end don't necessarily want to be pickers or packers'.

The manager was expressing a concern of being guided only by the test result.