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# Learning numeracy on the job: A case study of chemical handling and spraying

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An Adult **Literacy** National **Project** Report

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# Publisher's note

Additional information relating to this research is available in *Learning numeracy on the job: A case study of chemical handling and spraying—Support document*. It can be accessed from NCVER's website <http://www.ncver.edu.au>.

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# Contents

# Key messages

This research illustrates the challenges faced by industries using chemical handling and spraying as they attempt to ensure that workers have the appropriate numeracy skills.

- ✧ The 'numeracy' task of preparing and applying chemicals requires that the person responsible takes a complex set of variables into account. Although chemical sprayers and handlers may have undergone specific training and/or learned the required mathematical skills at school, they still require further on-the-job mentoring and support.
- ✧ The worksite influences both the type of numeracy skills needed, as well as how they are deployed. In other words, the task, the history of the task (for example, how previous records were taken), and the equipment used determine the sorts of calculations people must be able to make. Once these are learned, they have to be embedded through practice.
- ✧ Workplace numeracy education cannot be approached from a traditional 'school mathematics' mentality.
- ✧ Workplace numeracy requires training that reflects workplace practices and incorporates authentic problem-solving in real or simulated tasks in small groups with shared responsibilities. It also needs to incorporate the development of metacognitive skills, such critical thinking, learning to learn, planning and problem-solving.

# Executive summary

The processes of preparation, application, handling, storage and transport of chemicals are key elements of a range of economically significant industries, and place high demands on workers' literacy, and especially numeracy skills. Many of these skills are acquired during employment on the job or in associated off-the-job training.

It is important to gain an understanding of how these skills are developed and maintained in workplaces where there are significant risks to personnel, production and the environment, if these critical tasks are undertaken incorrectly. This understanding is important, not just for numeracy practitioners, but also for policy-makers who frequently view numeracy as a generic skill whose application may be easily transferred from a formal learning context to the workplace, or from one work context to another.

In fact, a substantial body of research evidence demonstrates that such skill transfer is achieved only with difficulty, and that numeracy skills are highly context-dependent. This research therefore sought to investigate actual tasks demanding numeracy skills at a range of worksites in a number of industries.

The research involved a literature review and documentary analysis in relation to legislation, training package common units and the National Reporting System. Empirical work involved 13 case studies of enterprises in New South Wales and Victoria, all of which used chemicals extensively. Industries selected included rural production, amenity horticulture, local government, outdoor recreation and warehousing.

## Definitions

The international research literature distinguishes between numeracy and mathematics, yet maintains that mathematical skill underpins, but does not equate to numeracy. Steen (2001) makes a distinction, arguing that mathematics requires a distancing from context. Numeracy ('quantitative literacy' in his terms), on the other hand, is anchored in real data which reflect engagement with life's diverse contexts and situations. Numeracy offers solutions to problems about real situations.

There is a growing understanding of how mathematical knowledge is used in real situations of life and work, to which the present research is a contribution. Following Bernstein (2000), it is argued that the use of common sense—of relatively little value in formal mathematics—is essential in numeracy.

Observations of workplace numeracy practices indicate that knowledge is embedded in ongoing practices. Such knowledge is 'directed towards specific, immediate goals, highly relevant to the acquirer in the context of his/her life' (Bernstein 2000, p.159), and is usually learned face to face and, if necessary, repeated until the particular competence is fully acquired.

Just as there are fundamental differences between mathematics and numeracy, workplace numeracy education requires a fundamentally different curriculum and teaching/learning strategies from those required for teaching school mathematics. However, these would need to encompass underpinning mathematical knowledge and skills in ways that enable the generation of 'new' knowledge in order to solve problems which cannot always be known in advance.

# Findings

The tasks of preparing, applying and handling chemicals require that a complex set of numeracy variables—much more complex than the simple application of mathematical skills learned in school or vocational education—must be taken into account by the person responsible. Critical tasks include the calculation and measurement of chemicals, taking note of:

- space (areas to be sprayed), time of day (night, early morning) time of year (for example, not too close to harvest), carrying capacity of particular tanks
- weather conditions (humidity, wind speed and temperature)
- economic and legal contingencies
- the calibration of equipment (with associated calculations)
- the need for accurate record-keeping and consultation with previous records
- efficient location of chemicals in warehouse situations.

Estimation is always necessary, based on prior experience of the kind of spraying needed. Common sense is essential. Mistakes in the actual process may threaten public safety and also the livelihoods of the workers.

Workplace numeracy tasks are always a social–historical and cultural practice, in the sense that previous experience and historical data play a major role in determining the reasonableness of answers. At the same time, calculations are double-checked, and team and group work are fostered as part of workplace practice. Artefacts (equipment, tables, chemical labels, charts, ready reckoners) are used as resources to aid formal calculations, or in other situations requiring assessment and evaluation.

# Implications for policy and practice

In the workplace the priority and intended outcome are to get the job done as effectively and efficiently as possible, assisted by numeracy as but one tool. In a formal education setting the intended outcome is the learning of mathematics. Unlike a formal education setting, the results obtained in the workplace really matter in terms of public and personal safety, the environment, economic costs and maintaining one's job. Solutions to calculations for chemical spraying must necessarily be error-free, but in contrast to formal education, the actual methods used allow some discretion, and more importantly, they involve collaboration with or validation by at least another person.

Numeracy in the workplace involves the practical application of rational numbers and the metric measurement system with contextualised approximations and estimations in critical calculations, often with other workers. It also may incorporate each of the key competencies (for example, planning, organising, cooperating and communicating effectively). This is in marked contrast to the traditional conception of mathematics education as an abstract, rule-bound, individual activity, with one correct answer (usually a number, an algebraic expression, or a standard graph), and where mistakes are temporary setbacks.

Numeracy educators need to ensure that workers have a deep understanding of the metric system within the context of common workplace usage. An understanding of rational numbers (that is, fractions, decimals) will result from carefully chosen practical activities and explicitly made connections, as well as from sophisticated calculator activities. Learners need to be presented with opportunities to become familiar with, and use various artefacts from relevant workplaces, for example, reading and interpreting non-standard graphs, chemical labels, tables, charts, calibration charts for specific equipment, and other ready reckoners. They also need to learn how to complete record sheets and templates for calculations accurately.

Given that learners will need to make sense of activities and ill-defined problems in unfamiliar workplace situations, problem-solving activities are recommended, using case study examples from industry workplaces. Realistic group projects with open-ended solutions and shared responsibilities need to be devised. As workplace activity shapes the process and meaning of the mathematics used, simulations can be applied off the job. In addition, viewing video material relating to specific weather and workplace conditions could also be used to provide contextualisation. Teachers could make links with enterprises for the use of part of their premises, for example, a golf course. Encouraging learners to keep a logbook, or journal about strategies they would adopt in certain situations is also an invaluable exercise and an individual 'living' resource. In order to develop workers' ability to interact with computerised systems, which may hold vital information, authentic data could be obtained (with permission) and a simulation organised.

Although workplace supervisors tend to assume a strong foundation of school mathematics, and the transference of such knowledge, this is not necessarily the case for many workers involved in chemical spraying and handling. Specialised tuition may be needed to enable workers to develop the relevant mathematical skills (or earlier learning reinforced) in relation to the mandatory chemical spraying and handling training required in these industries. Findings from this study indicate that, although most workers have undertaken formal chemical use training, mentoring and support in how numeracy processes operate within the particular enterprise are still required, since each workplace is individual.

Because enterprise numeracy skills are so specific and not every context/situation can be covered in formal training, metacognitive strategies (learning to learn, critical thinking, planning, problem-solving) are crucial and need to be consciously developed.

Questions arise over how competently workers would be taught by teachers or trainers with little or no background in mathematics education, or with little or no knowledge of the social–cultural numeracy context of the workplace. There is an urgent need for mandatory specialised preparation of and/or professional development for teachers and trainers involved in adult numeracy, even if this is not their principal role.

In addition to this report, the study produced an extended literature review and more detailed descriptions of the case study sites. These support documents are available at NCVER's website <http://www.ncver.edu.au>.

# Research issues

## Context

A range of economically significant industries make extensive use of chemical handling and spraying. Private and public sector enterprises in which this process is a vital operation include plant production, amenity and commercial horticulture, transport, warehousing and storage, local government (especially in regional and outer suburban areas), wine making and recreation.

The processes of chemical preparation, application, transport, handling and storage undertaken by workers are high-risk activities in terms of occupational health and safety of the workers and their clients, and in relation to production in their industries and protection of the wider environment.

Chemical handling and spraying place high demands on workers' literacy and, especially, numeracy skills. Many of these skills are acquired in employment, on the job, or in associated training through a registered training organisation. On the other hand, the quantitative reasonings involved relate to fundamental mathematical operations learned in school or in other areas of formal education. It is important to develop an understanding of how these skills are gained and maintained within the workplace, so that programs of formal training and informal learning can offer optimal support to workplace learning and therefore effectively meet the needs of the industries served.

Such an understanding is important not only for practitioners but also for policy-makers, who often share the widely held view that mathematical knowledge, once gained, can be transferred from one context to another and re-applied with little difficulty. This notion is discussed by Johansen (2002): 'It is as if they see numeracy skills as a toolbox you can carry around. As soon as you have this toolbox you can use it everywhere' (p.6).

According to Virgona et al. (2003), although numeracy as a generic skill is regarded in the abstract by policy-makers, it only becomes meaningful for teachers and students when in context. (A full literature review on adult numeracy and workplace learning can be found in the support document at <http://www.ncver.edu.au>.)

## Research questions

Researchers in many areas of education have long noted barriers which limit the transference of knowledge and skills from one area to another, and practitioners are familiar with the difficulty of transporting learnings, even from one classroom setting to another. Workplace learning involves an additional dimension because the acquisition and application of employment-related skills are substantially context-dependent. This is especially true for the workplace use of mathematical skills.

Zevenbergen (1996) investigated the mathematics used by pool builders, finding that workers used very little formal measurement but relied on skills of estimation which were taught and learned on the job. FitzSimons's study of the pharmaceutical industry reported that the workplace itself should have primacy in the development of numeracy rather than its being a preconceived notion of basic skills (FitzSimons 2002). McKenzie, discussing research on how nurses learn maths found that skills learned in their nursing training were not easily transferred to other contexts (McKenzie 2001).

The present research aimed to investigate numeracy practice in chemical handling and spraying by workers within the amenity horticulture, rural production, local government, warehousing and outdoor recreation industries. The purpose was to answer the following research questions:

- What critical tasks occur in these industries which rely on workplace numeracy?
- What are the formal mathematical ideas underlying the numeracy of the critical tasks?
- How is numeracy taught and learned in the workplace?
- What strategies could be applied by workplace trainers and by teachers?
- How does workplace learning of numeracy relate to 'school' mathematics?
- How can observed practices inform delivery of training package competencies?

# Research in adult and workplace numeracy

The present research has the capacity to contribute to emerging 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. Misconceived attempts to recollect imperfectly remembered classroom practices are a frequent cause of mistakes in the workplace and can lead to the suppression of common sense instincts. On the other hand, all recent surveys stress the importance of a foundation of mathematical knowledge.

What are the distinctions between mathematics and numeracy? Following the work of Bernstein (2000), it could be said that, while in mathematics there is a well-known hierarchy between common sense and its opposite (the strict, increasingly abstract rules of the discipline of mathematics), common sense is the essence of numeracy. The high-level abstractions of formal mathematics alone are insufficient and may even prove counter-productive in the workplace. Observations of workplace numeracy practices indicate that knowledge is embedded in ongoing practices. Such knowledge is 'directed towards specific, immediate goals, highly relevant to the acquirer in the context of his/her life' (Bernstein 2000, p.159) and is usually learned face to face and, if necessary, repeated until the particular competence is fully acquired.

Current research positions numeracy as a social and cultural–historical process—to use terms drawn from activity theory (Engeström 2001). This approach recognises that humans pass on tools and procedures for their use to the next generation. As an activity, work is a collective process, dependent on interaction and communication, using artefacts, such as tools, written materials, tables and charts, as an integral part of the process.

Mathematical work in manufacturing and the agriculture/horticulture industries is highly dependent on the tools, machinery and equipment used in the workplace. Numbers and computations come from measuring physical quantities that really matter in production. Workers need to understand conceptual qualities such as averages in cases of problematic data. Assembly and operative work does not require more mathematics, but mathematics that is used and interpreted in context.

In summary, reports of workplace numeracy/mathematics suggest that the skills required are not necessarily found high up in school curricula; rather they are often regarded as 'basic' or lower high school level, but are applied in complex ways to ill-defined and ever-evolving problems which themselves may not be inherently mathematical. Clearly, mathematical skills and knowledges developed in school and vocational education play an important underpinning role in workplace numeracy practices, but workplace numeracy education cannot be approached from a traditional 'school mathematics' mentality.

Just as there are fundamental differences between mathematics and numeracy, workplace numeracy education requires a fundamentally different curriculum and pedagogy from that of school mathematics. However, such a curriculum and pedagogy would need to encompass underpinning mathematical knowledge and skill in ways that enable the generation of 'new' knowledge in order to solve problems which cannot always be known in advance.

In the workplace, the object is to complete a task as efficiently and effectively as possible, assisted as appropriate by the incorporation of numeracy as but one tool. In the classroom, the object is generally to produce more text, utilising textual and other mediating artefacts, with the intended outcome of learning being more mathematics. Clearly the conditions for teaching and learning numeracy are very different in these two sites. Even when a classroom lesson is designed to simulate the workplace, it can never completely capture the exigencies of actual practice.

# Legislation

An important background factor in workplace learning in industries which employ potentially hazardous or environmentally damaging chemicals is the need to comply with extensive governmental regulation. In the two states in which the present research was conducted, New South Wales and Victoria, there are different approaches to the training of workers in the use of chemicals.

In New South Wales, the *Pesticides Act 1999,* operating from 1 July 2000, includes a requirement for compulsory training in the use of chemicals. There are strong corporate and individual penalties for the wilful or negligent misuse of chemicals in ways which contravene the act. In Victoria, training in the use of chemicals is not compulsory, but the *Agricultural and Veterinary Chemicals (Control of Use) Act 1992* and the 1996 regulations require the registration of pesticides and the licensing of those applying them.

# Training package units

More extensive regulation has required greater efforts in training workers who employ chemicals in a range of industries. Rural/conservation common units of competency relating to chemical application were developed by the Rural Training Council of Australia for the Australian National Training Authority (ANTA) and are incorporated into the following training packages relevant to this study: RTF03 Amenity Horticulture; RTE03 Rural Production; SR003 Outdoor Recreation; TDT02 Transport and Distribution; RTD02 Conservation and Land Management; LGA04 Local Government.

The numeracy demands of the common units were identified using the National Reporting System ('workplace sample activities') as a reference point. Funded by the former Department of Employment, Education and Training and ANTA, the National Reporting System (NRS) (Coates et al. 1995) was originally developed to provide a nationally recognised mechanism for reporting adult English language, literacy and numeracy skills in vocational education and training (VET), labour market programs and adult community education (ACE). The 'workplace sample activities' were developed to support use of the National Reporting System in workplace contexts.

Initial levelling of the common units of competency indicated an NRS level 3 numeracy for the unit of competency used within Australian Qualification Framework (AQF) II qualifications, and an NRS level 4 numeracy for the unit of competency used within AQF III qualifications (see support document).

# Methodology

## Research design and procedure

### Research framework

The research proposal was developed within an ethnographic research framework. Ethnographic research emphasises social relationships. Thus the core of the empirical work consisted of visits to work sites, and interviews, observations and collection of records and artefacts on site.

A project reference group with broad representation of industry stakeholders (industry training advisory bodies) and practitioners in numeracy education was established. The reference group assisted in identifying enterprises within New South Wales and Victoria for study within the industries selected and with facilitating visits.

## Selection of industries

### Rural production and amenity horticulture

Advice and a review of Australian Bureau of Statistics (ABS) production and employment data suggested that rural production and amenity horticulture, local government, outdoor recreation and warehousing accounted for the major users of chemical handling and spraying.

Specialisations within the rural production and amenity horticulture industries that undertake chemical handling and spraying include: viticulture; parks and gardens; landscaping, turf management, nurseries, arboriculture; fruit and vegetable growing; crop production; and animal production.

Application of chemicals may include: animal drenching; animal vaccinations; the use of hand-held spray guns; stem injection; volume spraying with a boom spray; air blast spraying; and modified boom spraying.

### New South Wales and Victoria rural production profiles

**Table 1: Principal rural production, 2000–01, NSW**

| | |
|---|---|
| Wheat production | 7.9 million tonnes |
| Orange production | 258 100 tonnes |
| Potato production | 160 100 tonnes |
| Meat cattle numbers | 5.8 million |
| Sheep and lamb numbers | 40.9 million |

Source: ABS (2001)

**Table 2: Principal rural production, 2000–01, Victoria**

| | |
|---|---|
| Wheat production | 3.1 million tonnes |
| Pears (excluding Nashi) production | 148 800 tonnes |
| Tomatoes production | 329 200 tonnes |
| Meat cattle numbers | 2.4 million |
| Sheep and lamb numbers | 22.3 million |

Source: ABS (2001)

The case studies included several vineyards, nurseries and vegetable growing operations.

## Local government

Local councils are involved in chemical handling in relation to outdoor recreation areas, such as parks and gardens, swimming pools, green keeping and noxious weed eradication, and waterways treatment. Compared with open space crop growing/production, work on parks for example, tends to involve general 'round up' type chemicals, which are not as potent as pesticides and fungicides.

Two local government bodies were included in the study. Work undertaken by councils includes chemical handling in industry areas relevant to this research: parks and gardens (local government and amenity horticulture); turf management; greens, parks and swimming pools (outdoor recreation); and storage and transport of chemicals (warehousing).

## Outdoor recreation

The industry is vast and has different contexts in which chemical spraying and handling are conducted. Such contexts include green keeping (bowls and golf courses) and pool maintenance. Several golf courses participated in the research.

## Warehousing

Over 55 000 enterprises are engaged in transport and storage in Australia. Two warehouses storing and handling chemicals were included in the study.

# Research procedures

An initial approach was desk research, involving:

- an environmental scan
- a literature review of existing Australian and international research relating to workplace learning, on-the-job use of numeracy and chemical use
- a survey of documentation of legislative requirements
- a documentary examination of units of competency relating to rural production, amenity horticulture, outdoor recreation, local government and transport and distribution training packages.

Secondly, empirical data were gathered on site at 13 locations, using semi-structured interviews, recorded electronically or by rich note-taking as the participants preferred, in some instances supplemented by observations of operations, with interview summaries signed off by informants.

Workplace sites selected covered a representative range of enterprises, including small, medium and large enterprises. At least one informant was identified within each workplace. Detailed observation of participants, that is, workers undertaking numeracy tasks during chemical spraying, or numeracy/literacy tasks during chemical handling occurred where possible. Non-participant observation was also required to get a feel for the setting and the cultural environs. Detailed field notes were taken.

Where permission was granted, observation and the collection of artefacts such as templates, tables and charts, or completed records, took place.

Finally, analysis involved integration of the interview and observational data with the outcomes of the literature review, document analyses and principles of adult and workplace numeracy teaching and learning.

## Limitations

There was some reluctance from several enterprises in both New South Wales and Victoria to participate in this project, particularly single owner/operators. Even among participants there may have been some initial misgivings about being part of a process which asked questions about workplace practice, particularly work involving the use of chemicals, and which is closely monitored through legislation. As a result, some enterprises did not participate beyond the interview.

# Case study findings

Numeracy in the workplace is much more complex than the simple application of mathematical skills learned in school or through vocational education. The present research aimed to:

- identify critical tasks which rely on workplace numeracy
- identify formal mathematical ideas underlying the numeracy of the critical tasks
- examine how the required numeracy is taught and learned in the workplace.

Findings on these questions, derived from analysis of the 13 case studies which formed the empirical basis of the study, are outlined in this section.

In the next section, these findings are integrated with outcomes from the review of literature and technical documentation to address the remaining research tasks, to:

- analyse the impact of workplace learning processes on teaching practices
- identify strategies that could be applied by workplace trainers and teachers.

## Outcomes of case studies

### Critical tasks

The 13 case studies described a wide range of activities involving workplaces dealing with chemicals in ways which require quantitative thinking, measuring and reasoning. These operations ranged from simple numerical recognition systems, for example, in warehousing, to wide acre fertilising, bush care and weed control, all requiring complex understandings of mass-to-volume conversions, allowances for speed of vehicles, nozzle pressures and spray drift. Chemicals applied varied from minimally toxic to poisons which, if misapplied, place production, workforce and public safety and the environment at risk. Most enterprises required some form of calibration of equipment.

Many of the larger enterprises exhibited a high degree of sophistication in chemical management. For example, a large nursery in New South Wales operated an on-site laboratory concerned with the balance of chemicals used in pest control. Similarly, a large nursery in Victoria constantly shared knowledge with a sister operation in Sydney, while regularly utilising state government advisory services. Many private enterprises and most local governments integrate their spraying practices with other forms of care and control; for example, a Sydney local government council which has developed an integrated bush management plan and budget involving bush cut-backs and bush regeneration as well as chemical pest control.

In warehousing the task is primarily one of accurate recording, location and retrieval. A large Victorian chemical warehouse utilises spreadsheets to record incoming materials and production, requiring the conversion of volumetric measures to mass. Monitoring the storage capacity of tanks and requiring the same conversion of litres to kilograms is a key task, as is the segregation and location of chemicals according to multi-digit identification systems. At another large warehousing operation in Sydney, the storage of chemicals is treated as 'just another box', but a high level of emphasis on safety and avoidance of spills means that steps are taken to systematise identification systems to remove criticality from the workers' activities as far as possible.

A number of commonalities may be detected in most case studies.

The use of the National Reporting System as a reference point when analysing the numeracy demands of relevant units of competency provided an initial indicative numeracy level of NRS 3 and NRS 4, levels which appear to be supported by the observed and reported calculations from the case studies. The observed and reported calculations appear to be most strongly linked to the NRS at level 3 in all categories of 'meaning-making strategies', 'mathematical knowledge' and 'mathematical representation'. In the case of 'problem solving strategies', level 4 seems more appropriate, especially in relation to gathering information, developing estimation skills and comparison of results with anticipated outcomes.

The numeracy aspects of the tasks of preparing, applying and handling chemicals require that a complex set of variables—-much more complex than the simple application of mathematical skills learned in school or vocational education—must be taken into account by the person responsible. Critical tasks include the calculation and measurement of chemicals, taking into account variables of space, time, carrying capacity of particular tanks, and weather conditions; the calibration of equipment (with associated calculations); accurate record keeping and consultation with previous records; and efficient location of chemicals in warehouse situations.

The following example from a workplace calibration record sheet collected as part of a visit to an orchard highlights the specificity of calibrations and the impact of variables in chemical spraying.

**Table 3: Calibration**

| | | |
|---|---|---|
| Tornado 3000L sprayer | | Kubota 8030 (tractor) |
| Nozzle output per 100m | | 66 litres |
| Speed per 100m – 56 seconds | = | 6.43 km/hr |
| Volume rate | | 66 x 100<br>6m (row width) |
| Use 1st gear high range (1700 revs) | | |
| Use – Litres per hectare | = | 1100 litres |

The calibration table (table 3), developed by a supervisor, relates to a situation where a particular tractor (Kubota 8030) and a particular sprayer (Tornado 3000L sprayer) are used. If, for example, the nozzle of the sprayer begins to wear, the output from the sprayer will change and the equipment will need to be re-calibrated. The nozzle output would need to be checked and the calibration table re-calculated. The speed of the tractor has been worked out for a particular tract of land. If the tractor is used on hillier land, the speed would be different, impacting on the calibration table. This calibration table therefore only relates to this specific situation and would need to be re-calibrated as variables change.

Estimation is almost always necessary, based on prior experience of the kind of spraying needed, or even of just sensible results for the benefit of the novice. Common sense is essential. In most of the case studies, questions about what might go wrong elicited replies that emphasised lack of a realistic approach and common sense—in general terms, an inability to estimate realistically. Workplace numeracy tasks are always a social–historical and cultural practice—previous experience and historical data play a significant role in determining reasonableness of answers. All calculations must be double-checked, and asking questions where any doubt exists is strongly and repeatedly encouraged. Mistakes may threaten public safety and the livelihoods of the workers and their managers. Team and group work is fostered as part of workplace practice.

Many workplaces attempt to minimise the need for workplace initiative or innovation through the use of artefacts—physical and paper-based devices, such as measuring cups, pre-set mechanisms, equipment, charts, tables and ready reckoners. Meticulous record-keeping and development of histories and databases characterise many operations and aid in the minimisation of personal initiative. Measuring and similar devices are to aid formal calculations, or for use in other situations requiring assessment and evaluation.

# Underlying mathematical ideas

The following were identified as the underlying mathematics concepts in chemical spraying and handling: addition, subtraction, multiplication and division of whole numbers and decimals; ratio and proportion; measurement (length, area, volume, capacity, mass [usually metric]); estimation; and approximation.

Most of these basic calculations involve mathematical skills initially taught in school. Most, if not all of the workers involved in spraying have completed chemical spraying and handling training, and the relevant calculations are revised and practised in (semi-) contextualised settings. That is, the learners get to observe and experience actual measurement skills. However, what they lack in such training are the ongoing records of any one particular site which add a deep sense of meaningfulness to their calculations.

In the workplace, calculations are always checked in some form by another person, whether the supervisor or the tractor driver, for example. Previous experience and historical data play a significant role in determining the reasonableness of answers.

# How numeracy is taught and learned in the workplace

Learning in the workplace differs from school mathematics education in that workers are always reminded to check their calculations for reasonableness, to ask questions if they are not sure, and to consider their own and others' personal safety, as well as safeguarding the workplace (herbs, plants, or crops being produced or maintained; safe storage in chemical warehouses) and the greater environment.

Even so, there is considerable evidence of formal mathematical training behind the artefacts and experienced-based practice of the workplaces investigated. Often workers at managerial and supervisory level have qualifications at degree or advanced diploma level, and are commonly the originators of standardised calculations used in the workplace and frequently check and assess calibrations and calculations.

The processes and strategies used by workers to undertake calculations include:

- estimation, pencil-and-paper methods, use of basic 4-function calculator
- oral or written communication of mathematics to other workers and the interpretation of the mathematics of other workers
- consultation with prescriptive calculations sheets and with historical records
- completion of up-to-date records of chemicals used and their amounts.

Complex contextual factors to be considered include:

- date/time of spraying
- block area
- crop to be sprayed; crop stage
- weed/pest/disease targeted
- chemical group
- rate/ha, litre spray applied, method of application

- temperature, wind speed, wind direction, rainfall, humidity
- variations in equipment.

Economic and legal contingencies are implicated within the contextual factors.

Learning on the job is largely experiential, with opportunities provided for workers to become ‘encultured’ into communities of practice through interrelationships with other employees. Supervisors are often involved in initial training and check regularly on work practices. Most workplaces place a strong emphasis on ensuring that workers are prepared to check before acting, of being unafraid to ask a ‘dumb’ question.

# Analysis and implications

## Perspectives on numeracy

Numeracy has been defined in many ways (see for example, Evans 2000; Gal et al. 1999; van Groenestjin 2002). The focus of the present research has been on teaching and learning numeracy on the job or in training closely associated with the workplace. The most useful definition for this purpose appears to be that proposed by Coben.

> 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, p.35 cited in Coben 2003, p.10)

The international research literature distinguishes between numeracy and mathematics, yet maintains that numeracy must be underpinned by mathematical knowledge of an appropriate kind. From the United States, Steen (2001) makes a distinction supported by the findings of the present research, arguing that, while mathematics requires a distancing from context, numeracy ('quantitative literacy' in his terms) is anchored in real data which reflect engagement with life's diverse contexts and situations.

Coben (2002, p.28) also discusses adults' engagement with mathematics and numeracy in terms of use and exchange value, emphasising distinctions within adult numeracy as skill, practice, learning, and education. She summarises the major differences in perspectives in figure 1, 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**

| | Domain One | Domain Two |
|---|---|---|
| | Use value low; exchange value high | 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') | Learners: everyone, as part of processes of enculturation into 'communities of practice' |
| | Teachers: professional experts (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 | 'Teachers': more experienced people, who 'know the ropes' |
| When? | At set times (except in open and distance learning) | Anytime, incidental |
| Where? | In set locations (except in open and distance learning) | Anywhere, in context, in 'real life'; 'everyday life'; workplace; at home |

Source: Coben (2002, p.29)

It appears that the discipline of mathematics as traditionally taught in schools and some post-compulsory educational settings aligns with Domain One, while the workplace learning reported in this study, and some more authentic simulations in off-the-job environments, aligns with Domain Two.

In Australia, discussion of numeracy is commonly associated with discussion of literacy and, not infrequently, subordinated to it. Concern with literacy and numeracy, in turn, arises from the increased emphasis on core, key or generic competencies which has been evident since the 1992 Mayer Report (Mayer 1992).

The key competencies proposed by Mayer were:

- collecting, analysing and organising information
- communicating ideas and information
- planning and organising activities
- working with others and in teams
- using mathematical ideas and techniques
- solving problems
- 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; it is also the underpinning knowledge essential to achievement across many of the other key competencies.

In many official reports, the literacy and numeracy skills implied in the Mayer competencies have been conflated, despite research and reporting systems which stress distinctions (for example, Griffin & Forwood 1991; Coates et al. 1995). In Australia, the National Reporting System clearly distinguishes between English language, literacy and numeracy in developing its mechanisms for reporting outcomes in these areas in VET, ACE and labour market programs.

Similar problems can arise from the otherwise desirable practice of integrating the teaching of literacy and numeracy into workplace training. One difficulty is that numeracy may be treated as an appendix to literacy, as in Falk and Millar (2001), or the term ‘numeracy’ may be used when discussing generic skills without defining it or indicating its problematic nature, as in the Kearns review (2001).

The Dawe (2002) report on generic skills in training packages acknowledged 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. 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.

# The impact of workplace learning on formal teaching practices

## Numeracy competencies in the workplace

The challenge of numeracy education is to develop effective means of workplace learning and, at the same time, ensure that underpinning knowledge is transmitted and acquired. A useful conceptual framework for understanding the distinction between numeracy and mathematics is provided by Bernstein (2000), who developed a concept of ‘vertical discourse and horizontal discourse’, linked with his performance and competence models of education.

Mathematics, especially in a school setting, is an example of 'vertical discourse' because of its coherent, explicit, and systematically principled structure. Numeracy is an example of a 'horizontal discourse', because it is 'embedded in ongoing practices, usually with strong affective loading, and directed towards immediate goals, highly relevant to the acquirer in the context of his/her life' (Bernstein 2000, p.159).

There is now a substantial body of evidence-based knowledge of the ways numeracy is acquired, maintained and developed in workplaces. In Australia, the following studies are relevant: short-term work shadowing workers in 30 workplaces (Australian Association of Mathematics Teachers 1997); operators in the light-metals industry (Buckingham 1997); front-desk motel and airline staff (Kanes 1997a, 1997b, 2002); pharmaceutical manufacturing workers (FitzSimons, 2000); and swimming pool construction workers (Zevenbergen 1996).

Internationally, studies have included: landless peasants in Brazil (Knijnik 1997, 1998); supermarket shoppers in the United States (Lave 1988); CAD/CAM technicians in Slovenia (Magajna & Monaghan 2003); carpet layers in the United States (Masingila 1993); in the United Kingdom, 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 United Kingdom police (Wake, Williams & Haighton 2000), studies of 11 United Kingdom workplaces (Wake & Williams 2001); work shadowing of semi-skilled operators in Denmark (Wedege 2000a, 2000b, 2002).

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 technical 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. Finally, because the focus is on task completion within certain constraints (for example, time, money), mathematical correctness or precision can be somewhat negotiable, depending on the situation at hand.

## Curricular and pedagogical implications

Understanding the way numeracy skills are acquired and developed in the workplace has implications for the teaching of underpinning knowledge in formal teaching and learning environments. For workers to achieve maximum benefit from workplace learning, attention needs to be paid to vocational education and training and, indeed, school curricula and teaching methodologies, for it is in these systems 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. (Forman & Steen 1999, p.12)

Forman and Steen (1999) also provide multiple examples of mathematics in life and work which encompass 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 twenty-first 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. The following are the essential elements of 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 relevant to other school subjects.
- By emphasising problem-solving and reasoning skills, mathematics instruction would better prepare students to deal with unfamiliar situations.
- By learning how to ask questions and demanding 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.

It is clear from the present research that workplace learners need to develop a broad range of skills. Most basically, workers need to become proficient in using the real number system for practical purposes, together with sensible use of (pre-scientific) calculators in the estimation of reasonable answers and the rounding-off of calculator-generated answers appropriate to the purpose at hand.

Related to this proficiency is an ability to calculate within the metric system, including practical measurement of chemicals, distances, areas, speed etc.—generally from milligram to kilogram, and millilitre to litre, millimetre to metre, square metre to hectare. Associated tasks include measuring out calculated amounts within margins of error appropriate to the task at hand and reading and interpreting non-standard (that is, not Cartesian) graphs, tables, chemical labels, charts, and other ready reckoners.

Many workplace numeracy tasks also incorporate literacy and communication skills, such as completing record sheets and templates for calculations accurately, and communicating effectively about this with other workplace personnel. Similarly, workers need to be able to follow workplace instructions in regard to best practice, locate information using chemical labels, have the ability to perform calculations in context and have an understanding that numerical tasks are rarely carried out in isolation from a 'real situation'.

Other requirements are those necessary for working in teams to work out calculations, including working alongside experienced workers to gain the knowledge of how to most expeditiously work out calculations. Workers also need to develop their own experiential learning; undertake planning and organising tasks (when given responsibility) to ensure effective use of time, equipment, and consumable materials; and prioritise tasks according to individual worksites, for example, some may emphasise 'area' and some may emphasise 'quantity'.

Skills focusing on chemical applications include:

- identifying those critical factors, including pest identification, that could impact upon the numerical calculations of chemicals used
- understanding related impacts of numerical calculations on workplace practice having occupational health and safety implications, for example, the speed and weight of vehicles
- practising calibration calculations specific to each workplace task and situation, particularly some of the 'tried and true' methods found in some workplaces

- ✧ using formulae
- ✧ completing numerical tasks that have an impact on workplace output in a timely manner
- ✧ retrieving information from electronic databases to access product details, where applicable to the enterprise.

Mathematics educators need to consciously draw attention to relations with the real number system, including common fractions and decimals. Strategic calculator games can be used to reinforce these skills. Specialised calculator skills of estimation and rounding-off also need to be developed and reinforced.

Learners need to be presented with opportunities to become familiar with and use artefacts from relevant workplaces; for example, reading and interpreting non-standard graphs, chemical labels, tables, charts, calibration templates and other ready reckoners; using calibrated equipment; and completing record sheets and templates for calculations accurately. They also need to be able to plan, organise, cooperate and communicate effectively in realistic situations. Given that learners will need to make sense of activities and possibly ill-defined problems in unfamiliar workplace situations, realistic group projects with open-ended solutions and shared responsibilities need to be devised. Because enterprises are so specific and not every context/situation can be incorporated into formal chemical use training, metacognitive strategies (learning to learn, critical thinking, planning, problem-solving) are crucial and need to be consciously developed.

# Learning in the workplace

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:

- ✧ the available skills and learning abilities of the employee
- ✧ the employee's willingness to learn
- ✧ the on-the-job learning opportunities
- ✧ the availability of on-the-job training
- ✧ the relationships and mutual influences of all of these.

Both the job content and the work environment can open up learning possibilities.

Billett et al. (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. Brown (1998) includes among critical learning processes, encouraging workers to reflect upon their own learning, to see beyond the surface level, and to see their own practice as continually developing rather than being 'the acquisition of a fixed body of knowledge or a set of immutable competencies' (p.169).

Brown supports Billett et al.'s (1997) claim that there is no one best context for 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 (for example, Sefton, Waterhouse & Deakin 1994; Sefton, Waterhouse & Cooney 1995;

Waterhouse 1996). Mathematical knowledge and skills are totally integrated into the program of work-based learning, with successful outcomes for a range of workers, including workers from non-English speaking backgrounds.

Ethnographic studies also 'emphasise that the nature of work itself is collective, and almost always requires the informal collective interaction and action among individuals' (O'Connor 1994, pp.281–2). 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.

Working and learning numeracy, as part of a community of practice is one of the consistent themes emerging from the present research, so opportunities should be encouraged to share information and work out numerical problems. These opportunities could flow into the practical exercises that could become part of any learning situation, and which several of the research participants found to be relevant and invaluable for their initial learning.

Measurement tasks—especially as group activities—provide an excellent vehicle for teaching and reinforcing knowledge of the real number system, at least as far as the rational numbers are concerned. Learners need to gain an embodied experience of relevant measures, discussed above. Most of all, they need to understand the fundamental relationships of the metric system, that is, the relationship between the capacity of one litre, the weight (mass) of one kilogram of water, and the volume of a cubic decimetre (10 cm x 10 cm x 10 cm). Or, that one millilitre of water weighs one gram, and would have the volume of one cubic centimetre.

According to Coben et al. (2003), the nature of adults' contexts—their possibilities and constraints—needs to be made prominent and integral to the process of teaching. 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 for achieving particular workplace goals.

Workplace resources and ideas could also come from some of the statutory authorities, particularly those departments that require mandatory reporting of chemical handling and spraying. When developing the notion of numerical calculations being made with environmental conditions in mind, some simulation could be applied off the job, but there may be other times when opportunities to view video material relating to specific weather and workplace conditions are more appropriate.

Reflective thinking is required for mathematical literacy. To develop such reflective thinking, Keitel, Kotzmann, and Skovsmose (1993) propose starting from a meaningful problem context, an idea which accords well with Onstenk's (2001) problem-based model of developing broad occupational competence. In both formal education and workplace learning, it is desirable to encourage learners to keep a logbook or journal about strategies they would adopt in certain situations. To this end, learners should also be encouraged to collect copies of their manager's and supervisor's 'tried and true' methods worked out over a period of time, to cover a number of different situations.

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. 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.

Transfer may be assisted by embedding numeracy learning into a wider context. For example, within the context of chemical spraying, learners' workplace numeracy skills will actually be enhanced if they understand the whole process of chemical spraying (in horticultural/rural contexts, this is called the integrated pest management plan), such as:

- the identification of the pest
- the most appropriate response—biological or chemical responses
- the life cycle of the pest and at which stage the chemical will be most effective
- the numerical calculations to allow for the impact/influence of factors such as pest identification and the use of certain enterprise-based 'spray models'.

They will learn how to think more critically about issues of workplace safety and business through the decisions they make concerning rotation and choice of chemical.

In the case of numeracy in the warehousing enterprises, there are some further considerations for trainers and teachers to consider—which also relate to the other industries. These concern the workers' ability to interact with computerised systems which could hold information that is integral to the effective running of the business. A survey of those enterprises involved in training at the time, and which use such systems to carry out some kind of interface with chemicals, may contribute to further teaching strategies being implemented, as well as providing a useful resource for the learner. In the case of sensitive data, a simulation could be organised.

# Conclusion

## Discussion of findings

In light of the case study findings, the definition of numerate behaviour by Coben seems the most appropriate in the context of teaching and learning numeracy on the job:

> 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, p.35 cited in Coben et al. 2003, p.10)

The findings of this project support the messages from the international literature on mathematics/ numeracy in the workplace; for example, that mathematical elements in workplaces are subsumed by workplace routines, structured by mediating artefacts (such as tools and equipment, calibration templates, record sheets), and are highly context-dependent. In other words, the priority is to get the job done as efficiently as possible—not to practise and refine mathematical skills.

Although, in contrast to formal education, solutions to calculations and eventual measurements and operations for chemical spraying must necessarily be error-free, the actual methods used allow some discretion with respect to the manner in which results are achieved. More importantly, they involve collaboration with or validation by at least one other person with experience of the task, as well as the use of historical records.

Unlike formal mathematics, the results obtained really matter in terms of public and personal safety, environmental protection, and maintaining one's job. Somewhat paradoxically, the mathematical correctness or precision may be negotiable, according to the task at hand; for example, rounding 447 litres to 450 litres, or judging 15 ml to be about half-way between 10 ml and 20 ml on a graduated scale.

## Implications for policy/practice

Although workplace supervisors tend to assume a strong foundation of school mathematics and the transference of such knowledge, this is not necessarily the case for many workers in chemical spraying. Often these skills need to be reinforced in the mandatory training required by the legislation in New South Wales and Victoria, as well as in training packages. Findings from this study indicate that most workers have undertaken formal chemical use training. However, as each workplace is individual, mentoring and support in the implementation of numeracy processes within the particular enterprise are still required. Because enterprise skills are so specific and not every context/situation can be covered in formal training, metacognitive strategies (learning to learn, critical thinking, planning, problem-solving) are crucial and need to be consciously developed.

Learners need to have their existing skills and knowledge recognised and built upon. They need to become reflective of their own practice and their own learning, able to use the reflection to inform practice, and understand that learning is ongoing and that practice is always developing. Learners also need to work as part of a group—within a community of practice—to work out chemical calculations and to manage knowledge relating to specific chemicals, equipment and other variables.

Although an analysis of common units of competency suggests that they appear to capture numerical outcomes (but not necessarily the complexity of context) in accordance with observations from the case studies, questions arise as to how competently the units of competency would be developed by teachers or trainers with little or no background in mathematics education or little or no knowledge of the social–cultural numeracy context of the workplace.

In any case, holistic rather than atomistic teaching methods would enhance the capacity of learners to accommodate the complexity of demands they face on the job. Teachers and trainers need to be aware that numeracy is not just 'basic maths' but a complex set of skills and knowledges drawn upon in often ill-defined situations for ever-evolving problems. There is an urgent need for specialised preparation of and/or professional development for teachers and trainers involved in adult numeracy.

Sanguinetti and Hartley (2000) highlight that the assessment focus of training packages limits opportunities for the development of knowledge listed under the 'required knowledge' heading within units of competency. Training package developers need to identify numeracy demands in specific ways and to incorporate this information at an appropriate level (for example, unit, element), not simply as 'required knowledge' or 'key competencies'. This would enable learners to be given recognised opportunities to develop their numeracy skills, on and off the job.

This research on learning numeracy in the workplace has identified a gap in the literature which needs further development. The literature review identified research on mathematical/numerical skills used on the workplace, how it might be taught in formal educational institutions, and general literature on workplace learning. However, there has been little attention until now focused on how numeracy is learned in the workplace, taking into account the complex issues which surround apparently simple calculations, and the importance of social, cultural, and historical contexts. Similarly, research is also needed for the further development of vocational teacher/training education in relation to workplace numeracy.

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# Support document details

Additional information relating to this research is available in *Learning numeracy on the job: A case study of chemical handling and spraying—Support document*. It can be accessed from NCVER's website <http://www.ncver.edu.au>. The document contains:

- Literature review
- Analysis of rural/conservation common units of competency against the National Reporting System
- Case studies

# Other publications on adult literacy and numeracy

*Adult learning through fire and emergency service organisations in small and remote Australian towns*
Christine Hayes, Barry Golding, Jack Harvey

*Adult literacy and numeracy: At a glance*
Sue Foster, Francesca Beddie

*Building sustainable adult literacy provision: A review of international trends in adult literacy policy and programs*
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For further information about these publications visit the NCVER website
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