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Teaching and learning numeracy on the job: the case study of chemical spraying and handling. Work in progress.

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Abstract

In this paper we discuss our recently completed National Centre for Vocational Education Research project. Between us we visited 12 work sites encompassing five industries in NSW and Victoria. We interviewed supervisory and operative staff, collected artefacts relevant to the numeracy of chemical spraying and handling, and made observations. Through our data collection and analysis, we became aware of the complexities involved in actual practice, even though the calculations themselves involved no more than the four basic processes, measurement, and ratio/proportion. Drawing upon a sociocultural and historical activity theory foundation, the presentation will share the findings and their implications for teaching and learning numeracy in the workplace as well as in institutional settings.

Introduction

The activities of chemical preparation, application, transport, handling and storage undertaken by operative workers are high risk activities in terms of occupational health and safety of workers and their clients; also in relation to environmental damage (e.g., Robinson, 2003). They place high demands on workers' numeracy and literacy skills. Although there is a growing body of literature worldwide on what mathematics or numeracy skills are used in the workplace, there is very little research on how these skills are actually learned in the workplace (FitzSimons, 2004).

Thirteen enterprises in NSW and Victoria were selected for interview and/or observation. These included two metropolitan councils, one orchard, two vineyards, three golf courses, one vegetable grower, two large nurseries, and two chemical storage warehouses. Detailed observation of participants, that is operative workers undertaking numeracy tasks during chemical spraying occurred where possible. Semi-structured interviews were also undertaken with operators and/or their managers. Where permission was granted, the collection of artefacts took place, including actual samples of materials used (for example procedures, manuals, charts).

Activity theory

Yrjö Engeström (1999) describes Activity Theory as providing a worthy unit of analysis for enabling a theoretical account of the constitutive elements of an object-oriented, collective, and culturally mediated activity system in all its complex interactions and relationships. The minimum elements of this system include the object, subject, mediating artefacts (signs and tools), rules, community, and division of labour (Figure 1).

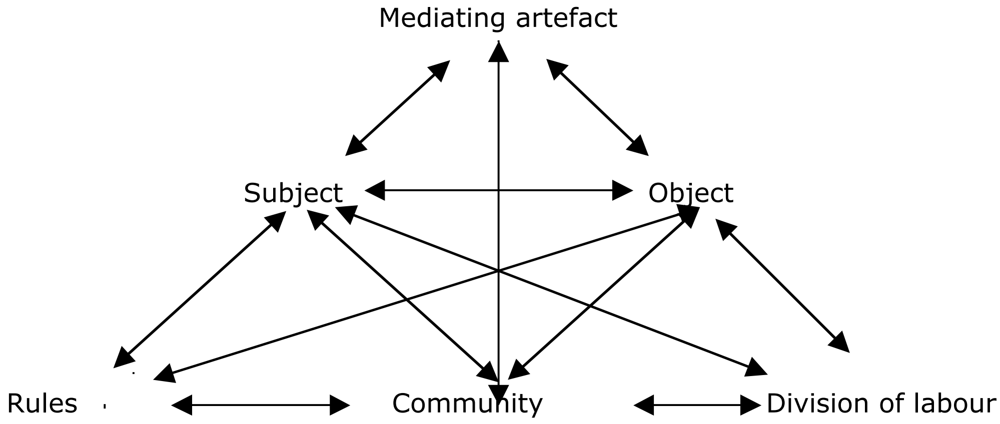

Figure 1. The basic mediational triangle expanded (after Engeström, 1987)

Engeström (1999, p. 9) continues that: "the internal tensions and contradictions of such a system are the motive force of change and development."

Engeström (2001) elaborated five principles to summarise activity theory and cross-tabulated these with four questions central to any theory of learning (Figure 2). In this context the concept of learner is taken broadly, to include *all* participants in the dynamic process.

	Activity system as a unit of analysis	Multi-voicedness	Historicity	Contradictions	Expansive cycles
Who are learning?					
Why do they learn?					
What do they learn?					
How do they learn					

Figure 2. Expansive learning model (Engeström, 2001, p. 138)

This model served to frame the interview questions and subsequent analysis. (See FitzSimons, 2003, for further elaboration on activity theory in relation to further education.)

Findings

Although there have been many definitions of numeracy proposed over recent years, the definition of numerate behaviour by Coben (2003) which seems the most appropriate in the context of teaching and learning numeracy on the job is as follows:

> 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. (p. 10)

The following were identified as the underlying mathematics concepts in chemical spraying and handling: addition, subtraction, multiplication & division of whole numbers and decimals; ratio & proportion; measurement: length, area, volume, capacity, mass [usually metric]; estimation; and approximation. The following were identified as processes used by workers to undertake these calculations: estimation, pencil & paper methods, use of basic 4-function calculator; verbal or written communication with other workers; consultation with prescriptive calculations sheets and with historical records; completion of up-to-date records of chemicals used and their amounts; and consideration of other contextual factors, e.g., date/time; block area; crop; crop stage; weed/pest/disease targeted; chemical group; rate/ha; litre spray applied; method of application; temperature; wind speed; wind direction; rainfall; humidity.

How do workers learn to do these calculations? Most of these basic calculations are taught initially in school prior to the post-compulsory years. In the case of chemical spraying, most, if not all, of the workers have the Farm Chemical Users Certificate, or equivalent, and the relevant calculations are revised and practised here, in (semi-) contextualised settings. That is, the students get to observe and experience actual measurement skills, but what they lack are the ongoing records of any one particular site which provide a deep sense of meaningfulness to their calculations. For the other workplace observations, it seems that most relevant learning is done in the contextualised workplace, through observation, reflection, and creative adaptation to the artefacts and problems or goals at hand. However, these need to be supported by a firm foundation in formal mathematics education together with a determination to make sense of available data (present and historic), and a positive, creative approach to problem solving, especially in workplaces where timely and cost-efficient resolutions are imperative.

In what ways did the workplace setting impact on how the calculations were done and how the processes were learnt by workers? In the chemical spraying 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 big role in determining reasonableness of answers. It also determines whether and how to approximate answers. Most importantly, the learning in the workplace varies from school mathematics education in that workers are always reminded to check their calculations for reasonableness, to ask repeatedly if they are not sure, and to consider their own and others' personal safety.

Implications

The numeracy task of preparing and applying chemicals requires that a complex set of variables must be taken into account by the person responsible. Numeracy in chemical spraying and handling is always a social-historical and cultural practice, involving the transformation of school-based mathematics. Estimation is always absolutely necessary, based on prior experience of the kind of spraying needed, or even of just sensible results for the novice. Common sense is of the essence. Judgements are needed as to when it is appropriate to approximate the chemical mixture and when it is not, and how this approximation may be usefully made. It is never acceptable to make a mistake in the actual process — it may threaten public and environmental safety, also the livelihoods of the operators and their managers. All calculations must be double-checked, and asking questions where any doubt exists is strongly and repeatedly encouraged. Confidence in undertaking the numeracy tasks comes from several sources, including the support of 'expert' knowledge from the managers within the workplaces as well as the internet. Team and group work is fostered as part of workplace practice. Artefacts are used as resources to aid in formal calculations, or in other situations requiring assessment and evaluation.

What does this mean for ACAL numeracy practitioners? First of all, Coben's (2003) definition of numeracy suggests adopting a critical approach to mathematics. In other

words, there may be occasions when a non-mathematical approach is best suited to the context at hand. It is also necessary to take contextual factors into account in drawing upon a repertoire of mathematics or numeracy skills and knowledges and in deciding the degree of accuracy appropriate to the task. As far as is humanly possible, workplace tasks need to be error-free — this requires a sociocultural-historical approach to problem solving.

Our observation of workplace learning processes suggests that learners need to develop the skills of:

- 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
- calculating with parts of the metric system within the parameters of practical measurement of chemicals, distances, areas, speed, etc. — generally from milligram to kilogram, and millilitre to litre, millimetre to metre, square metre to hectare
- actually measuring out calculated amounts within margins of error appropriate to the task at hand
- reading and interpreting non-standard [i.e., not Cartesian] graphs, tables, charts, and other ready-reckoners
- completing record sheets and templates for calculations accurately
- communicating effectively with other workplace personnel in relation to the above
- planning and organising tasks [where given responsibility] to ensure effective use of time, equipment, and consumable materials.

Strategies that could be applied by workplace trainers and teachers

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. 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 in an embodied way: that is, relationship between the capacity of one litre, the weight [mass] of one kilogram of water, and the volume of a cubic decimetre [10cm x 10cm x 10 cm]. Or, that one millilitre of water weighs one gram, and would have the volume of one cubic centimetre.

'Body maths' helps learners to align various standard measurements with parts of their body (e.g. "Find somewhere on your body which is 1 cm, 10 cm, 15 cm, … 1 m in length. Record and share your findings with other members of the group.) 'Container maths' asks learners to guess and check (with kitchen or scientific measuring equipment) the weight, volume and/or capacity of variously sized used bottles and packages where the official measurements have been removed. Activities which use small variously coloured sweets with chocolate centres can draw on the fact that a 250 gram pack contains about 250 sweets, and learners can develop a real sense of the weight of 1 gram, for a start. 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

As noted above, learners need to be presented with opportunities for reading and interpreting non-standard graphs, tables, charts, and other ready-reckoners, and for completing record sheets and templates for calculations accurately. They also need to be able to plan, organise, co-operate and communicate effectively in realistic situations. Problem-solving activities are recommended, using case study examples from each of the industry workplaces. In order to optimise further these learning experiences it is also recommended that realistic group projects with open-ended solutions and shared responsibilities, including public presentation of the process, be devised.

Resources may be drawn from ARIS publications, from specialist mathematics education resource providers including the Australian Association of Mathematics Teachers, or even from the more learner-focussed secondary mathematics textbooks. 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.
Working, and learning numeracy as part of a team, is one of the consistent themes that has come out of this research, so opportunities should be encouraged to share information and work out numerical problems. These opportunities could flow into the practical exercises that should be part of any training situation and which several of the research participants found to be relevant and invaluable for their initial learning. There may be further opportunities for practical activities, on a larger and more varied scale, if teachers could make links with enterprises for the use of part of their premises, for example, on a golf course. Encouraging learners to also keep a logbook, or journal about strategies they would adopt in certain situations is also an invaluable exercise and an individual 'living' resource. To this end, workplace 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.
Conclusion
In this paper we have highlighted the importance of a critical approach to numeracy to ensure the safety and well-being of workers, the public, and the environment in the hazardous work of chemical spraying and handling. We have identifed the kinds of mathematics/numeracy skills and knowledges likely to be needed for this kind of work, and outlined some pedagogical strategies for their development.

Crucially, the practice of using and learning numeracy in the workplace is a sociocultural-historical activity — a far cry from the traditional formal mathematics education experienced by most people in school, especially in days gone by. The ability to communicate is of the essence, and this incorporates mathematical understandings even though they may be largely invisible most of the time. The development of authentic communication skills should form an integral part of any vocational numeracy education.

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