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DOING, THINKING, TEACHING, AND LEARNING NUMERACY ON THE JOB: AN ACTIVITY APPROACH TO RESEARCH INTO CHEMICAL SPRAYING AND HANDLING

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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 ethnographic observations. Through our data collection and analysis, we became aware of the complexities involved in actual practice, even though the calculations themselves were relatively straightforward. These complexities were strongly related to the notion of 'joint practice', workplace culture, context, and history. Drawing upon a sociocultural and historical activity theory foundation, the paper will discuss the research process, findings, analysis, and the 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. They place high demands on workers' numeracy and literacy skills. In NSW and Victoria there are stringent legal requirements on the handling and spraying of chemicals, including substantial record-keeping detailing the many and varied contextual factors which may be in operation. The purpose of this project was to investigate numeracy practice in relation to Chemical Spraying and Handling by operative workers within the amenity horticulture, rural production, local government, outdoor recreation and warehousing industries.

There are many recent studies of how mathematics/numeracy is used in the workplace which take sociocultural context into account (e.g., Hoyles et al., 2002; Kanes, 2002; Wake & Williams, 2001). These studies show that mathematical elements in workplace settings are subsumed into routines, structured by mediating artefacts, 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 (FitzSimons, in press). However, there appears little on how numeracy is actually taught and learned in the workplace —Kanes's discussion of the transformation of school-based mathematical knowledges and skills into workplace numeracy outcomes is as an informal rather than an intentional educational process.

There have been many definitions of numeracy in relation to adults proposed in recent years (see FitzSimons, in press, for examples), but the definition of numerate behaviour by Coben (2003) 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. (p. 10)

Regarding workplace numeracy education, the literature suggests that it requires a fundamentally different curriculum and pedagogy from that of school mathematics, encompassing 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. Studies of workplace education and training point to one way in which this process could be enhanced whereby workers are included more effectively and equally into practice through a process of being scaffolded jointly with knowledgeable others in an exchange of both tacit and expert knowledge (see for example, Gee, 1999).

Methodology

The project involved ethnographic research in which a major concern was to look at the cultural systems/patterns of culture within the workplace setting. Thirteen enterprises were identified during the initial stage of the project through consultation with relevant national Industry Training Advisory Bodies. We visited sites including parks, vineyards, orchards, plant nurseries, golf courses, and chemical warehouses. Qualitative data was then gathered (via 12 visits and 1 phone interview) through semi-structured individual interviews with operative workers, supervisors/mentors, and one workplace trainer, to capture a range of perspectives. Where permission was granted, the interviews were audiotaped for further analysis. Observation of the actual numeracy processes involved in undertaking chemical tasks occurred where possible, and artefacts (e.g., procedures, manuals, charts) were collected (with permission). The interview data and observations were analysed to identify common themes, issues and potential strategies that could inform teaching practice.

Interview questions and observations were derived from sociocultural activity theory as outlined by Engeström (2001). Activity theory, historically linked to the work of people such as Vygotsky and Leont'ev, proposes that the object of learning for a subject or a group of subjects is mediated by cultural artefacts such as tools, texts, and language. These are set in the context of social/collective elements of rules (principles of regulation of action and interaction), community (individuals or groups concerned with the same object), and division of labour (the division of tasks and status relations between actors) (Daniels, 2004). Each of these elements is dialogically related, and Engeström (2001) draws on ideas of multi-voicedness, historicity, and contradictions to develop the framework to take account of expansive learning at work informed by activity theory.

While there was encouragement to revisit the enterprises at a later stage, there was a sense of urgency on the part of the researchers to get as much information as possible on the day of interview. This limited amount of time did not always provide an opportunity for in-depth observation of workplace practice — due to night spraying, or the time of the growing season, for example. Also, it was not always possible to

interview the operators who conduct the spraying, or to complete interviews with other workers apart from the manager or supervisor of the workplace. However, in some cases, managers had already organised for one of their supervisors to follow them in speaking with the researcher. Consequently, most of the data was drawn from supervisors rather than operators, although at least two current trainees from quite different industries, were also interviewed and provided a rich source of information about their learning process.

Findings

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 not only by the person responsible, but by all those workers involved in situations of ‘joint practice’. Critical tasks included the calculation and measurement of chemicals, taking into account variables of space, time, carrying capacity of particular tanks, and environmental scans; 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 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; litres of 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. 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. Apprentices and new workers are ‘scaffolded’ into the appropriate practices relevant for each of their workplaces.

In what ways did the workplace setting impact on how the calculations were done and how the processes were learnt by workers? 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 big role in determining reasonableness of answers. It also determines whether and how to approximate answers. Most importantly, 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.

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 not only public safety but also the livelihoods of the operators and their managers. Workplace numeracy tasks are always a social-historical and cultural practice — previous experience and historical data play a big role in determining reasonableness of answers.

Discussion

Eraut (2004) acknowledges the complexity of transfer of knowledge from school to workplace, and identifies five interrelated stages:

1. the extraction of potentially relevant knowledge from the context(s) of its acquisition and previous use;
2. understanding the new situation—a process that often depends on informal social learning;
3. recognizing what knowledge and skills are relevant;
4. transforming them to fit the new situation;
5. integrating them with other knowledge and skills in order to think/act/communicate in the new situation. (p. 256)

Although, as noted by Eraut, points 2, 4, and 5 tend to be ignored in formal institutional education and workplace training processes, their importance is underlined in the particular case of workplace numeracy, as reported in this study (see also Kanés's, 2002, study of the hospitality industry). In workplaces such as those we observed, the personal knowledges that operators bring to the workplace situation, both codified and non-codified, are important factors, as is the non-codified cultural knowledge of the workplace. In these industries codified knowledge is also essential due to the high risk factors involved with chemical spraying and handling.

Boreham (2004, p. 209) describes work process knowledge as “a systems-level understanding of the work process in the organization as a whole, enabling employees to understand how their own actions interconnect with actions being taken elsewhere in the system.” He goes on to suggest that, as a synthesis of “codified knowledge about the work domain with experiential knowledge of that domain, work process knowledge goes beyond what was known before” (p. 215). Crucially, he argues, this synthesis of codified and personal knowledge allows sufficient sense-making to enable people to act in the work situation. In the situation of chemical spraying and handling, workers need to be acutely aware of the possible consequences of their actions (especially mistakes) for the entire enterprise, as well as for the wider community. Boreham's observation that work process knowledge is embedded in the artefacts, routines and practices of the workplace, together with interactions between the workers in their stories, is supported in our observations and interviews.

Interrelated with formal learning in the workplace is the informal learning which also takes place as workers listen, observe, and reflect, practising and refining their skills. As noted above, the sociocultural and historical support structures are essential. Eraut (2004) identifies an eight-category typology of aspects of informal learning in the workplace which he suggests might better be used as part of an heuristic process for use in research and consultancy. Drawing from the extensive range of Eraut's exemplars, outstanding impressions of integral components of successful workplace practice in chemical spraying and handling include:

- (a) having an awareness and understanding of the problems and risks,
- (b) having the confidence and knowing when to seek and gain information and confirmation from other workers, manuals, package labels, historical records, and even the internet,
- (c) being able to cope with the complexity of information potentially available,
- (d) having the ability to learn from experience, and
- (e) developing the teamwork skills of joint planning and problem solving.

Eraut notes the vital importance of giving and receiving feedback. Our research shows that supervisors allowed novices restricted parameters for decision making, always under guidance, until they had a proven record of safe practice. In this way serious mistakes could be avoided, yet opportunities for reflection on misjudgements could be provided as learning experiences. This is in striking contrast to the individual focus typical of formal mathematics/numeracy education where mistakes are commonplace but without any serious consequences.

It is important to highlight the crucial role played by artefacts in workplace learning. Drawing on the work of Vygotsky, Stetsenko (1999, p. 246) argues that cultural tools “can and should be viewed not merely as objects (things), but as embodiments of certain cultural practices, crystallized templates of action, schematized representations of certain ways of doing things in human communities.” The artefacts utilised in chemical spraying and handling included: (a) the equipment used, in setting parameters for practicable quantities and the associated reasonableness of calculations; (b) the mathematical and related safety information obtained from labels, manuals, charts, the internet, etc.; and (c) the historical records enabling past and future comparisons of chemical quantities, areas, locations, times, weather conditions, and so forth, to be made. All of these were underpinned by communications with fellow workers as participants in this community of practice, albeit with varying degrees of responsibility, who were involved in the task. According to Engeström and Middleton (1996), expertise is viewed as an “ongoing collaborative and discursive construction of tasks, solutions, visions, breakdowns, and innovations” (p. 4).

Discussing joint, collective activity in relation to communication, Lektorsky (1999, p. 110) notes that it presupposes “inter-individual relations, not simple activity and actions, but inter-activity and inter-actions. ... Collective activity presupposes a goal that is common for all participants and cannot be achieved by them separately.” However, the ways of achieving this goal can be different, as can the forms of collective activity. In the case where collective activity is distributed, the activity consists of a number of different actions, and each participant fulfils his own actions. Lektorsky observes that the “research has shown that in particular the process of interiorization should be understood not as the result of the transformation of individual activity, but as the form of the individual appropriation of collective forms of activity.” In terms of our research on how numeracy is learned in chemical spraying, the goal is the safe and effective application of spray to the targetted area. The activity is distributed between supervisors, operators, and sometimes other personnel such as tractor drivers. In relation to the practical outcomes derived from numerical calculations, the responsibility is jointly shared. However, it appears that for the newcomer there is a need firstly to transform their school-based numerical knowledge into a workplace numeracy tool, supported by other workplace colleagues and artefacts. Once they are considered

competent for the task at hand, then the operator may be considered to appropriate ‘collective forms of activity’. Gradually, the tasks might increase in complexity as the operator moves up in the organisation.

Adopting an activity theoretical framework in relation to learning associated with work, Griffiths and Guile (2003) stress the importance of (a) the historical and organisational contexts; (b) the mediation of the relationship between different kinds of knowledge and experience (i.e. theoretical and everyday); (c) “opportunities to participate in forms of social practice, for example, using context-specific language to clarify understanding and resolve problems” (p. 58); and (d) assistance for learners and educators “to create new knowledge and new educational and workplace practices” (p. 59). These factors were particularly salient in our research, especially in relation to numeracy. However, to be numerate in the workplace requires a foundation of mathematics knowledge.

Boreham (2004) observes that new German GAB vocational curriculum places a high priority on continuing mathematics education in its own right in parallel with vocational education. The assumption is that since knowledge creation is an intrinsic part of the work process, the cognitive resources of the academy and the workplace should be treated as mutually constitutive. Mathematics knowledge assists workers to be creators — not just users — of knowledge that will enable them to participate in processes of continuous improvement.

In terms of formal workplace numeracy training in Australia, questions arise as to how competently workers would be taught by teachers or trainers with little or no background in mathematics education, particularly in relation to adult learners or early school leavers. Teachers and trainers need to be aware that numeracy is not just ‘basic maths’ but a complex set of skills and knowledges, extending far beyond the four processes. 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 a world of rapidly changing technologies and continuously evolving problems requiring creative solutions, rote learning of algorithms is not (and never was) sufficient.

Implications

Numeracy in the workplace involves the practical application of rational numbers and the metric measurement system with contextualised approximations and estimations in critical calculations. It also may incorporate each of the Mayer (1992) Key Competencies (e.g., planning, problem solving, organising, co-operating 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 Cartesian graph), and where mistakes are but temporary setbacks.

Pre-vocational education in mathematics needs to develop embodied knowledge of the metric system and its integral links with the real number system. It needs to place emphasis on accurate recording and interpretation of complex data via the media of non-standard graphs, tables, chart, and other ready reckoners. Allied to this is the need for effective communication with other workplace personnel, along with all other key competencies (Mayer, 1992). These skills might be further developed through authentic group project work, including multimedia presentation of the entire process to other members of the class. Simulations based on videos, even videopapers (Olivero, John, &

Sutherland, 2004) of *actual* work practices might also be of value in developing the broader skills required for participation in the world of work and democratic citizenship. Unlike formal mathematics education, value judgements about people and their environment are an explicit or implicit concern in chemical spraying and handling.

Training package developers need to specifically identify numeracy demands and incorporate this information at an appropriate level (e.g., unit, element), and not only 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. Although workplace supervisors may assume a strong foundation of school mathematics skills this is not necessarily the case for all workers involved in chemical spraying and handling.

Specialised tuition, taking account of the literature on learning as a sociocultural activity, may be needed for workers to develop or reinforce the relevant mathematical skills in relation to the mandatory chemical spraying and handling certificates required in these industries. Formal workplace training needs to go beyond the prevalent context-reduced, worksheet-oriented, individualised learning mentality to place the required skills and knowledges in possible authentic contexts of use — as described above. Learners who have been away from formal education for some time, and others who did not succeed in the school environment, may need some assistance in learning to learn and the development of metacognitive skills. Most important, however, is the acknowledgement of their existing skills and knowledges.

Conclusion

This research on learning numeracy in the workplace, which takes into account the complex issues surrounding apparently straightforward calculations, and the importance of social, cultural, and historical contexts, needs further development. This research project has taken a small step in that direction, to underline the importance of such an approach which goes well beyond the identification of 'functional skills' in isolation from context — typical of workplace research in days gone by.

Similarly, research is needed for the further development of vocational teacher/training education in relation to workplace numeracy. If workers are to participate effectively in processes of continuous improvement in workplaces, they need a strong foundation in a broad range mathematics knowledges and skills which are able to be (re)constructed and utilised in situations with important practical outcomes. This has implications for both compulsory and post-compulsory education and training, and needs to be underpinned by serious efforts at collaboration between mathematics education researchers, industry workers with immediate workplace experience, and (potential) numeracy/mathematics teachers.

The challenge for the future is to adequately prepare numerate citizens for whatever life and work circumstances they confront.

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