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MATHEMATICS IN THE WORKPLACE: ISSUES AND CHALLENGES

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Abstract

This chapter argues that there are contrary views regarding the mathematical needs of employees in workplaces, and this results in confusion around debate on the issue. The problem has been exacerbated by the ubiquity of information technologies and the widespread automation of routine procedures, which have resulted in little if any trace of the mathematical processes going on. Following a short survey of research in the field, we summarize recent research that has identified a particular difficulty in terms of widespread pseudo-mathematical interpretation of symbolic output in workplaces. Such interpretations are shown to impede communication, but can be challenged by developing relevant techno-mathematical literacies among employees. Effective strategies for developing techno-mathematical literacies relevant to specific work sectors are described.

Key words: technology, techno-mathematical literacies, workplace mathematics**.**

MATHEMATICS IN THE WORKPLACE: ISSUES AND CHALLENGES

In political and educational debate, there is contrary opinion about the mathematical needs of employees. Several influential studies report that, apart from recognizing the need for a small layer of 'symbolic analysts' (Reich, 1992), employers do not prioritize mathematical skills (e.g., Department of Labor, 1991). In the contrary direction, there are studies in economics and educational policy, which assert that a mathematically literate population is crucial for the economic future of developed countries (Steen, 2001; Wolf, 2002; Confederation of British

Industry, 2008). How can this apparent contradiction be understood? We suggest that the contradiction arises from a confusion about what constitutes mathematics and consequently, how mathematical skills are identified (FitzSimons, 2002).

Until the middle of the nineteen-eighties, research into the mathematical requirements of workplaces assumed that the mathematics used was unproblematically visible to employers and employees alike, so that data on mathematical needs could be obtained by conducting interviews with appropriate personnel and asking for descriptions of workplace activities in mathematical terms. Invariably, such studies demonstrated that little mathematics was used in work and what *was* used was restricted to procedures and calculation, measurement and arithmetic (see, for example, Fitzgerald & Rich, 1981; and for a critique of this approach, see Noss, 1998). The purpose of this Brief Report is to summarize a more nuanced picture of how workplace mathematics should be understood and developed, as emerging from the most recent research in workplace mathematics (in particular Hoyles, Noss, Kent, & Bakker, 2010).

Findings from ethnographic studies

One step in this direction has been a series of ethnographic studies of particular work settings. The seminal work by Scribner (1984) on the cognitive (including mathematical) strategies of dairy workers provided important insights into how people regulate and think about their activities by exploiting salient features of their environment. Since then, a range of occupations has been examined, often focusing on disruptions in the routines of work, disagreements between communities as to required action, or problematic communication. It is at these points that mathematical reasoning aligned with workplace expertise has become more visible (Hall, 1999; Hoyles, Noss, & Pozzi, 1999; Bakker, Hoyles, Kent, & Noss, 2006; Williams & Wake, 2007). Many employees have been the focus of such studies, including carpet-layers

(Masingila, 1994), automotive industry workers (Smith, 1999), technicians (Magajna & Monaghan, 2003), engineers (Gainsburg, 2007; Kent & Noss, 2003), bankers (Noss & Hoyles, 1996), nurses (Pozzi, Noss, & Hoyles, 1998; Hoyles, Noss, & Pozzi, 2001; Noss, Hoyles, & Pozzi, 2002), and employees having 'intermediate-level skills' in sectors such as tourism and food processing (Hoyles, Wolf, Molyneux-Hodgson, & Kent, 2002).

From this corpus of work, we draw two main conclusions. First, the *visible* mathematics of work tends to be fragmented and associated with routine workplace activities involving measurement and recording, or simple calculations. Although these fragments are meaningful to practitioners in terms of solving particular, well-understood problems, they are finely tuned to specific circumstances, and rarely interpreted as applications of more general mathematical concepts or relationships. Second, the less visible mathematics at stake is routinely tacit, rarely articulated in either written or spoken form. Tools and artifacts regulate activities and scaffold actions, so performance in authentic workplace settings generally outstrips performance on standardized written mathematical tests. For example, a review of 30 studies of practicing nurses (Perlstein, Callison, White, Barnes, & Edwards, 1979) revealed significantly flawed performance on pencil and paper tests of drug calculations, average of 76.6% (range: 45%-95%). A later study of expert nurses' actual practice on the ward, showed how they eschewed the formal mathematical methods they had learned in training, in favor of error-free strategies tied to individual drugs, their packaging and the organization of clinical work (Hoyles et al., 2001). Information and communication technologies have introduced further layers of invisibility between employees and the mathematical models embedded in the computer systems used as part of routine work practice. The result has been that little trace is evident of the mathematical processes behind results which appear on screen or printout (Kent, Noss, Guile, Hoyles, & Bakker, 2007).

Thus employers might think that any mathematical knowledge required for effective workplace activity can safely be outsourced to the technology. However, such a deskilling assumption takes as read that outputs of computers can be interpreted unproblematically (which is not even the case for expert scientists, see Roth & Bowen, 2003). Moreover, interpretation and communication between the different communities in any workplace has become increasingly important, under the pressure of business goals in a global and highly competitive market (Bogni, 2010). Technical and analytic information needs to be communicated between shop floor and management, and to customers who are demanding more transparency, more explanations and more flexible responses to their needs (see for example, Victor & Boynton, 1998; Zuboff & Maxmin, 2004). In other words, the tacit mathematics of the workplace needs to be made explicit in ways that are sensitive to the needs of different audiences.

To name the mathematical knowledge that is required to be effective in an ICT-rich context, we have coined the term 'techno-mathematical literacy,' TmL. It is akin to literacy, in that it involves interpretation as well as the ability to appreciate and communicate with others about mathematical information; and it is mediated by technology - *techno* - in that the information is expressed through symbolic artifacts generated by automated systems.

Methods

Our recent work (Hoyles et al., 2010), involved two phases: ethnographic (Phase 1) and developmental (Phase 2). In Phase 1, we developed in-depth ethnographic case studies in a variety of workplaces in the manufacturing and finance sectors, in order to characterize the kinds of techno-mathematical literacies at stake. Methods included work-shadowing, analyses of documentation and semi-structured interviews with managers, team leaders, and a wide range of employees. We progressively focused on the ways in which computer-generated *symbolic* artifacts (charts, graphs, tables of figures, algebraic formulae, and numerical summary measures of performance) served as communicative devices, in the workplace, or between the workplace and customers or suppliers externally. We joined team meetings and listened to conversations around these outputs, to ascertain if problems of communication might be arising and how employees reacted to them; involving 95 person days of ethnographic study in 14 companies, engaging with over 240 personnel, an intensity of work necessary to understand each practice, its distinctive language, and communication requirements.

In Phase 2 computer tools were co-designed with employer partners. These tools modeled elements of the work process, or were reconstructions of the symbolic artifacts identified in Phase 1, as intending to serve a communicative purpose. We called them 'technology enhanced boundary objects' (TEBOs). The aim was that by engagement with TEBOs, a layer of structure could be revealed that we (employers and researchers) deemed to be essential for effective communication, adding, for example, different representations of the output and the functionality to visualize the effects of changing critical variables. In all, we undertook 85 days of development work in 8 companies engaging with over 110 employees.

Techno-mathematical literacies in manufacturing and financial industry

We found that ambiguity and difficulties of communication tended to stem from the *different meanings* accorded to the symbolic outputs of workplace artifacts: the symbols afforded a visible framework that allowed diverse communities to act and think *as if* they had a common purpose, but this was, in fact, rarely the case. Symbolic outputs were interpreted very differently as, on the one hand representing fragments of mathematical ideas derived from an underlying mathematical system, and on the other, as part of workplace or management culture with little or no inherent logic. This latter interpretation we described as *pseudo-mathematical*, rather like numbers on buses.

In Phase 1, a range of TmL was identified in the manufacturing sector including understanding systematic measurement, data collection and display; appreciation of the complex effects of changing variables on the production system as a whole; being able to identify key variables and relationships in the work flow; reading and interpreting time series data, graphs and charts (Bakker et al., 2006; Noss, Bakker, Hoyles, & Kent, 2007). Overall, we identified a ubiquitous requirement to understand and reduce variation, as documented in quality control charts and summarized in two process capability indices, Cp, a measure of spread, and Cpk, a measure combining spread and central tendency in relation to specification limits (Hoyles, Bakker, Kent, & Noss, 2007; Bakker, Kent, Noss, & Hoyles, 2009). Cp summarizes the spread of a distribution in relation to the required specification for the process: .

$$Cp = \frac{USL - LSL}{6\sigma}$$

where: USL = upper specification limit
LSL = lower specification limit
σ = standard deviation

We found that employees across many levels of the workplace interpreted both charts and indices pseudo-mathematically, with weak connections to data or underlying mathematical relationships (Hoyles et al., 2010). In the case of charts, employees, including trainers and managers, failed to understand control limits as artifacts of the distribution, and in the case of process capability indices did not link higher values with reduced variation. There was a tendency to conceive both as arbitrary targets imposed by management.

The TmL at stake in the financial sector included: appreciating the existence of a mathematical model underlying computer output and which variables were critical in determining output; understanding growth (compound interest) and present value of money; interpreting graphs and charts and making estimates and predictions of the costs of loans based on customer requirements and personal details. Here too, the prevalence of pseudo-mathematical interpretations became evident. A remarkable example was that employees who daily engage with loans or life insurance, rarely appreciated that there was *any* relationship between monthly and annual rates of interest, let alone what it might be.

Developing techno-mathematical literacies

The ubiquity of pseudo-mathematical interpretations and the invisibility of mathematical structures suggested a way forward in addressing the problem of developing techno-mathematical literacies in Phase 2, by rendering work process models manipulable through engagement with interactive software tools.

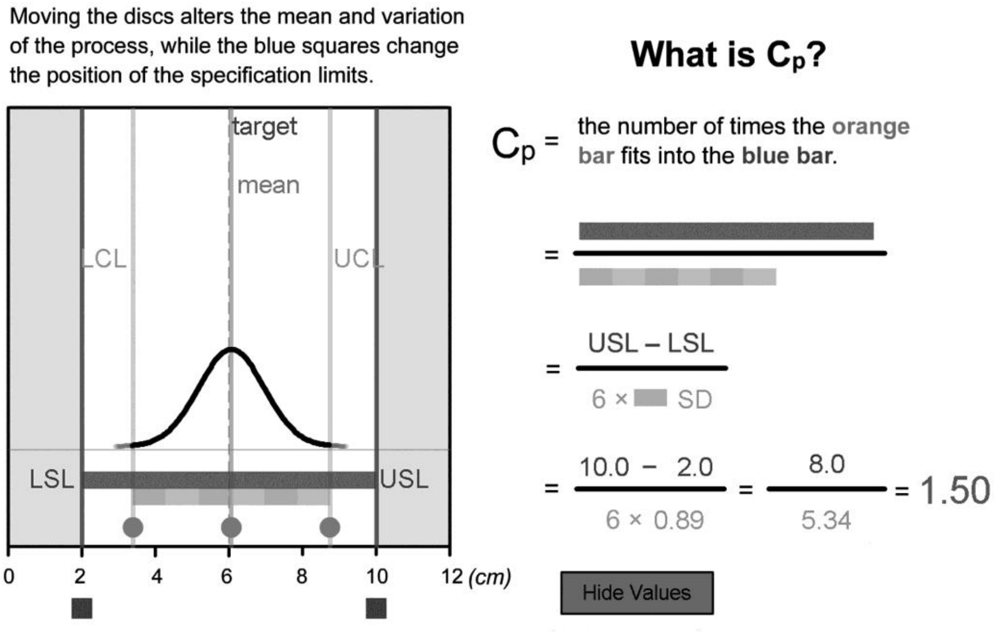

Figure 1: Screen capture image of the Cp tool.

Figure 1 illustrates one TEBO aiming to reveal the fundamental nature of Cp without the need for engagement with the algebraic definition or manual calculation, which we had noted in Phase 1 had diverted employees' attention from underlying mathematical relationships. The TEBO provided employees with an interactive system for manipulating the key variables, the mean and the spread, in relation to the specification limits. A similar TEBO was built for Cpk.

Although our samples were small, we identified in every sector improvement in the relevant techno-mathematical literacies after engagement with the TEBOs, as evidenced in interviews with senior management, and with employees themselves. In the case of the Cp and Cpk TEBOs, there has been remarkable and sustained take-up: In the original factories where the tools were developed, not only with the shop-floor workers but also with supervisors and engineers; and beyond the factories, spreading to SPC courses worldwide (Bakker et al., 2009).

Conclusions

These findings have far-reaching implications. First, automated systems create new knowledge requirements – techno-mathematical literacies – an awareness of how models underpin systems and an understanding of how the values of variables define a system's behavior. Second, this knowledge is largely invisible and rarely picked up on the job. Third, numbers, tables and graphs are widely interpreted pseudo-mathematically, as labels or pictures with little if any appreciation of any underlying mathematical machinery. Pseudo-mathematical interpretations of symbolic information clearly impede communication of technical information between communities, and the interpretation and explanation of computer output needs to be informed by sound and appropriate mathematical judgment. However, the design-based approach suggests that the techno-mathematical literacies required can be developed with the help of suitable computer tools.

References

Bakker, Arthur, Celia Hoyles, Phillip Kent, and Richard Noss. 2006. Improving work processes by making the invisible visible. *Journal of Education and Work* 19(4): 343-361.

Bakker, Arthur, Phillip Kent, Richard Noss, and Celia Hoyles. 2009. Alternative representations of statistical measures in computer tools to promote communication between employees in automotive manufacturing. *Technology Innovations in Statistics Education* 3(2). http://www.escholarship.org/uc/item/53b9122r (accessed October 15, 2010).

Bogni, Rudi. 2010. Data, information and illusion. *Wilmott Magazine*, issue 45.

Confederation of British Industry. 2008. *Taking Stock: CBI Education and Skills Survey 2008*. London: Confederation of British Industry.

Department of Labor. 1991. *What Work Requires of Schools (A SCANS Report for America 2000).* Washington, DC: United States Department of Labor.

Fitzgerald, A., and K. M. Rich. 1981. *Mathematics in Employment (16-18).* Bath, UK: University of Bath.

FitzSimons, Gail E. 2002. *What Counts as Mathematics? Technologies of Power in Adult and Vocational Education*. New York: Springer.

Gainsburg, Julie. 2007. The mathematical disposition of structural engineers. *Journal for Research in Mathematics Education* 38(5): 477-506.

Hall, Rogers. 1999. Rethinking mathematical practices in design-oriented work. In *Rethinking the Mathematics Curriculum*, ed. C. Hoyles, C. Morgan, and G. Woodhouse, 29-47. London: Falmer Press.

Hoyles, Celia, Richard Noss, and Stefano Pozzi. 1999. Mathematising in practice. In *Rethinking the Mathematics Curriculum*, ed. C. Hoyles, C. Morgan, and G. Woodhouse, 48-62. London: Falmer Press.

Hoyles, Celia, Richard Noss, and Stefano Pozzi. 2001. Proportional reasoning in nursing practice. *Journal for Research in Mathematics Education* 32(1): 4-27.

Hoyles, Celia, Alison Wolf, Susan Molyneux-Hodgson, and Phillip Kent. 2002. *Mathematical Skills in the Workplace*. London: The Science Technology and Mathematics Council. http://www.lkl.ac.uk/research/technomaths/skills2002 (accessed October 15, 2010).

Hoyles, Celia, Arthur Bakker, Phillip Kent, and Richard Noss. 2007. Attributing meanings to representations of data: The case of statistical process control. *Mathematical Thinking and Learning* 9(4): 331-360.

Hoyles, Celia, Richard Noss, Phillip Kent, and Arthur Bakker. 2010. *Improving Mathematics at Work: The need for Techno-mathematical Literacies*. Abingdon, UK: Routledge.

Kent, Phillip, and Richard Noss. 2003. *Mathematics in the University Education of Engineers: A Report to the Ove Arup Foundation*. London: The Ove Arup Foundation. http://www.lkl.ac.uk/research/REMIT (accessed October 15, 2010).

Kent, Phillip, Richard Noss, David Guile, Celia Hoyles, and Arthur Bakker. 2007. Characterizing the use of mathematical knowledge in boundary-crossing situations at work. *Mind, Culture, and Activity* 14(1&2): 64-82.

Magajna, Zlatan, and John Monaghan. 2003. Advanced mathematical thinking in a technological workplace. *Educational Studies in Mathematics* 52: 101-122.

Masingila, J. O. 1994. Mathematics practice in carpet laying. *Anthropology & Education Quarterly* 25(4): 430-462.

Noss, Richard. 1998. New numeracies for a technological culture. *For the Learning of Mathematics* 18(2): 2-12.

Noss, Richard, and Celia Hoyles. 1996. The visibility of meanings: Modelling the mathematics of banking. *International Journal of Computers for Mathematical Learning* 1(1): 3-31.

Noss, Richard, Celia Hoyles, and Stefano Pozzi. 2002. Abstraction in expertise: A study of nurses' conceptions of concentration. *Journal for Research in Mathematics Education* 33(3): 204-229.

Noss, Richard, Arthur Bakker, Celia Hoyles, and Phillip Kent. 2007. Situating graphs as workplace knowledge. *Educational Studies in Mathematics* 65(3): 367-384.

Perlstein, Paul H., Cornelia Callison, Mary White, Barbara Barnes, and Neil K. Edwards. 1979. Errors in drug computations during newborn intensive care. *American Journal of Diseases of Children* 133(4): 376-379.

Pozzi, Stefano, Richard Noss, and Celia Hoyles. 1998. Tools in practice, mathematics in use. *Educational Studies in Mathematics* 36(2): 105-122.

Reich, Robert B. 1992. *The Work of Nations: Preparing Ourselves for 21st Century Capitalism*. New York: Vintage Books.

Roth, Wolf-Michael, and Gervase M. Bowen. 2003. When are graphs worth ten thousand words? An expert-expert study. *Cognition and Instruction* 21(4): 429-473.

Scribner, Sylvia. 1984. Studying working intelligence. In *Everyday Cognition: Its Development in Social Context*, ed. B. Rogoff and J. Lave, 9-40. Cambridge, MA: Harvard University Press.

Smith, John P. 1999. Tracking the mathematics of automobile production: Are schools failing to prepare students for work? *American Education Research Journal* 36(4): 835-878.

Steen, Lynn A., ed. 2001. *Mathematics and Democracy: The Case for Quantitative Literacy*. Princeton, NJ: The National Council on Education and the Disciplines.

Victor, Bart, and Andrew C. Boynton. 1998. *Invented Here: Maximizing your Organization's Internal Growth and Profitability*. Cambridge, MA: Harvard Business School Press.

Williams, Julian, and Geoff Wake. 2007. Black boxes in workplace mathematics. *Educational Studies in Mathematics* 64(3): 317-344.

Wolf, Alison. 2002. *Does Education Matter? Myths about Education and Economic Growth.* London: Penguin.

Zuboff, Shoshana, & James Maxmin. 2004. *The Support Economy: Why Corporations are Failing Individuals and the Next Episode of Capitalism*. New York: Penguin.