STATISTICAL REASONING IN THE WORKPLACE: TECHNO-MATHEMATICAL LITERACIES AND LEARNING OPPORTUNITIES

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The "Techno-mathematical Literacies in the Workplace" project is investigating the needs of employees in a range of industrial and commercial workplaces to have functional mathematical and statistical knowledge that is grounded in their workplace situations and mediated by the technological artefacts that surround them. We present some emerging ideas using examples drawn from an industrial workplace where we have noted a "skills gap" concerning the use of statistical techniques for controlling a manufacturing process. We review our analytical framework, that combines activity theory and semiotic ideas, and we discuss some prototype "learning opportunities" for situated statistical reasoning based on the educational statistical software, TinkerPlots.

INTRODUCTION

The "Techno-mathematical Literacies (TmL) in the Workplace Project" [1] is investigating the combinations of mathematical, statistical and technological skills that people need in workplaces. We are investigating three contrasting industry sectors (Pharmaceuticals Manufacturing, Packaging, Retail Financial Services) and we focus on employees at "intermediate" skill level, typically non-graduates with A-level qualifications or equivalent who may be working in manufacturing industry as skilled operators or supervisory managers, or in service industry (such as banking) as sales agents or customer enquiry agents.

This research follows on from a previous project (Hoyles et al, 2002) which promoted the idea of "mathematical literacy" as a growing necessity for successful performance in the workplace. In the current project, we are using the term "Techno-mathematical Literacies" as a way of thinking about mathematics as it exists in current, increasingly IT-based workplace practices. We are convinced that the idea of literacy is really crucial: individuals need to be able to understand and use mathematics as a language which will increasingly pervade the workplace through IT-based control and administration systems as much as conventional literacy (reading and writing) has pervaded working life for the last century.

The project's research consists of two phases. The first (now drawing to a close) was concerned with identifying the mathematical and statistical practices which are present in the three industry sectors. This phase involved case studies in three or four companies per sector. Based on work-shadow observations and interviews, we aimed to understand the work process and to describe what was techno-mathematical about the practices that we observed. One of the results is a set of real contexts and situations in which we think employees' TmL can be improved.

The current phase of the research is concerned with the question of how we can support employees in developing the TmL that are useful in their work. We carry out design experiments (Cobb et al, 2003) in collaboration with companies and industry sector experts, which are characterised by design cycles of preparing, designing, testing and revision of materials that we call "learning opportunities". These are flexible resources for mathematical learning that will eventually be incorporated within, or be presented alongside, workplace technical training materials. Along the process of development, we continue to learn from the learners, trainers and managers within companies. We propose "learning" over "training" to emphasise that rather than thinking of training as transmitting our mathematical knowledge to operators and managers in companies we think of learning opportunities as "boundary crossing" activities (see below) involving the participants and ourselves. This implies we take their perspectives as seriously as ours and use those learning opportunities as windows on the participants' thinking. The learning opportunities are carefully designed to weave mathematical and statistical ideas into real situations and problems as we have observed them on the shopfloor, so as to facilitate particular kinds of discussion, and we value the meanings employees bring to graphs and mathematical concepts, even if they are seen formally as incorrect. Unpacking why they attribute possibly "incorrect" meanings to the graphs is an important element of the learning opportunity, both to them and to us. Without giving ample opportunities for participants to link their concerns with mathematical concepts it is unlikely they will develop a coherent understanding of the problem and theory at issue.

In this paper we will describe one example of a "skills gap" that we have observed in a manufacturing workplace concerning the use of statistical techniques for controlling a manufacturing process, and we will present some emerging ideas (as yet, very early prototypes) for learning opportunities intended to address this situation, based on the educational statistical software, TinkerPlots (Konold & Miller, 2005). This software is a dynamic, interactive data analysis tool that allows users to construct plots using mouse movements and basic operations such as "separate", "stack" and "order", even if they have little formal knowledge of statistics. This allows learners to express their informal ideas more formally, and thus to "construct" formal ideas for themselves, in line with the constructionist approach to learning, and at the same time it allows us to have a window on their thinking (Noss & Hoyles, 1996).

ANALYTICAL FRAMEWORK: WORKPLACES AS ACTIVITY SYSTEMS

We will briefly outline our theoretical framework for analysing mathematical practices in workplaces. We seek to understand how different companies deploy IT-based systems, the forms of (mathematical) knowledge required by employees to operate effectively and how these relate to the managerial strategies adopted by a company. The basic premise of activity theory is helpful in understanding the role of TmL in workplaces: that people work to realise an object of activity (i.e. the purpose of work) through actions which are mediated by artefacts, for example computers and the information that they provide. We interpret each workplace as a complex arrangement of interacting activity systems each characterised by its own object, mediated by artefacts and located in a context characterised by a specific "division of labour", sets of "rules" and inter-related workplace "communities" (see, for example, Kuutti, 1996; Engeström, 2001).

Our thinking about how to conceptualise the relations between the objects of activity and the actions carried out by individuals, both within and between activity systems, is influenced by the debate in the activity theory literature about "boundary-crossing" and "boundary objects" (Tuomi-Gröhn and Engeström, 2003). Boundary crossing builds on Star and Griesemer's (1989) notion of a boundary object, an object which serves to coordinate different perspectives of several communities of practice. Boundary objects are flexible enough that different social worlds can use them effectively and robust enough to maintain a common identity among those worlds. Boundary crossing happens if boundary objects are used across the boundaries of different activity systems and facilitate communication between those systems. Thus tacit knowledge and assumptions can be made more explicit and individuals from different communities can learn something new. For the purpose of our research we mainly think of operators, managers and ourselves as three different communities with different agendas, experiences and formal knowledge brought to bear.

The final, and currently most provisional, part of our analytical framework is the use of semiotic theory (see Bakker, 2004, for background). Activity theory provides a sophisticated "macro-level" account of how knowledge is acquired in becoming part of a workplace community, but the "micro-level" analysis of knowledge at individual and group levels has been less well theorised, and we are investigating how a semiotic analysis may offer a complementary theory for this purpose (cf. Bakker et al, 2004). One focus of interest is in the semiotics of mathematical signs and diagrams (graphs, charts, tables) and the roles they take in reasoning and decision-making in workplace situations.

SITUATED MODELLING

A form of workplace activity that we have encountered almost everywhere, initially identified in previous research (Hoyles et al, 2002) and which is indicative of TmL being involved, is what we call *situated modelling*, in which employees are required to manipulate qualitative *and* quantitative data to monitor processes, diagnose problems and search for solutions. Situated modelling requires some understanding of the sophisticated concepts of variable and functional relationship, however not in an abstract (mathematical or otherwise codified) sense but situated in the workplace context, offering a sense of the key variables and their relationships, supported by workplace-derived intuitions for the meaning of these concepts.

How might employees construct knowledge about models of processes that depend on a combination of contextual and mathematical issues? A core capacity to engage with situated modelling involves being able to make visible the relationships among variables in production processes. In the following we will present an example of a problematic workplace situation where situated modelling, in this case involving statistical reasoning, may help to provide a solution, and we will suggest some emerging ideas for learning opportunities that aim to address employees' development of situated modelling capacities.

AN ILLUSTRATIVE EXAMPLE: GAUGE CONTROL AT PACAWRAP

The following example concerns a packaging manufacturing company, Pacawrap Ltd, which provides an interesting case for study because the work of shopfloor employees involves both physical engagement with the manufacturing process, from which they largely draw their "meanings" for the process, and interpreting IT-based models of the process.

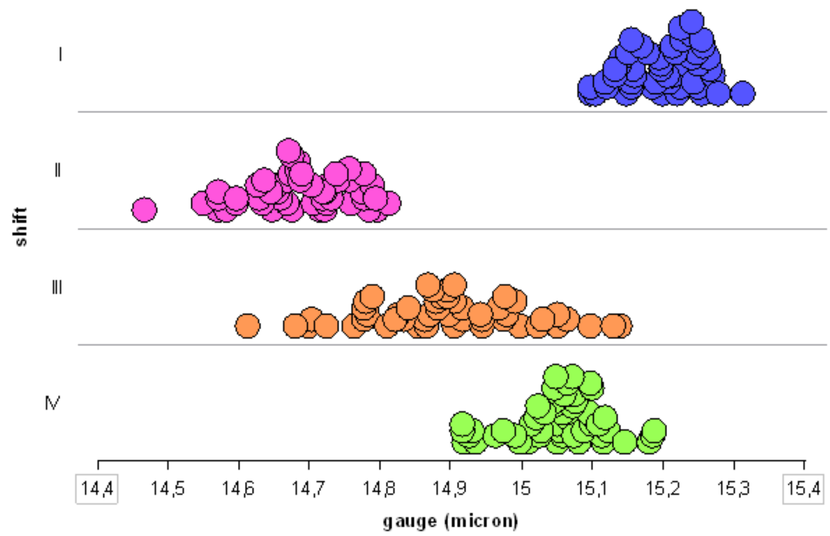
In the production area at Pacawrap, plastic granules are transformed into rolls of thin film by extrusion (various combinations of melting and stretching at highly-controlled temperatures and tensions): the output is film of 14.5 microns target gauge (thickness, where 1 micron = $1/1000^{th}$ of a millimetre), in large rolls that are just under 2 metres in width and 12,000 metres in length. A team of six people, including one Supervisor, works a 12-hour shift operating four extrusion lines. Each line is controlled by a computer system which monitors and records numerous process parameters – typical display screens present "flow diagrams" representing actual quantities and flows such as the temperatures and pressures, at different points in the line, or the amounts of raw materials in input hoppers. Despite its usefulness, only a small fraction of operators/supervisors have learnt to make use of this computer system (it seems that it is not company policy that they should do so), thus the primary mode of experience of operators is physical engagement with the process.

The basic issue is that operators generally do not produce film at the gauge target required by management. Operators produce film at significantly higher gauge than the target of 14.5 micron, up to 15 micron and higher, although the natural variability of the process is around ±0.15 micron (a fact that the operators are not aware of). The operators' main concern, through constant *manual* adjustments, is to produce even film, that is with little variation in the gauge across the whole width, which they can determine by continually *feeling* the film as it winds onto the output roll. They did not seem to be very concerned with the significant cost impact of producing film that is thicker than necessary, and the average gauge is something which can only be perceived through "abstract" measurement.

In fact, gauge is measured (as average values and ranges) by no less than four separate checking processes, three of which are directly carried out and recorded by the operators. Yet the record charts do not inform the team's actions; instead, the charts are at best perceived as records which are "something for the management", about which they receive little if any feedback, and at worst they are bluntly distrusted in comparison with the operators' physical engagement with the process.

LEARNING OPPORTUNITIES FOR STATISTICAL REASONING

We detect in the above situation a possible skills gap around statistical reasoning with average and variation. Any learning opportunity needs not only to address the specific statistical issues, but more generally it needs to connect with and yet at the same time establish some distance from the operators' dominant way of thinking. It is arguable that the operators know the process too well from the inside – to recognise the meaning of a mathematical approach they would have to be able to look "from the outside", to abstract themselves from the direct physical experience.



We are currently devising activities based on TinkerPlots software which attempt to make "average", "variation" and "target" explicit and quantitative topics of discussion, appealing to the operators' physical sense of variation, which is rather refined, and their more limited sense about average gauge. The context requires that operators should appreciate how mean and variation of the physical film gauge are related to abstract factors that are *invisible* in the production area, especially with regard to costs: the cost of raw materials; the costs of production; and the end price that the product is sold for. In terms of activity theory, we can consider this as making explicit some of the rules and divisions of labour between workplace communities, and how the object of the production activity system, the rolls of film, inter-connects with the wider activity system of the whole company and its external relations to its customers.

One activity we propose is to present learners with simulated data sets representing the output of four different shifts (*see figure*), which differ in how well the target is met, and the range of variation achieved. Learners will be invited to discuss the relative performance of the shifts; additionally, we try to broaden the discussion around costs: are the different performances "significantly" different, and what in fact is significant in this situation? Early try-outs of the learning opportunities with people from a range of industrial contexts showed that much of the meaning employees attribute to such plots stems from the context in which they work. In one extreme case, supervisors from a food packaging company could not allow for *any* variation to be present ("if a supermarket orders 10,000 packets you cannot give them 9,998"). The boundary crossing approach we take allows people to express such meanings for the statistical plots, which allows a window on their thinking and hopefully for them a way of articulating their tacit knowledge and connecting this to statistical meanings.

This stresses the importance of situated modelling, which takes into account more than statistical issues, and of the need for cycles of design, testing and revision of the learning opportunities.

NOTES

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