DESIGNING STATISTICAL LEARNING OPPORTUNITIES FOR INDUSTRY

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Our interest in the techno-mathematical literacies employees need in their jobs has led us to do case studies in different industrial sectors and to design learning opportunities for improving employees' techno-mathematical literacies. We conceptualise the learning opportunities not as training or transfer, but as forms of 'boundary crossing' between employees from a company and us as researchers. Two examples are given in which packaging managers explore and discuss a realistic problem using TinkerPlots, an educational software tool. The results emphasise how important it is to allow managers to bring their ideas and concerns to the problem situation so they can connect these to statistical theory that is relevant in statistical process control (SPC). This approach is contrasted with SPC training we have observed in two industrial sectors.

BACKGROUND

Put simply, the idea of learning statistics at school or college, or in a workplace training course, is that the acquired knowledge and skills can later be 'applied' in life and work. Some form of abstraction or generalisation is required to move from the specific context in which the statistics at stake is learned to the particular context in which it is applied. This issue has been investigated and debated for more than a century as a matter of *transfer*, but situated and socio-cultural theories problematise this notion, and recently, the notion of *boundary crossing* has come into the discussion. Such theories emphasise the relevance of context, participation, communities of practice, mediating tools and activity systems when learning and using what is learned, in particular if boundaries between training and work have to be crossed (Tuomi-Gröhn and Engeström, 2003).

The notion of boundary crossing builds on Star and Griesemer's (1989) notion of a *boundary 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 knowledge and assumptions can be made more explicit and people 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, though using the same boundary objects, in particular tables and graphs conveying statistical information.

Instead of thinking as training as transmitting our statistical knowledge to operators and managers we think of learning opportunities as boundary crossing activities involving the participants and ourselves. The learning opportunities are carefully designed to weave statistical ideas into real problem situations as we have observed them on the shop floor, so as to facilitate particular kinds of discussion. We take seriously the meanings employees bring to statistical graphs and concepts, even if they are statistically seen incorrect. Unpacking why they attribute such possibly incorrect meanings to the tables and 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 statistical theory it is unlikely they will develop a coherent understanding of the problems and theories at issue.

One way in which we facilitate the boundary crossing is by adopting a 'constructionist' paradigm (Noss and Hoyles, 1996) and by using software that allows participants to express informal ideas; this also allows us to investigate their thinking. For these reasons we employ TinkerPlots (Konold and Miller, 2005) as it is a 'construction set' for data analysis that allows users to organise data by using basic operations such as 'separate,' 'stack' and 'order,' even if they have little formal knowledge of statistics.

METHODS

Our research project, Techno-mathematical Literacies (TmL) in the Workplace, consists of two phases. The first is concerned with the question of which mathematical and statistical practices are present in different industrial sectors (Packaging, Pharmaceuticals Manufacturing, Automotive Manufacturing and Financial Services). This phase involved case studies in several companies per sector of up to 12 person-days per company. Based on work-shadow observations and interviews, we aimed to understand the work process and to describe what was techno-mathematical or statistical about the practice 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, second 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, Confrey, diSessa, Lehrer, and Schauble, 2003), which are characterised by design cycles of preparing, designing, testing and revision. Because we are not industry experts in any of the sectors under investigation, we do not seek to deliver complete training courses, but rather to design learning opportunities that may be co-developed with company trainers as elements of workplace-based training programmes. In this paper, we describe the process of designing and testing two such learning opportunities in the packaging industry, which we tried with two separate groups of managers (5 and 13 individuals) from different packaging companies, using their responses as a window on their thinking about mean and limits, as well as target and specifications, scale and trend. In this paper, given the early prototype stage of the learning opportunities used, we offer the managers' responses as impressions of issues for further research rather than as providing definitive conclusions about workplace understanding of statistics.

EXAMPLE 1: THICKNESS OF PLASTIC FILM

In one packaging company, we observed that different operators made plastic film (used for food-wrapping) at different gauges (thicknesses), often differing considerably from the target value of 14.7 microns. The natural variability, we were told, is +/- 0.15 micron, but operators are not aware of that. Their main concern is to produce even film, i.e. with little variation in the gauge, but they did not seem to be very concerned with the cost factor of producing film that is thicker than necessary. We used this example as a first learning opportunity to make 'average' and 'variation' topics of discussion in addition to more familiar notions such as 'target' and 'specification.'

First, we demonstrated a comparison of two shifts producing two different rolls of plastic film, with gauge measurements taken every five minutes; then we let them explore a more complicated data set with four shifts (Figure 1) in *TinkerPlots*. Our aim was that the managers' plots would come to function as boundary objects.

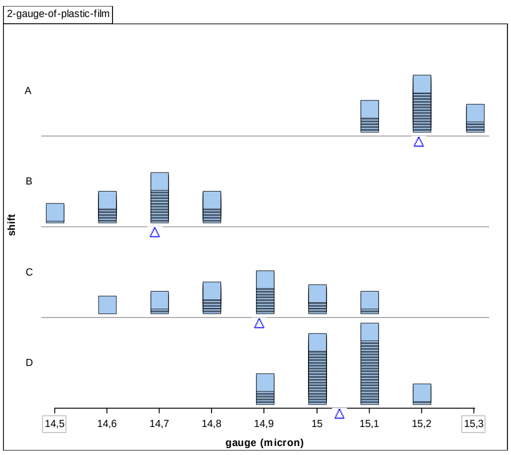

Figure 1: comparing four shifts (first group)

The first managers group only talked in terms of specifications: "shift B is in spec or below," but later, having used the average button in the software, they also included the averages in their reasoning. They also were concerned about the cost of producing film that was too thick and, contrary to what we had expected, they did not seem to be so concerned with the variation in gauge (this was similar in the second managers group). In the actual company we were told that operators were almost only focused on variation, not on the average. In both groups we sensed a deterministic view in interpreting specifications and a focus on targets rather than variation.

There were several examples of boundary crossing where the participants' interpretations changed our views and vice versa. For instance, we were mainly interested in mean and variation, but they asked us to provide more data as they felt they needed to know more about factors they found relevant, such as waste, costs, whether the film was sold by length or by weight and at what speed different gauges could be run. Having learned more about the problem ourselves, we indeed gave the second group a lot more information and yet they asked for even more: what is the shift pattern, were the ambient temperatures the same, were there differences between months? Again, context proved to be extremely important for interpreting the data.

EXAMPLE 2: STATISTICAL PROCESS CONTROL

The starting point of this learning opportunity was an actual control chart which we hoped would serve as a boundary object (Figure 2); we were not looking for ‘right answers’ in interpreting the chart, but rather the managers’ intuitive reactions to it. We enforced this by not providing a lot of contextual information to explain the chart, but rather to push the managers to draw their interpretations on personal contextual knowledge. The discussions about gauge targets and specifications in relation to average and variation were intended to form the basis for further discussion about process control charts. An extra complication of control charts is the pair of upper and lower control limits, which are (in this case) defined as the target value +/- 3 SD of (historical) data and which should be tighter than customer specifications. It turned out that only one participant in the first group knew about SPC; yet he interpreted the control limits as regulatory limits or as limits set by the managers based on the capabilities of machinery. During our discussions, we learnt that such limits were his primary concern, and it required a detailed discussion for him to express his ideas from his contextual viewpoint, and to link these to the actual context of what the software (‘Winchart’ in this case) was doing.

This boundary crossing approach thus contributed to our insights of why the other participants did not seem to allow for any variation in the process. In theory, if variation stays within the control limits, there is no need for immediate concern. Yet our managers seemed to adopt a very deterministic view: “If you have a target there, you want to be shooting for it.” Even data points that were just above or below the target value evoked phrases like these (with reference to Figure 2 about the production of adhesive labels in meters per week):

Manager 1: I would like an explanation every time [operators] did not hit the target.
Researcher: [surprised] Every time you are below that line [target]?
M1: Every time! Yeah. Probably the first thing you did when you came to work.
M2: If you have a target to hit, you have got to hit those targets.

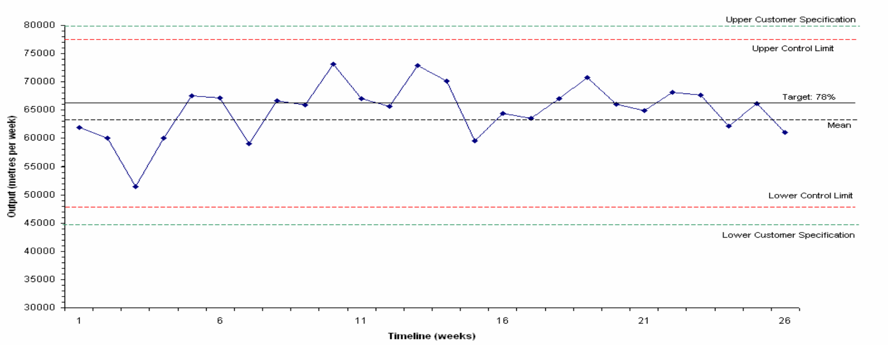

Figure 2: real control chart about output of adhesive labels in meters per week

It turned out that in the managers’ specific context of food production with a short shelf-life, and moreover, involving food that comes in discrete quantities (e.g., a pack of sandwiches rather than a bulk amount of food) underproduction *of any kind* is a problem: an order of 10,000 sandwiches has to be 10,000, not 9,998; counting discrete quantities is straightforward, and the receiving company will want to know why it is being asked to pay for even one or two more items than get delivered. Producing too many items may not be a problem for the receiving company, but is certainly perceived as an unnecessary waste for the producer.

DISCUSSION

We would like to contrast our learning opportunities with training courses we have observed in pharmaceutical and automotive companies. For example, we attended a well-delivered training course in SPC which employed a nice variety of settings (individual, pair and group work) and playful activities. Yet it focused entirely on the theory as found in most introductory books on SPC, whereas the control charts we saw on the shop floor were of a very different nature! In other words: neither of the two types of charts came to function as boundary objects. We were therefore not surprised about the trainers' expressed frustration that the SPC theory was not actually used on the shop floor. Our research suggests that such a course may improve the participants' appreciation of statistical techniques, but it is hard to see – given the dependence of meanings on the specificities of the practice – how it would help substantively in drawing SPC into the activity system of the production process.

We assume that the training approach we observed builds on the epistemological stance that SPC theory is relatively independent of its role in the production process. Some professional statisticians acknowledge that control charts are used in different ways depending on their purpose and context (Caulcutt, 1995) and, from a different perspective, the examples in this paper lead to a similar conclusion: the meanings that individuals bring to their interpretation of graphs are heavily contingent on the specificities of the context, and they struggle to interpret a graph which is not part of their own practice. From this perspective, the challenge for managers and operators is to 'web' their knowledge of the work process with knowledge of what the graphs and their statistical elements represent, and, reciprocally, to infer meanings of the work process from the statistical tables and graphs. Our challenge was to create opportunities for such webbing and to choose or design suitable boundary objects that would facilitate fruitful boundary crossing.

At this early design stage we can only point to significant moments during our learning opportunities where our participants realised that there were not just regulatory and engineering limits, but also statistical limits, and that many rules within the SPC software were of a statistical nature – not set by managers or engineers. They also realised that other contexts have other values and key concerns, e.g. while one manager was mainly concerned with yield, it took him some time to realise in a pharmaceutical problem situation that the main issue was accuracy of tablet weight, and not yield. Moreover, the managers valued our overall boundary crossing approach:

> M1: A lot of workshops you go off and you listen, they tell you what they want and that's it. You actually sat and listened to what we were saying and that was nice.
>
> M2: And it was also nice to understand what other companies say about graphs and how it works for them.

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