Constructive learning: a new approach to deploying technological systems into the workplace

Lia DiBello

Laboratory for Cognitive Studies of Activity, City University of New York Graduate Centre, 33 West 42 Street, New York NY 10036 USA

J-C. Spender

Faculty of Management, Rutgers University, 180 University Avenue, Newark NJ 07102 USA

Abstract: High-technology production and information systems are becoming increasingly common in the workplace. Those who work with them need formal and knowledge-intensive skills that match the way these systems work. The traditional methods of shopfloor education, learning-by-doing from other skilled operators, or from the equipment supplier, are risky, expensive and inefficient. Classroom training does not work well either. We describe two-day constructive learning workshops designed to help introduce MRP, the widely used computer-based production and inventory management system, into a major transportation maintenance facility. MRP is notoriously difficult to install successfully. These workshops worked well and reduced the operatives' learning period by upwards of a year.

Keywords: Organizational learning; constructive learning; workplace knowledge; complex systems training; training simulation.

Reference to this paper should be made as follows: DiBello, L. and Spender, J-C. (1996) 'Constructive learning: a new approach to deploying technological systems into the workplace', *Int. J. Technology Management, Special Issue on Unlearning and Learning for Technological Innovation*, Vol. 11, Nos. 7/8 pp.747–758.

Biographical notes: Lia DiBello is a Senior Research Associate at the Laboratory for Cognitive Studies of Activity at City University Graduate School in New York. She is also visiting professor at University of California, San Diego, teaching and researching team decision making in manufacturing environments. She received her PhD in psychology from CUNY Graduate School. She is an expert on adult cognitive development and constructive learning. Her early research concerned the development of expertise in technology-intensive work using a Vygotskian framework. She is working with a number of public and private sector organizations to design alternative educational approaches to accelerate the development of expertise in decision support technology, to improve the use of technology and workplace designs. She has published many articles in psychology and industry-related journals, as well as numerous book chapters.

J-C. Spender is Professor of Strategy and Chair of Entrepreneurship at Rutgers, Faculty of Management, Newark NJ. Before becoming an academic he spent fifteen years in the nuclear engineering, management information consulting, and computer industries. He has been on the faculty at the City University in London, York University in Toronto, UCLA, and the University of Glasgow in

Scotland. He holds BA and MA degrees in engineering from Oxford University (UK) and a PhD in corporate strategy from the Manchester Business School (UK). He has taught on four continents, has written two books, most recently *Industry Recipes*, Blackwell, (1989), and publishes in many journals and books. He serves on the Editorial Boards of the *Strategic Management Journal*, *Organization Science*, *British Journal of Management*, and the *Journal of Business Research*. His current projects include research into corporate downsizing, the teaching of technology to managers, theories of technology transfer, and the nature of organizational learning and workplace knowledge.

1 Introduction

In this paper we report 'action-research' with a North East US public transport maintenance facility to help introduce MRPII, the widely used computer-based production planning and inventory management system. MRP has been under development for decades but is still judged notoriously difficult to implement successfully. The City University of New York's Laboratory for Cognitive Studies of Activity (CUNY-LCSA) developed a two day workshop to train the facility's mechanics, supervisors and production analysts. In the first section of the paper we look at the conceptual background to these workshops, focusing on the different kinds of knowledge and learning present in the workplace. In the second we describe the workshops themselves. The third section details the results. In the final section we consider the implications of this view of workplace activity and share some insights into the problems of deploying complex technological systems.

2 Workplace knowledge

It is surprising that so much has been written about technology and its impact on the workplace yet so little about what operatives have to know to make any particular technology effective. One important exception is Kusterer.[1]. Researching several different workplaces as a participant-observer, he argued that the content of shop-floor knowledge can be put into five categories: one basic, four supplementary. The worker's basic knowledge is about the routine procedures, how to carry out the activity assigned to him/her. This task knowledge is explicit and formal, and controlled by management. It is the focus of the training programmes in which new recruits are taught approved procedures for completing their tasks.

This basic knowledge, however, is only valuable so long as the work process is orderly and going according to management's plan. Much of the time there is disorder, and this is when supplementary knowledge comes into play. One kind concerns the materials processed (by which we mean inputs of all types: materials, documents, infrastructure, customer inquiries, and so forth). Workers attend to those input variations that impact their work and threaten to disturb the 'basic' activity. Kusterer's co-workers in the paper cone-making plant paid great attention to the paper's waxiness and porosity because of the potential for machine jams. His bank employees paid attention to signatures and route codes. The supplementary knowledge called into play enabled the worker to see that what the 'basic' approach treated as a constant was actually a variable susceptible to the workers' control. They learned that their machines and systems could be 'tweaked' and this was crucial to becoming expert and getting the work done. Other areas of supplementary knowledge were about equipment, patterns of customer behaviour, and the functioning of the rest of the organization.

The thrust of Kusterer's [1] and Hirschhorn's [2] rather similar argument, is that it is supplementary knowledge that (a) keeps the plant moving, and (b) is developed 'informally' by the workers as they acquire expertise from each other. This knowledge is typically not available to those such as managers, who are not party to the system of activity, for this type of knowledge is 'situated' in the activity.[3,4]. Thus managers often make changes to the production system not knowing that they are disturbing the relationship between the production system and the supplementary knowledge that keeps it functioning. The training question is whether supplementary knowledge can only be acquired experientially. This is becoming important now that with the increasing use of formalized knowledge-intensive systems, workers seem to be required to acquire the necessary formal knowledge in 'informal' ways [5].

The work of the CUNY-LCSA stems from long-run efforts to examine the relationship between 'formal' school-based learning and experiential 'learning-by-doing'. MRP was chosen as the research domain because these systems are known to require their users to understand the system's formal underlying principles. Earlier, DiBello and Glick [6] showed that classroom instruction was an ineffective way to develop MRP skills. But given that people manage to develop such skills in the workplace, we need to understand by what means.

Previous analysis of work in organizations revealed two distinct patterns of activity which can be labelled 'constructive' versus 'formalized'.[7]. Constructive activities are those that have clear goals but poorly defined means. Formalized activities have clearly specified means. Basic knowledge, as Kusterer used the term, is formalized. It is decontextualized and abstracted. To the degree that it is explicit, it can be codified and taught in the classroom. Constructive activity is different. It is like Kusterer's supplementary category, the result of experimentation and experience. It is driven by 'problemistic search' [8] and evolves through feedback from the organizational system, from supervisors, and from the technology provided. Workers participate actively in the construction of this knowledge.

Constructive knowledge has implicit dimensions lacking in formalized knowledge.[9]. The different terms seem to imply different kinds of knowledge and learning. Recalling Singley and Anderson's [10] ACT* theory and their distinction between 'procedural' and 'declarative' knowledge, we see that constructive knowledge is 'procedural' and at least partially embedded in the work practice. Formalized knowledge is 'declarative' Constructive knowledge therefore has a depth, through its implicit content, which formalized knowledge lacks. In MRP, constructive problem-solving activity requires a grasp of its organizing principles, while formalized activity requires no such deep 'second order' understanding. Much of the literature on the difference between novices and experts [11] points to the importance of understanding the organizing principles behind the focal situation. In the earlier CUNY-LCSA research [6] when experience on the job, formal education and opportunities for constructive activity were correlated with MRP skill, only the number of opportunities for constructive engagement appeared significant ($p < .01$), even though such opportunities were fortuitous and unplanned.

3 · The MRP workshops

MRP can be thought of as a theory of manufacturing which is both logically constructed and adaptable to most production situations. It is based on models incorporating forecasting, purchasing, manufacturing, and assembling.[12]. Installing the system means translating the plant's demand, purchasing, manufacturing and assembling patterns into MRP format. This creates the Master Production Schedule which tells MRP about each particular finished part, what goes into it, what operations are involved in its manufacture, and how long it takes to complete each stage. It includes selecting the process's start dates, purchasing decisions, and production quantities. The complexity of MRP often leads to it being used only as an inventory management system. Indeed something like one half of all MRP installations are thought to be set up like this and so judged failures by MRP experts. This conclusion is often associated with the operatives' inability and/or unwillingness to develop the in-depth knowledge of MRP logic necessary to make the system fully effective.

Mastery of MRP can be associated with learning three underlying principles:

1. That all parts, assemblies and finished items are hierarchically related at various 'levels'. Parts come together into sub-assemblies and assemblies come together into finished items;
2. time, called 'phased time', is calculated with reference to completion time;
3. quantities are not fixed, they are relative to the time at which they are required, and the number in process or in stock. The quantities calculated by the system in response to demand are termed 'relative' or 'virtual' quantities.

Although these principles are straightforward, their interaction and the way they shape MRP's operations strike many as counter-intuitive and difficult to follow.

The workshop participants were volunteers from three job categories in the maintenance facility; air-brake maintainers (ABMs), their supervisors and managers, and planning analysts from the General Office. Only the ABMs were unionized. These categories of employee were chosen because (a) their jobs would be directly affected by the planned deployment of the MRP system, and (b) they occupied different levels in the plant's hierarchy. The workshops would be their only off-the-job MRP training. The ABMs were responsible for disassembling, repairing, cleaning, reassembling and testing the air-brake and compressor units. They had no official knowledge of the facility's production schedule, nor were they required to think about costs, parts' or materials' availability, or any other work-flow related issues. In practice, they were often held accountable for their productivity without being given the information that would enable them to manage their work better.

The analysts prepared the official schedules. These were often poorly coordinated with operations. The analysts got little feedback on the schedules they prepared. The plant was inclined to recycle purchasing and production schedules year after year, irrespective of whether they gave rise to excess inventory or enabled the plant to meet demand or not. The analysts also researched the acquisition of the materials necessary for production, especially to conform to changing safety standards. They evaluated new products and vendors, and the designs for small items such as door switches. Supervisors and managers kept the workforce occupied, scheduled labour, and otherwise attempted to meet both scheduled and unscheduled demand. They spent much of their time trying to find the materials necessary for the plant's activity, especially to meet the unplanned demand for components due to major vehicle breakdowns. The facility was clearly reactive and crisis-oriented, and normally got its work done only at considerable cost. All were aware that an effective MRP system could give them better control over their work.

The key to in-depth learning about MRP and acquiring the necessary supplementary skills seemed to be constructive activity. The workshops were designed to offer this while, at the same time, providing research data. The challenge was to devise some form of simulation or constructive task that would offer the same learning opportunity as the real task. Though constructive knowledge is partially embedded in practice, and thus contextualized, it does not necessarily follow that it can only be acquired in the precise context of its real application. Airline pilots get type-certified in simulators. They are expert pilots before they enter the simulator, so the analogy may not be entirely appropriate, though it does suggest that out-of-context training in contextually related skills is possible to some degree. Good simulations lever existing skills and knowledge in ways that are useful when people are challenged later in 'real' situations. For this research the team developed a multi-stage game that allowed participants both to apply their existing knowledge of the maintenance process and to invent procedures for running the same system using MRP's principles. This allowed the workshop organizers to explore the relationship between constructive and formalized activities, and the resulting learning, in a more systematic way than would be possible in the workplace.

The first stage involved pre-testing the participants. The research team collected data about each participant's education, work history, computer experience and knowledge of MRP. The participants were asked about their current responsibilities and notions of controlling manufacturing. They were then asked to perform a number of exercises designed to elicit their strategies for solving several specific manufacturing problems (Table 1). The first required them to schedule the production and purchasing activities necessary to make a number of fictional items (which had no physical correlates) by a certain time. The participants were given information about the make up of this item, its 'bill of materials', and the manufacturing and purchasing lead times for its parts and assemblies. They were asked to explain their decisions in 'knowledge elicitation' interviews which were recorded and transcribed.

Table 1 Pre-test performance exercises

Exercise	*Mfg. concept*	*MRP concept*
Scheduling Abstract Item	Finished part	Phased time
	Assembly process	Parts hierarchy
	Horizon and capacity	Quantity
Card sort	Finished part	Item structure
	Assembly process	
Tree	Finished part	Relative quantity
	Quantity on hand	Quantity

In the second task, they were given a set of file-cards which bore the names and stock numbers of the various components and sub-assemblies of a different finished part. They were asked to arrange the cards into the array which corresponded best to their strategy for making the part. During the sorting, the participants were asked for their reasoning, and this was recorded and transcribed. Finally, as a third task, they were asked to calculate the number of parts necessary to fabricate a quantity of a further item. Again their replies were transcribed. The participants then performed the simulation tasks. The exercises conformed with MRP's underlying logic and were checked against a commercially available MRP package.

To compare the effectiveness of constructive and formal learning, rather than have a control group who would have ended up with poorer training, it was decided to focus the constructive approach on only two of the above concepts. Previous research [7] showed that of MRP's three principles that of 'relative quantity' is most easily acquired while that of 'phased time' is acquired last and then only with difficulty. The final workshop design, following lengthy piloting, provided equal numbers of constructive activities dealing with MRP's treatment of hierarchy and phased time. The workshop offered only formalized exposure to virtual quantity, though complete separation was difficult because of the concepts' close relationship. We hypothesized that if constructive activity promotes learning, and the workshop offered constructive learning opportunities covering all three concepts, then they would be acquired in the same pattern as in other environments, though maybe in less time. But if the constructive learning was applied to only two of the concepts, the acquisition pattern would be changed, with the understanding of 'virtual quantity' lagging behind, and this change of pattern could be observed with our test probes.

The simulation involved the building of an origami model of a starship. The participants were teamed to run a miniature manufacturing facility that simulated the planning, parts ordering, production, and budgeting for this model. The participants also managed a physical stockroom with starship parts in cardboard compartments. They had a schedule to meet with a specific budget. Standardized production control forms were available, along with plenty of paper for plans and records. The participants were instructed to keep inventory low, maximize profit and increase cash on hand. Each period of the game lasted 20 minutes. Vendor and production lead times were to be honoured, for instance starship wings painted in one period could not be shipped until the following period.

Of the first day the teams were allowed to run their factories as they wished. This invariably led to poor performance. By the end of the morning most teams were bankrupt, unable to deliver against the schedule, or were arguing so much the game had to be stopped. The participants then filled out forms to help them analyze their process, evaluate their assets and losses, and reconstruct what had happened. The teams' results were compared with an MRP approach to the same production decisions. The next stage was to help the teams work out a manual (non-computerized) MRP-based approach. Once they had operated in this way they re-played the game with the same orders and budget. The results were satisfyingly different. Finally, the participants were 'post-tested' two months after the completion of the workshops. By then any simple memorization would have been forgotten and the MRP capabilities exhibited would be work-based extensions of the understanding developed during the workshop. The post-test exercises were similar to those in the pre-test, but were of greater variety. They included the starship from the workshop and the manufacture of familiar item which they had not been asked to think about before, a click-top ball-point pen (Table 2).

Table 2 Post-test performance exercises

Exercise	*Mfg. concept*	*MRP concept*
Scheduling abstract item	Finished part	Phased time
	Assembly process	Parts hierarchy
	Horizon and capacity	Quantity
Scheduling starship	Finished part	Phased time
	Assembly process	Parts hierarchy
	Horizon and capacity	Quantity
Scheduling click-top pen	Finished part	Phased time
	Assembly process	Parts hierarchy
	Horizon and capacity	Quantity
Card sort	Finished part	Item structure
	Assembly process	
Tree	Finished part	Relative quantity
	Quantity on hand	Quantity

4 Results

The activities were scored by content coding the interview transcripts covering the pre-test, workshop, and post-test exercises. Scores were based on the presence of 13 key behaviours which previous work [7] was associated with in-depth understanding of the three MRP principles (Table 3). Each task was given both an MRP score and a 'traditional manufacturing' score. The individual scores were then divided by the total possible scores, yielding relative scores for each domain. Generally, it seemed the participants switched from traditional to MRP strategies after the workshops. The pre test – post-test differences were all significant. In fact the post-tests found MRP scores somewhat higher than expected. They were comparable with those seen only in plants in which the MRP system had been installed and functioning well for 18 months or more [7].

Detailed analysis showed three trends. First, participants were replacing their traditional manufacturing strategies with ones based on MRP's principles. They were not simply adding MRP skills to their repertoire. Second, consistent patterns of 'misunderstanding' supported the idea drawn from developmental psychology [13,14] that the participants were coming to MRP by constructing mental models that underwent systematic shifts. Third, participants with different work histories were arriving at an understanding of MRP through different 'entry points'. We enlarge on these trends below.

Table 3

Manufacturing-related strategies:		
Time	1.	Schedules begin now with purchasing and work spread out until the due date (horizon method)
	2.	Scheduling begins with raw materials and other inputs
	3.	Scheduling continues by moving from inputs to end items. May not schedule sub-assemblies separately from end items.
Item	1.	End item comprises its part. May not be represented alone
	2.	Structure consists of routing relationships, what is to be done rather than when
	3.	Structure is non-redundant and cluster-like
Quantity	1.	Calculated as quantity per end item
	2.	On hand is physical count
	3.	Requirements are calculated at each level using aggregate method
	4.	Ordering is done in lots
	5.	Re-ordering is based on replenishment, not on demand
MRP-related strategies:		
Time	1.	Schedules backwards from future to nearer dates
	2.	Begins with end item when scheduling item and parts
	3.	Schedules parts beginning with level one items
	4.	Schedules levels sequentially
Item	1.	Structures end items beginning with end item
	2.	Structures levels according to things needed at the same time and on the same level
	3.	Structure is redundant with the whole item re-represented at least on level one
	4.	Does not re-present items that do not represent a re-stocked part
Quantity	1.	Quantity is calculated as quantity per parent item
	2.	On hand is physical count less allocated plus scheduled receipt
	3.	Upper level components used before low-level requirements are calculated
	4.	When lot sizes are not specified purchasing and manufacturing are calculated as 'lot of lot' or one made to one needed
	5.	Demand requirements are calculated before work is planned

The replacement of traditional manufacturing strategies by those based on MRP was most evident on the MRP scheduling tasks (Table 4). Of the three job categories, supervisors began with the greatest foreknowledge of MRP, an unusual result probably attributable to several of the supervisors at this particular facility having previous experience of MRP. Analysts showed a wider distribution of previous MRP knowledge while the ABMs had less. This difference is consistent with the differences in their work. An ANOVA comparing the Analysts and the ABMs showed they differed significantly in this respect (F=11.3; df=1.28; p<.002). After the workshops, the Analysts showed higher average scores, but the least growth. The ABMs' final scores were slightly lower than for the Analysts, but showed greater growth. The post-test differences between the Analysts and the ABMs were no longer significant (F=2.27; df=1.30; p<.14). Supervisors were excluded from this analysis because of the small sample size.

Table 4 Mean scores by occupational group

Group		*Pre-test*		*Post-test*	
	N	*Mfg.*	*MRP*	*Mfg.*	*MRP*
Supervisors	6	.52	.56	.42	.69
ABMs	18	.80	.13	.25	.67
Analysts	12	.52	.42	.06	.75

Mfg: ANOVA comparing Analysts' and ABMs pre-workshop averages across all tasks F (1.30) = 11.31 p<.0001

MRP: ANOVA comparing Analysts' and AMBs' pre-workshop averages across all tasks F (1.28) = 11.3 p<.002

Table 4 also shows that on the exercises designed to test their adoption of traditional manufacturing strategies, the Analysts averaged .52 before the workshops while the ABMs averaged .80. The differences were significant (F=11.3; df=1.28; p<.0001). However after the workshops the ABMs averaged only .25 while the Analysts had declined to close to zero (.06). The differences between the Analysts and ABMs were again no longer significant. This is especially interesting because many of the participants reported they could no longer remember how they had previously completed these exercises.

A few participants (drawn from both the supervisors and the ABMs) attempted to integrate the traditional manufacturing and MRP strategies. This implied bringing plant and labour capacity considerations into their problem solving. While they correctly adopted MRP's phased time, they went beyond MRP's principles and spread the work out so as to accommodate plant and labour capacity considerations. Capacity constraints are not considered within MRP. Previous work [7] suggested that an integrated approach indicates a sophisticated grasp of MRP's underlying concepts and of MRP's relationship with the actual production system. Such an integrated approach can take a long time to develop but did not with these individuals.

5 Discussion

The pre-test and post-test result differences showed that the workshops were relatively successful in facilitating entry into MRP system knowledge. In the post-test the MRP strategies were exhibited without prompting and appeared to have replaced the participants' initial approach. In other words, their knowledge was reorganized rather than merely supplemented. Some participants said they realized they had done these exercises differently in the pre-test but could not now remember or replicate their previous method. Inadvertently their performance on the job supported this interpretation. The facility's senior management changed some months after the research project began.

The new managers threatened to cancel the MRP deployment on the grounds that it was expensive, had yet to show useful results and was symbolic of the 'old regime'. However the shop floor personnel had already begun to use the system, so they instructed the incoming management in MRP's virtues and took data entry and system upkeep upon themselves.

The deeper research question is how constructive learning actually works. It seems to let individuals reorganize their implicit mental models and therefore to learn in ways that are closely related to their previous knowledge-base. For example, in the morning of the first day of the workshops, when the teams ran their factories by whatever means they considered appropriate, the participants almost always 'defaulted' to the strategies they used previously when on the job. ABMs typically delivered high quality product on time, but only by buying finished assemblies (as opposed to raw materials) and incurring the costs of sub-contracting, by over-buying materials, and by accelerating production with overtime. Analysts and supervisors were each unsuccessful in their own ways. Hesitant to overspend, they failed to meet customer's orders, waiting too long to order material and pushing production so hard that they produced poor work. The teams fell into these default modes under pressure even when instructed to operate differently. In the discussions, when they compared their own work with the MRP solution, they became conscious of their implicit strategies. During the subsequent MRP-based constructive periods, participants invented new solutions based on their intuitive knowledge of production, compared them against the available MRP solution and then reconstructed their solutions again using MRP logic.

At the end of the constructive process all the participants arrived at the same solution, but the analyses suggest they did so by very different paths. In short, constructive methods work because they seem to permit a variety of entry points to the knowledge they convey. Each individual proceeds on the basis of what they bring to the exercise. Constructive learning means reorganizing what is already known rather than overlaying this with something different. Current understanding is brought to bear on the problem and the results compared with desired outcomes. Understanding can be refined through the use of the tools being presented, in this case the principles underlying MRP. Each participant selects those tools which best suit their existing skills.

While the Analysts and the ABMs did equally on the post-test MRP oriented exercises, detailed analysis showed that the ABMs scored better on the starship and ball-point pen tests but poorly on the 'abstract item', even though this was a less complex task. The Analysts, in contrast, seemed unused to working with complex tangible items, and were more comfortable with the simpler abstract item. This supports the argument from developmental psychology that job-specific ways of thinking have a major influence on an individual's ways of learning. Thus situations that permit multiple ways of learning are more conducive to quicker and deeper learning than those that are more logically structured and constrained.

6 Conclusions

In this paper we report on constructive learning workshops designed to support the deployment of MRP. They were relatively effective. In speculating about why, we are drawn to several conclusions. First, shop-floor expertise calls for in-depth knowledge in which the formalized knowledge necessary to conform to the planned production routines is supplemented by second-order diagnostic and intervention skills which keep the production process going when unforeseen problems hit. Formal classroom instruction is a poor strategy for conveying such supplementary knowledge. Second, effective in-depth learning follows when students construct their own solutions. Third, the instruction method is more efficient when it lets the participants engage the learning process with what they already know.

Despite the small sample sizes, our conclusions are suggestive and seem intuitively sound. They have many implications. With the increased deployment of capital-intensive technological systems in the workplace, the traditional modes of operator-level learning, by making mistakes with the equipment or by informal learning from others on the shopfloor, are no longer adequate. This is partly for the reasons explored by Perrow [15], our increasing adoption of tightly coupled complex systems in which failures are costly and may be catastrophic. It is partly because these systems are increasingly extensive and entail interdependencies among many other processes whose operations cannot be interrupted while learning by doing is proceeding. But it is also about the deep formalization and logical structure of these systems. Though craft is always required at the boundaries of formal systems [16], the degree of formal knowledge required of operatives is increasing rapidly. Thus managers have no choice but to address directly the development and application of both the formal and the supplementary operator skills on which these new systems depend. Empowerment is more than a respectful attitude to those who operate these systems, it is also a recognition of the heterogeneity of the organization's knowledge-base, that operatives have supplementary knowledge which both the managers and the systems designers lack. Thus effective flexible specialization and post-industrial work depends on significantly raised levels of shop-floor task-specific skills, and on their ready application without recourse to management.

Many shop-floor skills are, in Kusterer's terminology, 'supplementary' and contextualized, and depend on a deep understanding of the fundamentals of the production system in use. Yet it seems that off-the-job education to provide them can work reasonably well. The challenge for instructors is to develop exercises that are effective simulacra to the real situation for which the students are being trained. This demands a strong theory of simulation and a great deal of preparation. Our project was based on Vygotsky's activity theory and a major effort went into developing and piloting the workshop's format and content. Simulations such as those used by airline pilots also call for strong theory and tremendous investments. Their high value can be compared to the high costs and risks of failure. In the case of technological workplace systems, such as MRP, the value in improved performance should be easy to determine. It makes little sense to invest in the hardware and software of an MRP system and then overlook the complementary investment in the 'liveware'.

Simulation, as a pedagogical device, demands a great awareness of what students bring to the exercise. Those simulations that allow a wider range of entry points offer better value than those which are constrained. At the same time, it appears that the reason why the constructive approach is more effective than the formal classroom approach, is that the students, being adults, already have a tremendous range of knowledge at their disposal. The process of learning becomes less an extension of what they know than a re-organization. Finally, having managers and supervisors go through simulations of the processes they manage can be very instructive. Working together with operatives gives them insights into the depth of knowledge necessary to keep things running, the depth of which they are typically ignorant. As Hirschhorn [2, p.165] notes, the managers of post-industrial organizations seldom work in teams with supervisors or operatives themselves and consequently lack the necessary in-depth supplemental knowledge of how 'new competition' organizations actually work.

References

1 Kusterer, K.C. (1978) *Know-how on the job: The Important Working Knowledge of the 'Unskilled' Workers,* Westview Press, Boulder CO, p.178.

2 Hirschhorn, L. (1984) *Beyond Mechanization: Work and Technology in a Postindustrial age.* MIT Press, Cambridge MA.

3 Rogoff, B. and Lave, J. (eds.) (1984) *Everyday Cognition: Its Development in Social Context,* Harvard University Press, Cambridge MA.

4 Lave, J. and Wenger, E. (1992) *Situated Learning: Legitimate Peripheral Participation.* New York: Cambridge University Press.

5 Scribner, S., Sachs, P., DiBello, L. and Kindred, J. (1991) *Knowledge Acquisition At Work.* New York: Technical Paper No. 22, National Centre on Education and Employment.

6 DiBello, L. and Glick, J. (1992) *The Relative Roles of On-the-Job Experience and Classroom Training for Employees Learning MRP,* Montreal: Paper presented at the APICS 25th International Conference.

7 Scribner, S., DiBello, L., Kindred, J., and Zazanis, E. (1992) *Coordinating Knowledge Systems: A case Study.* Laboratory for Cognitive Studies of Activity, New York: City University of New York Graduate School.

8 Cyert, R. M. and March, J.G. (1963) *A Behavioural Theory of the Firm,* Prentice-Hall, Englewood Cliffs, NJ, P.116.

9 Spender, J.C. (1994) 'Knowing, managing and learning: A dynamic managerial epistemology', *Management Learning,* Vol. 25, pp.387–412.

10 Singley, M.K. and Anderson, J.R. (1989) *The Transfer of Cognitive Skill,* Harvard University Press, Cambridge MA, p.31.

11 Chi, M., Glaser, R., and Farr, M.J. (eds.) (1988) *The nature of expertise,* Lawrence Erlbaum Associates, Hillsdale, NJ.

12 Hendrick, T.E. and Moore, F.G. (1985) *Production/Operations Management, Ninth Edition,* Richard D. Irwin, Homewood IL.

13 Vygotsky, L.S. (1978) *Mind In Society,* Harvard University Press, Cambridge MA.

14 Scribner, S. (1985) 'Knowledge at work', *Anthropology and Education,* Vol. 16, pp.199–206.

15 Perrow, C. (1984) *Normal Accidents: Living with High-Risk Technologies,* Basic Books, New York.

16 Bensman, J. and Lilienfeld, R. (1991) *Craft and Consciousness,* Aldine de Gruyter, New York.