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Chapter 16

Exploring the Relationship Between Activity and Expertise: Paradigm Shifts and Decision Defaults Among Workers Learning Material Requirements Planning

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With increasing advances in technology, the normal divisions between "manual" and "intellectual" labor are collapsing; as more industries move toward mediating and controlling work using computerized tools, a greater number of workers at all levels are being compelled to conceptualize work and judge situations on a very different level of abstraction than before. In addition, because of the nature of the processes being controlled, a background in the details of a specific industry is often proving a better prerequisite for effective technology use than, for example, a background in computer systems or computer mediated management. However, many efforts to implement advanced technologies fail because these systems are difficult for many people to learn, regardless of background. The study described in this chapter concerns three levels of workers in a large remanufacturing facility learning the logic of MRP (Material Requirements Planning) systems. As becomes clear, the important issues may not have to do with identifying who should or can learn these systems, but rather how learning occurs.

This specific study is part of larger program of research being conducted at CUNY's Laboratory for Cognitive Studies of Activity. The focus of our work concerns the cognitive impact of the introduction of technology into the workplace. Specifically, we are interested in exploring how workers' ways of thinking and understanding are affected by changes in the nature of work and workplace organization. Many of our questions have been addressed under a number of headings, such as "novice–expert shift" (e.g., Chi, Glaser & Farr, 1988) "situated cognition" (e.g., Rogoff & Lave, 1984), or "naturalistic decision making" (e.g., Orasanu & Connolly, 1993) and our work has been influenced by the methods and theoretical models from all of these various approaches. However, because the focus of our inquiry concerns the *development* of different ways of thinking in different domains, the research has been most influenced by the theories and methods of developmental psychology and particularly the developmental theories of Vygotsky (1987).

Some of this early research focused on identifying the factors associated with learning MRP. Material Requirements Planning was selected as a domain because it represents a class of technology that is widely known to require users who understand its underlying principles (in the sense described by Dreyfus & Dreyfus, 1986, or Polanyi, 1986) and it has a high failure rate because it is so difficult to learn. However, we do not consider our findings from these studies to be applicable only to MRP learning, but rather to the broader issue of learning complex technologies.

In one study of workers using MRP in two different factories (Scribner, Di Bello, Kindred, & Zazanis, 1992)—one with a successful implementation and one with an unsuccessful implementation — classroom instruction was shown to be an ineffective strategy for developing the kind of flexible mastery needed to effectively use MRP. However, some individuals do manage to master these systems. On-the-job activity proved to be critical, with particular kinds of activity responsible for the difference. An analysis of day-to-day job activity among workers revealed two distinct patterns of activity, "constructive" and "procedural." Briefly, constructive activities are those that have clearly defined goals and poorly defined means. The employee is compelled to develop in an iterative fashion a procedure, form, tool, or artifact that accomplishes the goal. In contrast, procedural activities are those that have clearly specified means and order of execution, whereas understanding the ultimate goal becomes secondary. Constructive activities are associated with an in-depth understanding of MRP's underlying logic, and procedural activities are not, even if the employees perform essentially the same functions and even execute the same kinds of actions most of the time. However, this study also showed that opportunities for constructive activities are usually fortuitous and ill structured. For example, they were most frequently encountered when an employee was forced to invent means to ends due to the sudden unavailability of documented procedures or knowledgeable persons (e.g., due to firings or sudden resignations).

In the study described here, the relationship between "constructive" and "procedural" activities is further explored in an ongoing study of skilled manufacturing workers (individuals with expertise in the skilled trades) who are learning MRP at a very large public rail transport remanufacturing facility. This study differs in a number of significant ways from our previous work and from other research on employees using complex computer systems. First, these workers were introduced to MRP in a 2-day workshop that we designed in order to engage workers with constructive and procedural activities in a more controlled way. We used a hands-on simulation or "game" that permitted participants to invent procedures for running a factory with MRP logic, but with little actual risk. Second, in direct challenge to the notion that MRP and such systems require "prerequisite" general formal education or computer experience, the training format did not differ for employees in different kinds of jobs or with different educational backgrounds.

WHAT IS MRP?

MRP is a family of computer-based systems that integrates information from all aspects of a company's operations and uses it to make decisions (recommendations) regulating production and inventory. MRP has also been characterized as a theory of manufacturing. It instantiates certain key economic concepts such as *zero inventory* and *just-in-time* production and is based on principles of manufacturing (for example, formulas regulating how future orders are forecast) developed over the last several decades (Hendrick & Moore, 1985; Timms & Pohlen, 1970). Its objects and procedures are generically defined and the system is content-free until implemented in a particular plant. Its power as a predictor is contingent on the data used (the content on which the logic operates) and the extent to which its assumptions match the way things are actually made in a given setting.

Employees working with the system must translate the company's anticipated demand into a form that the MRP system can "understand." This is done via a Master Production Schedule (MPS), which the system then interprets as a set of long range, abstract production goals for the company's finished goods. With the information the system has on "what" a particular finished good is (e.g., what parts go into it, what operations are involved, how long it takes to make each of its component parts and assemble it finally), it makes recommendations for every action leading up to the company's preset goals. This includes deciding on start dates and quantities for production orders and determining the most efficient pattern of purchasing. There are three "deeper" principles that organize the logic of MRP, and mastery of MRP seems clearly related to grasping these organizing ideas. This is not surprising, in that numerous studies in the "expertise" literature point to the importance of underlying concepts (e.g., Chi, Glaser, & Rees, 1982). A full exposition of these principles is beyond the scope of this chapter, but in order to make the sense of the results reported here, it is necessary to briefly describe them.

First, MRP conceives of all parts, assemblies, and finished goods as *hierarchically arranged items*, residing on "levels" that map onto how a given item is manufactured. Second, rather than using a linear, chronological representation of time, the timing of events is calculated beginning with a future date and moving back to the present. This is referred to as *phased time*. Third, quantities are not absolute, but relative to time and item. When making inquiries about how many of a given part are in inventory, the system calculates a *virtual* or *relative quantity*, based on a number of time-sensitive factors. Although these principles seem quite simple on the surface, they organize the data and operations of MRP in ways that strike many people as counterintuitive. In essence, it is MRP's counterintuitive structure that can make it so difficult to use.

METHOD

Subjects

Subjects came from three job categories of the transportation facility's Overhaul Division: Air Brake Maintainers (unionized mechanics), Supervisors and Managers (salaried and nonunion), and Analysts (a general office position for those involved in planning and special projects). All participants were drawn from a pool of employees who volunteered to participate in the MRP workshops. All expected to have their jobs affected by the planned MRP implementation and for many, our workshops would be their only form of introductory training.

Workshops

The workshops used with subjects were developed with the help of an MRP expert and others familiar enough with MRP logic to recognize activities and behavior that most richly represented the logic of MRP systems. For 2 days, the participants were required to run a miniature manufacturing and re-manufacturing facility using simple materials in the form of a "game" that simulated actual production, planning, ordering, and budgeting. The participants were required to produce three models of an origami "starship" with both common and unique parts. They purchased materials from a "vendor," sold finished ships to a "customer," and managed a "stockroom" made of foam-board compartments. They had a specific shipping schedule to meet, with a specific budget. A variety of standardized forms as well as blank paper were made available (for the asking) to participants as they set up and organized their "factory." They were explicitly instructed to keep inventory low and to maximize profits. Each "week" the game was 20 minutes long.

During the first morning of the first day, participants were allowed to run their factory according to any organizational scheme they wished. This invariably failed to achieve MRP goals (low inventory, increasing cash flow) and by the end of the first morning, most teams of participants went bankrupt, were unable to deliver, or began arguing with such intensity that the game had to be stopped. When this occurred, the game was paused and participants filled out a number of forms that helped them examine their patterns of decision making, evaluate their assets and losses, and reconstruct what had happened. These results were then compared by the participants with an MRP ideal of purchasing, production, and cash flow. After this phase, the participants were facilitated in the construction of a manual MRP system and introduced through various activities to its logic and overall functioning. Once they had a fully built and implemented "system," they played the game again with the same customer orders and budget, but with very different results.

Testing the Impact of "Constructive" and "Procedural" Activities

In order to examine the different effects of constructive and procedural activities, the workers were engaged with the three main principles of MRP via either "constructive" or "procedural" activities, but not both. The workshop included equal numbers of activities that would "constructively" engage participants with MRP's examples of Hierarchical Items and Phased Time. Considerable "procedural" activities and practice drill exposed the subjects to principles of virtual quantity. In general, the amount of time spent on each concept was equal across activities.

Pretesting Using Performance Probes

Prior to participating in the workshops, each participant filled out a form with information on previous work history, formal education, computer experience, and MRP experience. Subsequently, subjects were interviewed about their notions of manufacturing, and asked to do a number of performance tasks that elicited their strategies in response to a manufacturing task. These knowledge elicitation "probes" had been developed in previous research on MRP and were thoroughly tested using known MRP experts. Generally, these tasks were developed to tap into workers' understanding of key MRP and manufacturing concepts and were constructed to invite a variety of strategies.

This chapter mainly presents the results of one kind of performance task, the "scheduling" problems. Of the four kinds of performance tasks in the battery, the "scheduling" problems in their various forms were designed to invite the most comprehensive MRP, traditional manufacturing strategies, or both, and were the best measures of overall competency. (For a complete description of all probes, see Scribner et al., 1992; Scribner, Sachs, Di Bello, & Kindred, 1991). Briefly, these tasks required the subject to plan all aspects of purchasing and producing a specific quantity of some finished product by a specific due date. All the information MRP required to perform this function was provided to the subject.

Other probes were designed to explore individuals' grasp of very specific aspects of MRP in isolation from the system as a whole. The results from these probes are reported briefly in order to explicate some of the general findings. Importantly, all probes were designed to elicit either MRP *or* traditional manufacturing-based strategy, *or both*, so that it could be observed if an individual were using one or the other, or both.

Posttesting

Posttesting was conducted about 2 months after the workshops. It was expected that by then any rote learning that had taken place would be forgotten, and that MRP strategies exhibited by the subjects would reflect what they had actually come to understand about MRP. The "scheduling" postperformance probes were structurally similar to the pretest but were applied to more kinds of objects (i.e., the "abstract unknown," the "starship" from the workshop, and a familiar kind of button-top pen). These tasks again elicited strategies that would reveal understanding of MRP and traditional manufacturing principles.

Scoring Pretests and Posttests

The strategy elicited on each performance probe was scored for the presence, partial presence, or complete absence of 12 different behaviors that have been shown in previous work to be associated with in-depth understanding of MRP principles. The same protocols were also scored for typical traditional manufacturing strategies. Thus, each task protocol was given an "MRP total" and "Manufacturing total." These numbers were then divided by the total number of possible behaviors for each domain, giving a *proportional* score for each domain (MRP or Traditional manufacturing).

RESULTS

In general, traditional manufacturing strategies were replaced with MRP strategies after the workshops. The pre- and postworkshop differences were found to be statistically significant for all groups ($F(1,30) = 6.79$ $p. < .001$). In fact, the postworkshop scores were found to be somewhat higher than expected and comparable to those seen in plants where the system had been fully functioning for at least 2 years (Scribner et al., 1992). Table 16.1 presents a summary of the preworkshop and postworkshop means among groups.

As can be seen in Table 16.1, among the three job categories, Supervisors (SUPs) began with the most initial MRP knowledge, as a group, but this was largely attributable to two of the four individuals. After the workshops, Analysts showed higher aggregate scores for MRP knowledge. An analysis of variance comparing the Air Brake Maintainers (ABMs) and Analysts indicates that these differences were not significant. (Because of the small number of Supervisors, they were excluded from statistical analyses.)

Interestingly—although not statistically significant—the postworkshop difference between the two groups was due largely to one version of this probe. ABMs as a group seemed to have difficulty with "post-unknown abstract," which was a far simpler scheduling task (with 3 parts as opposed to the starship's 13 parts) but was abstract rather than concrete or "contexted." When scores for this probe were not used in the calculation of averages, group differences almost disappeared, with ABM's averaging .71 and Analysts averaging .75. However, an analysis of variance comparing the Analysts' and ABMs' performance on the "abstract unknown" (alone) after the workshops did show significant differences between the two groups, $F(1,30) = 6.09$ $p < .02$.

A few individuals showed an interesting deviation from the trend toward replacement. These subjects attempted to produce scheduling solutions that integrated MRP with traditional manufacturing strategies. A closer look at their scheduling strategies revealed a rather sophisticated attempt to integrate plant and labor capacity considerations into their scheduling solutions.

TABLE 16.1

Average Scores Between Domains for Each Occupational Group, Showing Replacement of Traditional Manufacturing Strategies With MRP Strategies

	Preworkshop		*Postworkshop*	
	Manufacturing	MRP	Manufacturing	MRP
SUPs	.52	.56	.42	.69
ABMs	.80	.13	.25	.67
Analysts	.52	.42	.06	.75

For example, although these individuals showed the "backwards time" scheduling strategy inherent to an MRP strategy, they attempted to spread out requirements evenly to accommodate plant or labor capacity. Capacity is one real-world aspect of scheduling that MRP cannot consider. In previous work, this kind of integration is an indication of rather sophisticated understanding of MRP concepts and the system's relationship to actual production. Such an understanding usually takes considerable time to develop. Not surprisingly, the postworkshop interviews revealed that these four individuals were among seven who had begun to use the system intensively (after our training) at least on a weekly basis in a pilot project to schedule the work in their division of the Pneumatic shop (compressors). Observations indicate that these activities were largely "constructive" as they involved setting up a new system without preset procedures. Supervisor 3, on the other hand, showed considerable MRP knowledge before the workshops and no manufacturing strategies (on the scheduling task). His subsequent experience with the system is not known.

Supervisor 3's profile suggests that replacing traditional manufacturing strategies with MRP strategies might precede integrating the two approaches. He moved from an MRP-dominated approach to a more integrated one. This may have been what occurred with ABMs 5, 6, and 7, and Supervisor 2 in the period between interviews, but this cannot be known for certain. However, the profiles of these four do suggest that certain kinds of on-the-job activity after training might effect integration. This is further suggested by the complete absence of integration among the Analysts, who have no opportunity for seeing how schedules are implemented on the floor.

Uneven Change in the Three Organizing Principles

As predicted, the learning did not occur evenly over areas covered by the workshop. As indicated, the workshops were constructed to provide extensive practice with the notion of "Relative Quantity," but subjects were given specific MRP calculation procedures and were not encouraged to invent or explore MRP algorithms for obtaining Virtual Quantities.

Table 16.2 shows relative performance in the three conceptual areas and the probe data scored. These data are percentages of subjects, taken from several probes, as noted. As can be seen, the fewest number of subjects achieved a truly flexible notion of Virtual Quantity. In addition, all subjects who came to understand Virtual Quantity also developed a thorough understanding of Phased Time and Hierarchical Item.

Table 16.2

Differences in Overall Performance on Three Core Concepts

	Relative Quantity	*Phased Time*	*Hierarchical Item*
Pretest	[a]0%	[b]12%	[d]15%
Posttest	[a]6%	[b]48%	[d]22%
Posttest "Starship" tasks	[a]NA	[c]74%	[e]79%

Note. Data from "tree," "scheduling," and "card sort" probes. Values Represent percentages of subjects with strategies showing full grasp of the principle involved. [a]Tree Virtual Quantity probe. [b]Phased time analysis from "scheduling abstract unknown" probe. [c]Phased time analysis from "scheduling starship" probe. [d]Hierarchical item analysis from "unknown object card sort" probe. [e]Hierarchical item analysis from "starship card sort" probe.

DISCUSSION

It is clear from the post test results that 2 months after the "constructive" activity training, workers performed at a level of mastery that is normally seen after 18 to 24 months in workers who had managed to learn to use the system effectively (in other sites) after no training, or classroom-based training. More important, workers exhibited these strategies spontaneously and appeared to have replaced old ways of doing the same problems with new approaches. In other words, knowledge was reorganized rather than added. Many subjects reported that they realized they had done it differently before but could not even replicate or remember their previous approach.

Their performance on the floor supported these results. Shop floor personnel who had system access made use of the system to manage their own work areas, instructed management personnel in MRP, and took upon themselves data entry and system upkeep.

The question remains—how did constructive activities affect this transformation? Although tapes from the actual workshops are still being analyzed along with other materials generated by participants, a great deal is suggested by preliminary analyses.

It appears that "constructive" activities permitted individuals to reorganize the implicit mental models driving the decision process. As indicated, during the first morning of the workshops, the teams of participants could "run" their factory in any way they chose. Without exception, under this kind of pressure, all groups "defaulted" to the strategies they normally used at work. Comparing the performance in the workshops (as indicated by the cash and material flow patterns as well as the participants' notes and inventory control records) with work history indicates a strong correspondence between current work practices and decisions under pressure. For example, mechanics almost always delivered a high-quality product on time and thereby managed to stay financially above water by ensuring income. However, they often did so by buying finished assemblies (as opposed to raw materials) at great cost, by accelerating production (which has the real-world equivalent in "overtime"), and by overbuying all materials. Thus, they sacrificed profits.

In contrast, Analysts and Supervisors were often *not* successful at meeting customer orders but they were very hesitant to overspend; often they could not meet orders because they had waited too long to decide to purchase the necessary materials. It is important to note that individuals resorted to their default strategies even when *explicitly instructed* to operate differently and when they were aware that the goal of the game was to make the most profit and buy the least material.

As indicated, during the workshops' first pause, participants evaluated their strategies and decisions using various tools. During the discussions that followed the self-evaluation, participants began to reflect on these default strategies and examined how a different approach might have accomplished their goals. It was only at this point that participants became aware of the assumptions guiding their decisions under pressure and the attendant results. We have come to call this the "deconstruction" phase and the beginning of "reorganization." During the MRP-oriented "constructive" activities that followed in next day and a half, participants were introduced to MRP concepts as they continued a pattern of inventing a solution using their intuitive understanding of manufacturing, noticing its mismatch with their goals, reordering what they had done, and comparing it again to their goals. At the end of this process, all participants arrived at the same solution but, it is important to note, they had all gotten there via different paths and had begun the process through sometimes radically different entries.

It seems that constructive activities work—and work for a wide variety of people—because they are both multimodal and self-modal. They permit a variety of entries to knowledge and they permit the individual's entry to be in terms of his or her existing way of thinking in that domain. Rather than overlaying existing knowledge, constructive activities permit the reorganization of knowledge that occurs when learners are compelled to bring their current way of thinking to bear on the problem, notice its mismatch with desired outcomes, and make refinements in accordance with the tools they are discovering (in this case MRP).

To further illustrate, let us return to some of differences found among the workers. Although there were no significant differences between the ABMs and Analysts on *aggregate* performance, differences in their patterns of response on different probes indicate they were "coming to" the same notions through different means. For example, on the "scheduling" tasks, almost all of the variance in average aggregate MRP scores was due to performance on the "abstract unknown" probe. Although this task was much simpler than the same probe using the starship or pen (3 parts as opposed to 13 parts with various lead times), Mechanics exhibited the most sophisticated strategies with the more complex, but identifiable objects.

The paradox of the more complex (but more concrete) being simpler for one class of subjects suggests interesting possibilities. It seems as though this group was not oriented to approaching problem solving when the context was presented abstractly, although they were capable of thinking abstractly and symbolically about contexted objects. Conversely, the Analysts were able to take better advantage of the simplicity of the "abstract unknown" and were more likely to make calculation errors on the starship task. This result is particularly interesting given that abstract problem solving is sometimes invoked as more sophisticated than "concrete" or contexted problem solving.

The Mechanics' ability to operate with the complex but concrete makes sense given their jobs. They are required to work with highly complicated assemblies having many small but essential parts. In order to perform well on the job they must pay attention to small details, and the impact of small assembly errors. It may be that the requirements of their jobs have oriented them to grasp general relationships or concepts through the specifics, while at the same time being more able to handle a large amount of detail in parallel. The difference between the ABMs and the Analysts supports the more general notion that job-specific ways of thinking may influence ways of learning, and that activities or learning situations that permit multiple ways to attend to information and concepts may erase normally observed group differences in overall ability to learn.

Another illustration is provided by the effects of the "procedural" activities. Despite considerable practice with MRP's methods of calculating virtual quantities, all but two participants (6% on Table 16.2) defaulted to their previous methods of calculating quantities during the postprobe interviews. In other words, no "replacement" took place for most when it came to quantity strategies. Clearly, hearing about concepts and even practicing formulas does not necessarily engender real change or in-depth understanding.

Although this chapter presents only a small portion of a much larger study—with much data still being analyzed—it makes a case for rethinking training for adults who already have considerable skills. These results suggest that the "default" modes or intuitive understanding that are developed with experience may act as both an impediment and bridge to learning new technologies in one's domain of expertise. Constructive activity-based instruction may offer a way to make an impediment into a bridge without sacrificing current experience and expertise.

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