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Cognitive Studies of Work

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Preface

We are pleased to host Sylvia Scribner and her associates in a special double issue of our *Newsletter* devoted to cognitive studies of work. The articles, all original contributions, address several topics of interest to our readership, among them: the context-boundness of thinking, transfer across cognitive domains, the importance of human agency, multiple perspectives in studying cognition in non-laboratory settings, and expert-novice contrasts that lead to an empirically-based notion of cognitive flexibility. Throughout the work, the question of method is always on the foreground; these issues are investigated and clarified through a series of clever and carefully conceptualized moves from ethnographic observations to the analysis of well-defined tasks in controlled environments and back. In short, ethnographically informed cognitive science.

A note on organization and content. The issue starts with introductory remarks by Professor Scribner. In them she provides a rationale for selecting thinking-in-activity as the focus of her research and discusses how this work is related both theoretically and methodologically to socio-historical psychology, in particular the ideas developed by L. S. Vygotsky, his colleagues and students. Professor Scribner's introduction is followed by a brief note describing the research setting, design, and identifying the investigators who conducted the work; this note, in turn, is followed by a full presentation of the research in a series of articles, including reports on five empirical studies, focusing on problem-solving in work environments and on the role of knowledge in thinking at work. In the final article, Professor Scribner brings the different strands together, proposing a model for cognitive studies of work.

But there is more. Three brief reports on work-in-progress provide previews of future directions of this work and, as is our custom, the issue concludes with annotated bibliographies.

Our thanks to Sandro Duranti and Catherine King for their editorial assistance. We are, of course, grateful to Professor Scribner and her associates for selecting our *Newsletter* as the forum for their ideas.

Luis C. Moll
Editor

Introduction to this Issue

We welcome the invitation of the *Newsletter* editors to prepare a special issue presenting some of our recent studies of practical thinking at work.

This line of research was initiated on a small scale four years ago in an industrial plant in a large Eastern city. The setting was an unusual one for basic cognitive research but our purpose was straightforward. We wanted to contribute to a functional theory of practical thinking and to test a research strategy for its investigation; we considered the workplace an especially suitable setting in which to elaborate the constructs and methods required by this enterprise.

Like others concerned with the need to ground psychological theories on a firmer grasp of the phenomena we seek to explain, we have ventured out of the laboratory to try and snare analyzable specimens of naturally-occurring cognitive tasks. This aspect of the enterprise places us close to the anthropological wing of cognitive science. Our interest in microscopic inspection of the specimens we collect, on the other hand, brings us close to experimental psychology and computer simulation: our objective is to identify the knowledge and operational components of cognitive systems involved in these tasks and to trace the course of their development. By choice and by necessity, we have had to move across the boundaries dividing disciplines and to draw upon concepts, models and knowledge accumulated in various subfields of the human sciences.

Although electicism seems unavoidable in these beginning stages, our research is guided by an overarching theoretical framework and a methodological principle which was developed in earlier cross-cultural studies (Scribner and Cole, 1981); it focuses on a topic in cognition -- practical thinking -- that seems "fitting" to both theory and method. Space does not permit a full exposition here -- we will have to rely on the individual articles to convey our key constructs and research techniques, but we will first make a few, brief comments on topic, theory and method as a way of providing some perspective for the empirical studies that follow. (Scribner, 1984, provides a more detailed account of the theoretical framework and background of this research.)

Topic: Practical Thinking

We have described the phenomena of interest as instances of "practical thinking" -- a term we are using in a heuristic rather than in a formal definitional sense. We have adopted this term as a way of referring to thinking that can be explicitly defined as embedded in larger purposive activities and that functions to carry out the goals of those activities. Activity goals may involve either mental accomplishments (e.g., computing a delivery cost) or manual accomplishments (putting up a wall), but whatever their nature, practical thinking is instrumental to their achievement. So conceived -- as embedded and instrumental -- practical thinking stands in contrast to the kind of thinking involved in performance of isolated mental tasks undertaken as "ends in themselves."

Since at least Aristotle's day, practical thinking has been opposed to and customarily considered a less "elevated" mode of thinking than theoretical thought. The putative distinguishing characteristics between the two modes are fuzzy (Scribner, 1984), but it seems clear that psychologists have long been preoccupied with intellectual achievements which, by rule of thumb, qualify as theoretical: logical operations (Piaget, 1950), scientific concepts (Vygotsky, 1962) and problem-solving in closed symbolic domains (Newell and Simon, 1972). Practical knowledge and thought for action have been underexamined and theoretically neglected topics in psychology. Yet, as emphasized by students of other disciplines, these topics are basic to human existence in all societies and central to the development of a psychological theory of the function and formation of human intellect. The present research is one of a growing number of efforts among psychologists and anthropologists (many reported in earlier issues of this *Newsletter*) to remedy this neglect.

Theory: An Activity Approach to Cognition

An inquiry into practical thinking requires a conceptual framework within which to pose questions about the relationship of cognitive processes ("thinking") and behavioral acts ("doing"). Such questions receive low priority in cognitive science today. Prevailing paradigms are based on theoretical models and investigative techniques that analyze mental functions (e.g., memory, perception, reasoning) in isolation from one another and separated from the sphere of action. Although these approaches to cognition have resulted in many important achievements, the very fact that they study mind as a disembodied system cut off from action, weakens their usefulness for functional inquiries.

We have adopted a theoretical framework which stems from a different philosophical tradition and one which we believe affords the prospect of an integrated account of mind-in-action. This framework, known as *activity theory*, has its origins in the works of L. S. Vygotsky, and has been developed over the years by his successors in psychology and philosophy; a leading exponent is the psychologist A. N. Leont'ev (1972; 1981; a general summary is in 1979; a useful secondary account is Wertsch, 1979). Here, very schematically, are some of its basic propositions.

Activity theory holds that neither mind as such nor behavior as such can be taken as the principal category of analysis in the social and psychological sciences. Rather, the theory proposes that the starting point and primary unit of analysis should be a socially organized human activity. An activity is a system of goal-directed actions integrated around a common motive and directed toward specific objects. Play, work and school have been proposed (El'konin, 1977) as categories of activities of special importance to intellectual development. Activities represent a synthesis of mental and behavioral processes and can be analyzed psychologically on a number of levels: on the molar level of activities as such, or in terms of the goal-directed actions which comprise them, or the specific operations by which actions are carried out. The central core of activity theory is its system approach:

> The fundamental difference between an activities-oriented approach to the subject of psychology and other approaches lies in the following: the object of analysis is the actual process of interaction of man with his environment and this is seen in its integral nature as a process related to the solution of specific tasks. Earlier approaches to that system of activities selected individual elements and analyzed them in isolation from that system. (Talyzina, 1981, p. 33).

We find activity theory most useful when considered as a meta-theory offering basic categories for future development in the various subfields of psychology; and we look upon our research program as one arena for working out these categories.

Method: Studying Activities

A methodological principle is implied in this theoretical approach: activities, basic units of psychological analysis, are also, and accordingly, basic objects of study. Stated concretely in terms of our enterprise: if we want to understand the characteristics of practical thinking, we need to begin with an analysis of the activities and actions in which it is embedded.

What activities should be selected for initial study? We chose work for reasons of both significance and strategy. Significance is apparent. In all societies work is basic to human existence; in most it consumes the greater part of adult waking time, and in many, it is a principal source of self-definition. Although we are certainly not wholly defined through our participation in society's productive activities, the circumstances under which we work and what we do when we work have deep implications for intellectual and personal development.

Considerations of research strategy pointed in the same direction and led us to concentrate on work activities involving manual components -- industrial and service occupations and crafts. Many of these occupations are highly structured and involve tasks whose goals are predetermined and explicit. They are thus more amenable to analysis than activities in other domains and offer favorable opportunities for devising and testing research strategies. An important advantage is that work activities, especially those carried out in institutional settings, are socially defined and organized *as* activities. In studying work, the investigator does not have to begin with *a priori* definitions of *activity* and *goal-directed action*, and wrestle with the difficulty of finding instances of those constructs in naturally-occurring streams of behavior. It is possible to start with behavioral definitions and classifications already existing in the workplace and allow the evolving research to test their adequacy. We adopted this strategem, and took *occupations* (e.g., assembler, delivery driver) as representing *activities* and *work tasks* (e.g., fill an order) as representing *goal-directed actions*. And we further strengthened our hand by conducting our first studies in the organized environment of an industrial plant.

In short, our general research objective -- to investigate the characteristics of practical thinking in naturally-occurring activities -- took the special form of analyzing the intellectual components of tasks at work, and we continue to pursue this course.

Bridging the Gap Between Lab and Field

Matters of method are the crux of this enterprise. Difficulties in studying cognition in naturally-occurring events are well-known and have led some (e.g., Bronfenbrenner, 1979) to suggest that the advantage of relevance gained by research "in the world" may be bought at the expense of the rigor achieved in the laboratory. The rigor-relevance controversy is often posed as an opposition between explanatory (usually equated with experimental) and descriptive (observational) methods of study. But a cognitive analysis of work activities requires both approaches. Observational methods are needed to determine what tasks are central to particular occupations, to describe their features and discover the constraints the setting imposes. Experimental methods are needed to refine these descriptions and analyze the component knowledge and cognitive processes involved in task accomplishment. Our research strategy incorporates both methods, and moves from broad-gauged exploratory inquiries to question-oriented studies.

As we have evolved the strategy in practice, it has taken on a three-phase pattern:

1) **Observation.** The initial impetus for all our studies is direct observation of people at work, carrying out their job responsibilities under normal working conditions. "Observation," of course, is a gloss for the very diverse investigatory activities required to get a grasp of what people are doing in an unfamiliar environment. We use informal chats, formal interviews and casual observation as preparation for controlled observations designed to produce analyzable records. In most cases we concentrate on identifying problem-solving strategies involved in various work tasks and documenting their variability across individuals and occasions. On the basis of descriptions derived from observations, we generate hypotheses or hunches about factors that might be regulating variability and about the features distinguishing skilled and novice problem-solving.

2) **Job simulation.** To explore these hunches, we devise job simulations which allow us to observe performance under more constrained conditions than those occurring in the ordinary work environment. Simulations provide a format for testing hypotheses about factors regulating skilled cognitive performance (for example, effects of knowledge or changes in goals) and for studying the acquisition of problem-solving skills. This "middle-link" between observation and experiment has also proved useful as a means of making population comparisons and testing transfer of problem-solving skills from one work task to another.

3) **Experiments**. As we proceed with task analyses we set up special experiments using established laboratory techniques to probe questions on a more specific level of analysis than simulation studies make possible: how workers organize their job knowledge, for example, or change their representations of objects used in their work environments as they acquire experience.

Not every work study involves all three phases, nor is the research movement entirely one way: in settings that allow continuing access, we often return to the workplace for additional observations directed at specific questions raised by simulations and experiments. Ideally, seeing and describing in the work-place and seeing and analyzing in the laboratory are activities that inform each other.

Much of our effort to date has concentrated on testing these research methods. We have prepared the reports in this *Newsletter* in such a way as to make maximally explicit how we went about conducting the research so that the process and its associated outcomes is available for evaluation. As will be seen, our successes have been variable (we have not reported our failures!). Our procedures have often been invented for the purpose at hand and retain something of the *ad hoc* character that appears to characterize practical thinking at work. Still, we think that the research outcomes confirm the general usefulness of the approach, and we hope that the studies reported here will encourage many others to tackle the project of studying mind-in-action.

Sylvia Scribner

Cognitive Aspects of Work: Selected Case Studies from the Dairy

Background Information

The setting. The research site was a medium-sized processing plant ("dairy") in a large Eastern city. The dairy employed some 300 workers, and had a full range of job categories typical of production and distribution functions in many industries, as well as specialty departments such as a laboratory, computer room and repair garage. As a non-partisan, basic research effort, the project was jointly sponsored by the union representing hourly employees and by the company.

The design. The research began with an ethnographic study of the dairy (Jacob, 1979) which provided background information on cognitive skill requirements in various occupations. Of these we selected four for intensive study: inventory men and product assemblers (sometimes referred to collectively as warehouse workers), wholesale drivers and office clerks. After conducting systematic observations of principal work tasks in these occupations, we designed a series of job simulations and experiments to analyze the constituent operations and knowledge involved in these tasks. Participating in these studies was a panel of 35 workers, 10-12 from each target occupation. In the job simulations, workers in the occupation from which the task was drawn served as experts; those from other occupations served as novices. Twenty-four ninth grade students from a nearby public junior high school were included in some studies for comparative purposes (Scribner, in press, provides details on informant selection; other publications include Jacob, 1979; Scribner and Schafft, 1982; and Scribner and Fahrmeier, 1982).

The staff. Sylvia Scribner was principal investigator, Evelyn Jacob, co-investigator and ethnographer, Edward Fahrmeier, research psychologist. A number of talented research assistants participated in interviews and data analyses and their specific contributions are acknowledged in the following articles. The research was supported by a grant from the Ford Foundation.

Practical Problem-Solving on the Job

Sylvia Scribner

Research on problem-solving has made great strides in the past decade under the impetus of theories and models developed within the information-processing approach (Newell and Simon, 1972; Bradshaw, Langley, and Simon, 1983). Computer programs based on these models solve physics and algebra problems, play chess and accomplish other complex intellectual feats.

Questions arise, however, as to how well these programs capture the characteristics of problem-solving in a wide range of human activities. Laboratory research has been restricted to a sample of tasks drawn primarily from academic and formal domains. These tasks qualify as instances of what Bartlett (1958) called "closed system thinking" and problem-solving models derived from them reflect the characteristics of such thinking. Most models presuppose situations in which problem-solving is undertaken as an end in itself, rather than as a means to an end. Consequently, they exclude from analysis the relationship between the problem-solver's proximal goal -- a correct solution, for example -- and the problem-solver's distal goal -- the larger objective to which her activities are directed. Laboratory models assume settings in which the problem-solver works in an isolated "mental space," having no transactions with the external environment or with other people. Consequently, they exclude from analysis the symbolic and material resources in the world which the problem-solver may draw upon to define, transform and solve problems.

Occupational responsibilities in the dairy included many problem solving tasks whose performance features differed from those represented in laboratory models. These tasks were embedded in larger sequences of activities whose purposes they served. Many occurred in settings in which modes of solution were constrained, not only by the internal structure of the problem domain, but by the objective, contextual aspects of the situations in which the problem arose. And in many, the process of arriving at a solution involved a continuing and dynamic interaction between the problem-solver and the world.

Studies of work activities thus provided an opportunity to enlarge the repertoire of problem-solving tasks available for theory building. Our selection of candidates for cognitive analysis was guided by several considerations. First, we concentrated on tasks that involved person-world transactions. In line with our interest in the relation between problem-solving and larger purposes, we also concentrated on tasks that were essential to, if not constitutive of, job performance in various occupations. To maximize analyzability, we selected tasks in which modes of solution, as well as solutions, included observable components; this criterion was best satisfied in blue collar occupations. Finally, to enhance the possibility of identifying characteristics common to a number of tasks, we chose only those which involved operations with written symbols. In blue-collar occupations in the dairy, these common symbolic operations turned out to be, in large part, operations with numbers.

In keeping with our overall methodological approach, we began our analysis of each task, not with an *a priori*, rational description but with an empirical description (see Resnick, 1976), based on observations of skilled workers performing the task under actual working conditions. Our aim was to identify the modes of solution skilled workers used and to document their occurrence across workers, problems and situations. We used this first-order description to generate hypotheses about factors that might be regulating the selection of particular solution procedures and then devised job simulations which allowed us to test these hypotheses. By building a novice-expert comparison into the simulation experiments, we highlighted the ways in which strategies of experienced workers differed from those of beginning problem-solvers, and, for some tasks, we were able to construct testable models of how skilled strategies might be acquired. We also used simulation studies to refine the task description, to bring it "down" from the level of strategy analysis to a specification of the knowledge and operational components from which strategies were constituted. During the experimental phase, we returned to the plant for additional on-the-job observations directed at particular questions which the simulations raised. Our long-range objective from this back and forth movement was to develop a fine-grained analysis of skilled performance and a tentative model of the course of skill acquisition.

This objective was imperfectly realized. Our ability to carry out the full program varied by task: some tasks proved more intractable than others to the conceptual schemes and methods we could bring to their analysis. Limitations of time, resources and access to the plant were formidable obstacles. With the exception of follow-up laboratory studies on product assembly, all research on these tasks was terminated at the conclusion of the Industrial Literacy Project, whose field period ran for two and one-half years. For these reasons, our substantive findings are stronger on the descriptive level and more tentative on the analytic. The reports here reflect our view that the usefulness of these studies lies not only in what they may tell us of the nature of practical problem solving but in how they exemplify the intricate interplay of field and laboratory methods that is needed to extend the boundaries of cognitive science beyond "closed system thinking."

For this issue of the *Newsletter*, we are presenting selected aspects of studies of three problem-solving tasks: taking inventory in the warehouse; filling orders in product assembly; and pricing tickets in wholesale delivery. In each, we have chosen to emphasize somewhat different features of problem-solving and to detail different phases of the research, now foregrounding the observational studies, now the experimental. The topic of all the reports, however, concerns the characteristics of practical problem-solving and how these are responsive to formal problem requirements, problem-solvers' purposes, and the means and conditions of problem-solving which the dairy setting provides.[1]

Notes

[1]One difference between the present analyses and problem-solving research in other domains should be kept in mind. We are not concerned with whether a correct solution is achieved, but rather with *how* it is achieved. All the workers we observed were successful in reaching solutions. Their performance was overwhelmingly accurate, although, from time to time an occasional error would occur. The following analyses deal only with accurate performance.

Taking Inventory: Counting as Problem-Solving

Edward Fahrmeier

Taking inventory in the dairy warehouse (called "icebox") involves careful assessment of the quantities of some 100 products and accurate recording of these amounts on the proper forms.

Two major inventories are taken daily. The first occurs about 2 a.m. after all trucks have been loaded for the next day's deliveries. Because only small amounts of unused stock remain in the box, this inventory is relatively easy and might be completed in as little as half an hour. A second inventory begins at 2 p.m. after the plant has been producing for an entire shift. Now the icebox is heavily stocked. The inventory man determines quantities of goods already in the box and continually updates the inventory as additional product runs come off the packaging lines. This count is critical. In the early evening, inventory amounts are compared to total orders on hand for the following day and steps are taken to correct any major discrepancies between what is needed and what has been produced. Counts for each product need to be accurate within a 1% or 2% margin of error. Larger errors may result in either shortages or overproduction, both costly events.

On-The-Job Observations

To learn the strategies used in counting these large masses of stock, I observed three men while they were taking inventory. Mr. D., an old-timer who regularly took the afternoon inventory, was observed on two occasions approximately six weeks apart; his work provides the basic data for this analysis. Additional observations of two substitute inventory men were undertaken to ensure that D.'s counting behavior was representative of inventory men in the plant and not merely a display of idiosyncratic procedures.

Observations were made during work hours and proceeded as follows.[1] I accompanied Mr. D. as he made the rounds, requesting that he do his counts out loud. As he stopped at an array, I diagrammed it, noted his procedures (gesturing, for example) and questioned him from time to time to bring out the considerations which prompted his choice of one or another procedure or to clarify what he was doing. Audiotape transcripts and written notes and diagrams provided raw data for the analysis. In all, 45 instances of product counts were recorded. ("Count" is used here in a generic sense to encompass all procedures, not merely enumeration techniques.)

The Setting

Before reporting D.'s strategies, I will briefly describe the physical layout and conditions of work which provided the context for counting. In the icebox, products are grouped together by type and often, though not always, the entire quantity of one product (say, gallons of homogenized milk) is massed together in a single location. This mass constitutes what we refer to as a product array. Most dairy products, and all those whose counts we recorded, are packed in standard-size dairy cases which are placed with sides touching and stacked six high, volume permitting. Width and depth of the arrays vary depending on the amount of a particular product and the configuration of the space in which it is stored. The largest array we saw being counted contained 864 cases, and extended 17 cases deep and 10 wide; the smallest contained 19 cases.

The icebox inventory results in a final product count in units (e.g., quarts, half-pint) but the inventory man is required only to report counts in cases (these are converted to units in the office). Mr. D., as most others, opted for the case counting procedure.

Because production expanded over the years while storage space remained fixed, the icebox was almost always densely packed. Products were stored so close to each other that inventory men had limited walk room for maneuvering around arrays. They had to seek out and reach vantage points from which a count could be made, often doing this by climbing on cases to "see over" the front row of an array. By this move, they could almost always see the top cases of stacks but not cases underneath.[2] For much of the time, then, they were taking counts of arrays containing invisible cases. They almost never moved stacks or cases to count cases.

What is Counting?

These circumstances make it clear that taking inventory is not a routine form of counting. One definition of counting considers it "the successive assignment of sequence number words to items existing in space or in time" and "constituting a well-defined set" (Fuson and Hall, 1983, p. 55). This definition entails that "in any particular counting act, a counting word has a referent -- the countable to which it is attached by the counter" (p. 55). Thus, in a logical analysis of the inventory job, it would appear that the case is the countable and the product array is the set of countables. But an empirical analysis of the job discloses that the invisibility of cases limits their utility as universal units of count. Moreover, the large size of some arrays (300-900 cases) would make the procedure of counting cases not only tedious and time-consuming, but error-prone as well.

How then do inventory men produce case counts? If they are not counting, what procedures do they use? And if they count, what "items" serve as "countables"? These questions suggest the feasibility of approaching the inventory job as a problem-solving activity. Each array presents a problem: given its state, what procedures will lead to the goal -- an accurate determination of quantity? To assist in the problem-solving process, inventory men carry a pencil, scratch paper, clipboard and inventory form. These are their only tools, and they are used sparingly. The men we observed often avoided using paper and pencil by converting quantities into "easy numbers" (their terminology) and by using other simplification techniques.

Strategies for Counting Product Arrays

Mr. D. had a wide variety of strategies for determining case number. Most were composite procedures, which combined arithmetic operations (multiplication, addition and subtraction) with enumerative operations in different mixes. Strategies differed as well in the way similar operations were combined and in the units that were selected as objects of enumeration. By attending to the dominant operations in a strategy, we classified counts into five major types. As we will see, choice of one of those types is regulated in large part by the properties of the product array and the inventory man's interest in achieving a good fit between counting technique and such array dimensions as size, shape and location. Mr. D. explained: "I think everybody does it just the way I do it. It's the easiest way. If there's an easy way I'll find it" (E. F. field notes).

Large Arrays: Primarily Multiplication

Quantities in large arrays (over 300 cases) were arrived at by procedures that built on multiplication. But within this common class, procedures were fine-tuned to specific array properties.

1) **Multiplication by known dimensions.** Large counts were easiest, according to Mr. D., when the warehouse workers stacked the product in a rectangular area with a depth dimension fixed by the storage space. Most commonly, this dimension was the distance between the wall and the conveyor track which held 17 cases. In large volumes, stack height was also fixed (6 cases). Thus, Mr. D. approached these rectangular arrays with a precalculated or known factor -- the number of cases in a row (depth by height or 102 cases); he had only to count the width dimension to arrive at a total. An array 8 cases wide, for example, would be 8 x 102 or 816. During our observations, there were four instances of this procedure on arrays ranging from 385 to 819 cases in size.

2) **Multiplication by determining dimensions: Squaring off.** Perfectly rectangular product arrays were infrequent. Almost always, arrays had either "missing" stacks or "odd stuff" (extra stacks or cases), depending on the inventory man's perspective. When arrays were large and irregular, Mr. D. began by "squaring off" (his term). As he described it, this procedure involved mentally separating a central core of products from other cases or treating an array with a gap as entirely filled in.

In the example given in Figure 1, the central core, determined by counting, was 5 x 9 stacks. To this core, Mr. D. added 5 stacks from the "odd stuff" (3 from Area A, 2 from Area B), and multiplied the product (50) by the known height dimension. He then proceeded to complete the assessment of Area B. Although the example is complex, it is typical and illustrates several commonly used simplifying procedures. Note that the squaring off process resulted in a number that accurately described the 5 x 9 array (i.e., 45) but was cumbersome for converting stacks to cases. Therefore Mr. D., pulled by the requirements of the *next* step in the solution procedure (multiplication), mentally subdivided the "odd stuff" to adjust the 45 to an easy number for multiplication (50). Here is a clear example of Bartlett's observation (1958, p. 19) that in some kinds of thinking the "character of direction assumes a preponderating influence": the step ahead determined the operation of the step before. Mr. D. then assessed the remainder of the "odd stuff" in Area B. In this segment, he displayed still another technique for mentally modifying the array in the interests of computational procedures. In counting the double row of stacks in Area B (see Figure 1), he treated all stacks as though they were six-high when one stack had only five cases. This "as though" tactic permitted him to arrive at total number of cases in the rows by multiplying number of stacks by six (the height factor). He preferred to take this route and subsequently adjust the product, than to take account of irregularity in stack height in the initial operations.

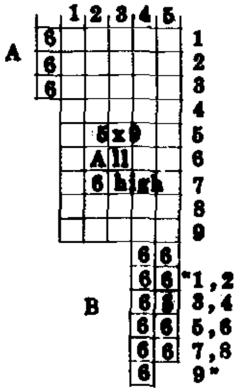
At other times, squaring off involved counting phantom (missing) stacks, then subtracting them from the squared-off product. This procedure was particularly useful when the depth dimension (from track to wall, for example) was known. Figure 2 illustrates this gap-filling procedure. It was easier for Mr. D. to treat this array as consisting of 17 full rows, since 17 x 6 was a known amount (see above) and subtracting a "missing stack" than it would have been for him to compute 4 x 16 x 6 + 3 x 6.

Figure 1

Inventory
Squaring Off with Odd Stuff

[a simplified example from observational transcripts]

Array



Mr. D. counts aloud:
"1, 2, 3, 4, 5 rows
1, 2, 3, 4, 5, 6, 7, 8, 9
5 9's is 45
6, 7, 48 stacks [e.g., 46, 47, 48; counts A]
9, 50 stacks [e.g., 49, 50; counts 2 stacks in B]
6 50's is 300
1, 2, 3, 4, 5, 6, 7, 8, 9 354
minus 1
would be 353 half gallons [cases]."

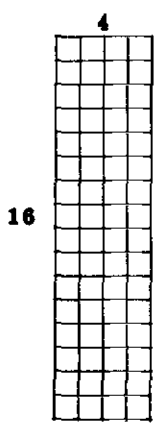
Mr. D. squared off a central core consisting of 5 x 9 stacks. To this he added 5 stacks from the cases of "odd stuff" (3 stacks in A, 2 stacks in B) to make an easy number, i.e., 50. He multiplied by the height factor, 50 x 6 = 300 and then continued the count of the "odd stuff" in B. He counted the remaining 6 high stacks, treating one 5 case stack as a 6 case stack in this count. Then he multiplied by height, 6 x 9 = 54 (without verbalization) and added 54 (without verbalization) for a product of 354. This figure was then adjusted to 353 to take account of the stack with the missing case, which he had previously counted as a 6-high stack.

* * * * * * *

Figure 2

Inventory
Squaring off with Phantom Stacks

[from observational transcript]



Mr. D. counts aloud:
"1, 2, 3, 4,
17
4 times 102 [e.g., 17 x 6]
that's 408 minus 6
402."

Medium and Small Arrays: Primarily Counting

Medium sized arrays were evaluated as collections of stacks whose size was determined by some form of counting; a single multiplication (by height) often completed the procedure. The unit of count varied, depending on the size of the array, its regularity, and other physical properties.

3) **Jump counting by stacks.** This was the most commonly used technique, one especially suitable for medium-sized arrays. Twenty-two of Mr. D.'s 45 counts used this procedure on arrays ranging from 38 to 417 cases.

The increment of count was determined by the layout of the physical array. Thus, if rows in an irregular array consisted of the following number of stacks -- 2, 2, 3, 3, 3, 3, 3, 1 -- the count would be "2, 4, 7, 10, 13, 16, 19, 20. Six 20's is 120" (multiplication by height factor). Frequently, irregular rows would be "regularized." For example, three rows of 4, 4, 3, would be counted as "4, 8, 12, minus 1."

4) **Single counting of stacks.** This procedure was generally used with small arrays (in our sample, 35 to 133 cases; 9 occasions). It was most often the strategy of choice when the product arrangement was one case wide, but was occasionally used in wider arrays.

5) **Jump counting by number of cases in each stack.** This procedure involved taking a running total of cases as the eye or finger moved across the array. Increments in this form of counting were equal to the number of cases in each stack, and, accordingly, multiplication by the height factor was eliminated. This strategy was primarily applied to small arrays (in our sample from 19 to 65 cases; six occasions) whose stacks were not the same height.

Similarity in Task Performance

To test the generality of Mr. D.'s procedures, I analyzed 16 additional "counts" from two men who took inventory on a substitute basis. All counts could be classified into the various multiplication and counting procedures described above. On several occasions, the men "squared off"; six of these involved adding-on phantom stacks, and one, subtracting "odd stuff." Both men adjusted their strategies to the size and regularity of the arrays, as did Mr. D., and neither of them used the single case as a unit of enumeration.

There is no evidence that this similarity is the outcome of instruction. All of the men claimed that they had no instruction, and we never observed any interactional sequence in the icebox that seemed to qualify as an instructional sequence. We think it likely that inventory was one of those tasks that persons had to figure out on their own.

Simulating Inventory

To determine whether inventory techniques were available for similar but out-of-context tasks, we devised a set of counting problems using a variety of materials. Informants were inventory workers, members of other dairy occupations and students. One such task was set up to parallel icebox inventory; it involved three dimensional arrays constructed from children's building blocks (standard size *Legos*). These arrays preserved actual stack height and represented the kinds of configurations found in the box: neat rectangular arrays and irregular arrays with "missing" or "add on" portions. Talk-aloud and probe procedures provided information on the strategies used for each array; these were supplemented by the interviewer's diagrams. We classified strategies and compared them to those used in the box. Here we will focus on inventory men's performance (for more detailed results, and comparisons with other groups, see Fahrmeier, 1981). With the exception of "multiplication by known dimensions" -- impossible under the circumstances -- there was strong concordance between inventory men's strategies in counting milk cases and *Lego* blocks. Of the 18 experimental problems analyzed (6 problems x three informants), counting strategies on 17 clearly fit into the previously observed strategies. The inventory men's preferred technique, in the experiment as in the box, was jump counting by stacks -- an indication of the effect of their on-the-job experience made even more striking by the fact that this strategy was rarely used by any other group.

Summary

The goal of inventory is to count the product in case amounts. Yet we never observed an inventory man using the single case as an operational unit of count. In all instances, inventory men reached the goal of a case count indirectly by working with units of other sizes. Their countables were, variously, rows of stacks, single stacks or case-multiples in partial stacks. Moreover, they had a repertoire of procedures for achieving counts, procedures composed of both calculating and enumerating operations. These procedures or strategies were employed flexibly, but not haphazardly. Strategy choice appeared to be responsive to two aspects of the "goal" of inventory: one an externally-imposed, management criterion for an accurate count and the other, inventory men's own intentions of satisfying this criterion the easiest way. No single strategy met the constraints of accuracy and easiness on all product arrays. Rather, the strategy of choice was conditional on properties of the thing to be counted -- the size of the array, its location and its regularity.

Inventory men's fine-tuning of strategies to the physical properties of arrays might suggest that their problem-solving was "stimulus bound," driven by the thing-to-be-counted. "Matching to the stimulus" was indeed a feature of problem-solving skill on this job, but it involved much more than acceptance of the stimulus array as it presented itself. Physical properties of the array guided but did not dictate strategy choice. Inventory men mentally transformed arrays in a variety of ways so they could be assimilated into "easier" assessment procedures. They imposed regularity on irregular arrays by squaring-off a central core from "odd stuff"; they mentally filled gaps and supplied missing units so they could apply more powerful procedures than counting to arrays of uneven height or irregular configuration; they extracted or constructed manageable units of count by mentally segregating and subdividing solid masses. Their problem space (Newell and Simon, 1972) was related to but not isomorphic with the environmentally given problem. Since the arithmetic and counting operations composing their procedures were not in themselves complex, inventory men's problem-solving skills can be seen as residing principally in their ability to assemble operations into procedures and to bring procedures and array properties into alignment with each other. Their mental manipulations of array representations played an important role in this dynamic process.

Notes

[1]Observational procedures were worked out and piloted with Evelyn Jacob; they were patterned on methods used by Lave, Murtagh and de la Rocha (in press) in their study of supermarket shoppers.

[2]This is a simplified description. Massed arrays sometimes consisted of two different products, stored contiguously, and boundaries of each product had to be determined. In addition, partially full cases had to be taken into account for some assessments.

Product Assembly: Optimizing Strategies and their Acquisition[1]

Sylvia Scribner

Product assembly is a night shift job which serves as the middle link between the dairy's production of milk products and their distribution to a wide network of institutional and commercial customers. It is classified as an unskilled manual job, and paid accordingly, but satisfactory performance requires not only physical labor but intellectual operations in a symbol system of some complexity.

In this article, we discuss one task which, for purposes of analysis, we simplified and extracted from the interlocking sequence of actions that go to make up "product assembly." (See Scribner, Gauvain and Fahrmeier, this issue, for analysis of another product assembly task.) Filling product orders is a component of the assembler's job that requires well-regulated coordinations between mind and hand; it thus offers rich possibilities for studying working intelligence when it is engaged in actions with material things.

Filling Product Orders: A Job Description

Assemblers work in a refrigerated warehouse (known as the icebox). They are responsible for locating and sending out to the loading platform exact amounts of products ordered by wholesale delivery drivers for their next day's deliveries. They must be accurate -- each is held responsible for his errors. And quick -- the work shift does not end until all orders are loaded.

Assemblers secure information about the products they must gather from load out order forms (see Figure 1) which represent product quantities according to a setting-specific system. Drivers place their orders for fluid products in terms of the number of *units* they need (e.g., number gallons, quarts, etc.) but fluid products in the plant are packed and stored in *cases*. When order forms are produced, a computer program converts the driver's orders to case equivalencies. This procedure sometimes results in "left-over" units. If the leftover amount equals half a case or less, the order is expressed as number of cases *plus* number of units; if the leftover amount is more than half a case, the order is expressed as number of cases *minus* number of units. Using quarts as an example (16 quarts = one case), an order for 18 quarts is expressed as 1 + 2, an order for 10 quarts as 1 -6. Since cases are a standard size, the number of units they hold varies with the size of the unit container (a case holds four gallons, nine half-gallons, and the like).

It follows that the designation "one case" on the order form is a variable, not a quantity. It takes on a range of values depending on the product in question. Each time the assembler encounters a case-and-unit problem, (s)he must interpret the symbolic representation on the form to determine the unit quantity needed, map this quantity on to physical arrays, and collect as many units as will satisfy the order.

As this description indicates, filling product orders has a number of formal features: it proceeds within a rule-regulated number representation system, in a determinate universe of admissible problems (orders), and according to fixed criteria for acceptable (accurate) solutions. It thus shares some features with formal problem-solving tasks studied in the laboratory, yet it differs from them in other features crucial to the distinction between formal and practical thinking. These include the relationship of the problem to the problem-solving environment, (i.e., the actual product arrays in the icebox) and, as we shall see, the relationship of the problem goal (i.e., problem solution) to the general work goals of the problem solver.

On-The-Job Observations

We began the task analysis by systematic observations of two product assemblers filling mixed case-and-unit orders on their regular shift. Observational records included orders on the load-out order form, diagrams of the product arrays confronting the assembler, diagrams of his/her physical moves when making up the cases to satisfy orders, and observer comments and descriptions. This information allowed us to analyze "order-filling" as a succession of moves transforming an initial problem state (the given physical array) into a final problem state (a case containing the number of units specified in symbolic form on the order). In this analysis, the number and pattern of moves compose "modes of solution."

Variable Solutions to "Identical Problems"

As a first step, we examined the relationship between modes of solution and the numerical properties of the orders on the load-out order form. In a formal analysis of the task, one would expect a predictable relationship between the two. Observational findings ran counter to this expectation. Modes of solution that assemblers used on particular problems were not deducible from numerical properties of the orders. Identical orders received different modes of solution on different occasions. Here is one example from observational records:

> The order "1 - 6 quarts" (i.e., 10 quarts) recurred six times during the observation. On two occasions, assemblers filled the order by removing six quarts from a full case. Their behavioral moves were isomorphic to the symbolic moves in the problem presentation (subtract six quarts from one case). We refer to these as literal solutions. On two occasions, assemblers took advantage of partially full cases in the area to modify the numbers in the subtraction problem: they removed four quarts from a partial case of 14, one quart from a case of 11. On the two remaining occasions, they behaviorally transformed the subtraction problem to an addition problem: they made up the required case of 10 by adding two quarts to a partial case of eight and four quarts to a partial of six. We refer to these as nonliteral solutions. (For an illustration of a literal and a nonliteral solution to the same problem, see Figure 2).

Solution variability commands special interest for at least two reasons. First, it is not necessary for satisfying task requirements. In all instances, assemblers could produce correct solutions (cases with the correct number of containers) by following literal instructions. And, second, recourse to nonliteral solutions would appear to increase the mental difficulty of the task. One aspect of mental difficulty involves memory requirements: the assembler must keep in mind the quantity specified in the order[2] while walking through the warehouse to locate the product. Literal and nonliteral modes of solution impose comparable memory demands of this nature. But, beyond these, nonliteral solutions require some additional mental manipulation of the original order information so that it can be mapped onto quantitative properties of different physical arrays.

A Least-Physical-Effort Hypothesis

Why did product assemblers choose to engage in such extra mental work? What regulated their choice of solution mode on a particular problem? Talks with assemblers suggested that one of their personal work objectives played a regulating role; as several said, "We want to save our backs." This observation led us to put forward two hypotheses concerning solution variability: 1) choice of solution mode is regulated by a criterion of least-physical-effort; and 2) extra mental effort may be expended to satisfy this criterion. In this view, problem-solving skill in product assembly consists of choosing just that path to solution which requires the least number of moves to fill a particular order in a given set of circumstances.

By defining number of moves as the number of unit containers the assembler transferred from one case to another, we could test the least-physical-effort hypothesis against the observational evidence. The outcome: 83% of assemblers' literal solutions, and all of their nonliteral solutions satisfied this criterion. The consistency with which assemblers adapted their solution mode to the least-physical effort criterion suggested the operation of a higher-level problem-solving strategy, which we characterize here as an optimizing strategy. Note that an optimizing strategy calls for selective use of both literal and nonliteral solutions.

Novice-Expert Comparisons on a Simulated Task

As a second step in the analysis, we devised a simulation study to investigate how novices compared to experts in their modes of solution, and to probe the hypothesized mental effort-physical effort tradeoff. Experienced product assemblers were the experts; inventory men and wholesale drivers, the majority of whom had prior experience in product assembly, were semi-experts; office workers in the dairy were semi-novices since they knew the dairy but not the job; and ninth grade students were true novices, uninformed about either the dairy business or the job.

The simulation task used facsimile order forms and actual materials (cases and empty paper containers). The individual proceeded to an assembly area which held a pre-arranged display of cases of quarts or, on alternating problems, pints. Displays always consisted of three cases -- a full, an empty, and a partial -- but the number of units in the partial varied from trial to trial to fulfill parameters of the problem list. We classified problems into four types based on the operations hypothetically required to convert literal into nonliteral optimal solutions, and ranked these for mental difficulty on an intuitive basis (the greater the number of hypothetical operations, the greater the difficulty). We expected fewer nonliteral optimal solutions on the more difficult problems. We also varied level of physical savings: a least-physical-effort solution could save one, two three or six moves over other possible solutions for the problem. In the majority of problems, nonliteral solutions were optimal, but in some (and to prevent a problem-solving set) literal solutions were optimal. Informants received ninety problems in two sessions.

Results

Principal outcomes with respect to solution strategies include the following:

1) **Experts used an optimizing strategy.** Product assemblers used least-physical effort solutions on all problems in which these coincided with literal solutions and on 72% of the problems in which these coincided with nonliteral solutions. Their optimizing strategy was consistent with the strategy regulating their actual job performance. Inventory men and wholesale drivers performed in a similar but less consistent manner; they selected nonliteral modes of solution on 65% of the problems on which they were optimal.

2) **Student novices used a literal strategy.** Students, like assemblers, used modes of solution indicative of a consistent higher-order strategy. But their strategy was one of enacting literal instructions. They switched to nonliteral solutions on only 25% of the problems on which these represented least-physical effort choices.

3) **Semi-novices were neither optimizers nor literal strategists.** Overall, office workers' use of nonliteral solutions when these were optimal was on a chance level: they selected them on 47% of the problems on which they were least-physical-effort choices. However, their performance changed during the course of the simulation; overwhelmingly literal on the first trial, they increased their use of nonliteral least-physical-effort solutions in the second session.

No relationships were uncovered between features of problems and modes of solution. Variations in levels of physical savings had no effect on the frequency of nonliteral, least-physical-effort solutions, nor did their frequency appear to be affected by attempted variations in levels of mental difficulty.

The simulation confirmed our hypothesis that a defining feature of skill in product assembly involves the ability to deploy a variety of solution modes to problems in the interests of saving physical effort. The simulation also raised the possibility that this skill is acquired through practice -- solely through task performance and without explicit instruction. The learning exhibited by office workers during the sessions provided support for this notion, as did the comparative standing of true novices (students) and semi-novices (office workers). On the basis of these findings, we posited that the course of skill acquisition would take the following form: novices at the outset would rely on an algorithm for solving all problems, namely, use literal solutions exclusively; at intermediate stages they would begin to use nonliteral solutions but not follow a consistent least-physical effort strategy; with continued practice, they would flexibly deploy literal and nonliteral solutions according to a consistent optimizing strategy. We turned to the laboratory to test this acquisition model.

Acquisition of an Optimizing Strategy[4]

The product assembly simulation, with some changes in problem lists, was set up as a learning task in the laboratory under conditions favorable to videotaping. Ten ninth-grade students, comparable to the former student group, served as pseudo-assemblers. We introduced the study as part of an ongoing research program on how basic skills are used at work, but gave no instructions as to how the orders were to be filled except to stress that accuracy was required. The study extended over three days. On each of the first two days, students filled orders on two problem lists, each consisting of 32 quarts and pints problems; on the third day, they received a transfer task. All procedures remained identical but problems now involved new numbers: the size of the case was enlarged so that it held 24 quarts or 48 pints instead of the 16 quarts and 32 pints of the standard cases used in the learning trials.

Results

Analyses are still in progress, but highlights of strategy acquisition can be reported. The principal outcome is that students did acquire, as a result of practice alone, a higher-order optimizing strategy. On the first trial their optimal solutions were at a chance level, but on the fourth and final learning trial, 79% of their problem solutions conformed to the least-physical-effort principle. Since the learning lists were repeated, the strategy switch involved solving an old problem in a new way. A student's protocol (Figure 2) vividly illustrates the change -- and indicates that different "computational processes" are often involved in different strategies.

Students maintained the same level of optimization on the transfer task. The task was a "near transfer" (with the exception of the numerical operations, all features were identical to the learning task), and thus only a first step in probing the generality of the strategy, but it provides important corroborating evidence that students did, indeed, acquire a strategy and not simply learn solutions to the problems in the original set.

Figure 1

Load-Out Order Form Used in Product Assembly

LOAD OUT ORDER

DIVISION 32 ROUTE 336 TUE AUG 05

1-OFFICE

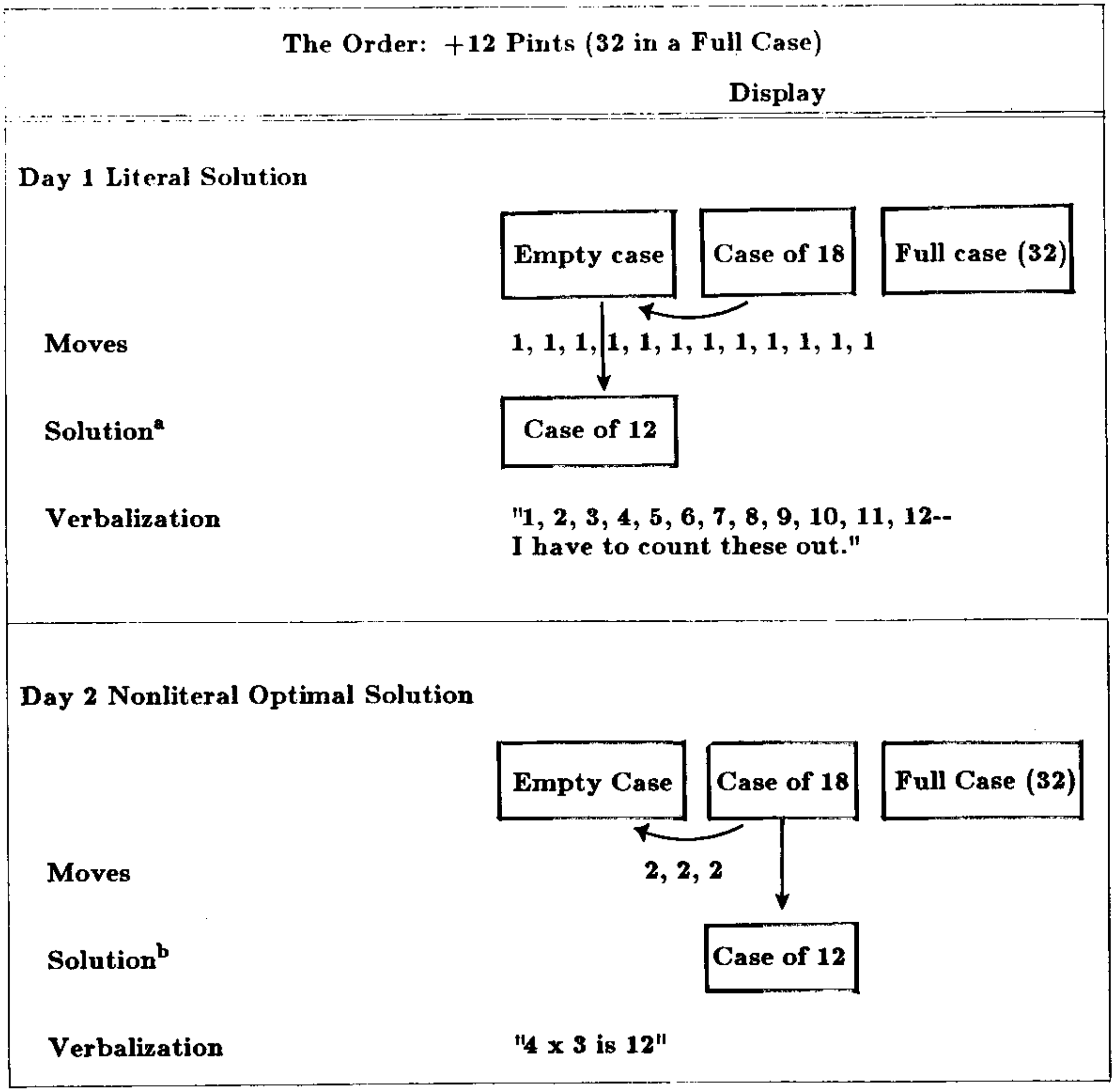
32 336 TUE AUG 05

Manual Cases	Manual Bottles	Computer Cases	Computer Bottles	Load	Size	Product		W
		36	+ 2	146	GAL	HOMO D L	091	
		7	+	28	GAL	2%LOWFT L	093	
		- 1	+ 4	13	H/G	2%LOWFT P	101	
		7	+	7	5GL	HOMODIS	107	W
		18	+	162	H/G	HOMO VD P	110	
		6	+ 6	102	CT	HOMO VD P	111	
		5	+ 12	172	PT	HOMO VD P	112	W
		43	- 16	2048	HPT	HOMO VD P	113	W
		15	+	720	HPT	2%LFHVD	115	W
		1	+	9	H/G	SKIM P	160	
			+ 5	5	CT	SKIM P	161	
		4	- 14	172	HPT	SKIM P	163	W
		6	- 6	90	CT	BUTMILK P	201	
			+ 24	24	HPT	BUTMILK P	203	W
		3	+	12	GAL	TM CHOC	210	
			+ 3	3	CT	CHOCO P	211	
		3	+	96	PT	CHOCO P	212	W
		1	- 13	19	PT	HALF P	232	
		1	+ 1	5	5LB	PL CHSE	271	
		1	+	24	122	PL CHSE	273	
			+ 2	2	242	PL CHSE	278	
		2	- 2	16	H/G	VIM MIX P	293	W
			+ 24	24	CT	GLAS OJ	600	
		3	+	48	CT	PURE OJ P	601	
		14	+	44	GAL	PUNCH P	603	
		8	+	32	GAL	ORANGE P	607	
			+ 5	5	250	SLENCRM	612	W
		1	+	4	GAL	LEMON P	418	
			+ 4	4	HPT	SOUR CR	634	
			+ 2	2	HPT	BLUE-YO	641	
			+ 2	2	HPT	STRA-YO	642	
			+ 2	2	HPT	CHER-YO	643	
			+ 2	2	HPT	RASP-YO	644	
			+ 2	2	HPT	PINE-YO	645	
			+ 2	2	HPT	PEAC-YO	646	
			+ 12	12	CAN	GS WHIP	650	
		6	+	420	402	ORGJUCE	682	W
		194		4566		CASES	888	

TOTALS →

Void

Figure 2
Product Assembly Simulation
Learning Study
Example of a Student's Change in Solution Mode



[a]*Observe that, in filling up the empty, the informant went* past *the solution in the partial case of 18.*

[b2]*The informant removed six pints in such a way that the remaining 12 were arranged in three rows of four pints.*

Some students' initial performance conformed to a literal strategy; some, however, displayed mixed modes of solution at the outset and gradually extended their selection of least-physical-effort solutions until they were consistent optimizers. Thus, the study supported the learning aspect and end-point of the acquisition model but not its prediction that the initial phase of problem-solving on this task would always be characterized by use of a literal algorithm. Patterns in acquisition of an optimizing strategy and changes in computational processes are now being analyzed from videotape transcripts.

As in the first study, variations in level of physical savings had no effect on time of initial occurrence or frequency of least-physical effort solutions. We will return to this observation in the discussion. However, this study yielded the strongest evidence to date of a mental effort-physical effort tradeoff. On this occasion, we ordered problems into levels of mental difficulty according to whether quantities on the order forms were expressed as *plus* units or *minus* units (see above).[5] On a *prima facie* basis, *minus* expressions require more interpretive processing for nonliteral solutions. An order "+5 quarts" at one and the same time expresses the goal which the assembler must reach (a case with 5 quarts) and a set of instructions by which (s)he might reach it (add 5 quarts). In contrast, an order "1-5 quarts" represents only instructions (remove five quarts) but not the goal (a case with 11 quarts). If the assembler fills orders under a literal strategy, *plus* and *minus* orders are of equivalent mental difficulty -- all that is required is following instructions. But if the assembler during the learning period searches for nonliteral least-physical effort solutions, *plus* orders should be easier to process. The assembler starts off with the solution (e.g., five) and need consider only how to arrive at it. In *minus* problems, (s)he must "compute" the solution (e.g., eleven) as well as consider how to arrive at it. Initially then, optimal solutions for *plus* problems require less mental effort than for *minus* problems. If this analysis is correct, *plus* problems should receive optimal solutions earlier than *minus* problems. Results confirm this expectation: optimal solutions for minus problems lagged substantially behind those for plus problems -- 30% compared to 66% on the first trial -- and while the gap narrowed over learning, it was not completely eliminated under the conditions of this study.

Discussion

Following Bartlett, Welford (1976) and other modern investigators have singled out flexibility as a defining characteristic of perceptual and motor skills: an expert performer reaches a given end using different means on different occasions.

The present analysis of filling product orders departs from much traditional research on work skills because it focuses on the cognitive aspects of skill, rather than on perceptual and motor processes. The product assembler's movements with containers and cases were relevant to the analysis only as indicators of mental processing. We were not concerned with whether these movements were "skilled" or "efficient" in an industrial engineering sense -- whether, for example, an assembler moved one container, or two or more containers at a time; whether his reach for a case was on or off target; whether her movements were slow or hurried, and the like. The inquiry was directed to the nature of the assembler's problem-solving processes -- more specifically, processes involved in interpreting and satisfying the quantitative relationships specified in arithmetic-like problems. Observational and experimental evidence resulting from this inquiry unequivocally supports the extension of the concept of flexibility, traditionally applied to perceptual-motor skills, to problem-solving skill on this task. This extension is more than metaphoric: flexibility here meets exactly the condition that psychologists have specified for skilled performance -- namely, that the operator use different means to reach a given end. Expert product assemblers used different modes of solution on identical problems requiring identical "answers."

Flexibility, of course, implies more than use of different means. Random variation or error might also result in different solutions for identical problems. Flexibility, as a hallmark of skill, requires that variation serve the purpose of "fitting means precisely to their occasions of use" (Welford, 1976). In product assembly, we found that this fittingness was indexed by a least-physical effort criterion, and we described such fittingness as the outcome of a higher-order optimizing strategy. In this analysis, it is the strategy, rather than the observed flexibility *per se*, that defines problem-solving skill. An optimizing strategy may or may not require flexibility. Consider the following: if the environment in the icebox were invariant, a single mode of solution would always meet the least-physical-effort criterion for a particular problem. The conjecture strikes us as absurd: how could the icebox remain the same when products are continually taken out of it? But raising this possibility serves the important purpose of making explicit an aspect of practical problem-solving that customarily remains implicit: it often occurs in a changing environment. Certainly, in product assembly, as in many activities in the dairy, the environment is in constant flux. In a changing environment, a "best solution" is a transient solution. A product assembler displays problem-solving skill when (s)he can simultaneously take into account the invariant attributes of the formal problem (e.g., an order for 1-6 quarts is always represented as 1-6) and the ever-changing features of the objective task environment (cases on hand, whether they are full or partial, and the like).

Understanding the nature of problem-solving skill in product assembly thus requires that the changing task environment be taken into account in the analysis. But even this enlargement of the unit of analysis is insufficient to account for skill. The statement that "assemblers fine-tuned their solutions to the changing conditions in the task environment" is descriptively adequate, but limited in an explanatory sense. The availability of empty or partially filled cases in the environment did not *impose* particular solutions on assemblers, nor do these conditions account for the existence of an optimizing strategy. Assemblers might have ignored the partial cases or used them in such a way as to increase, rather than reduce, the number of moves needed to fill the orders. (We observed such inefficient use of the partials among student novices.) The objective conditions in the task environment represented potential resources for problem-solving. But it was the assemblers' purposes -- their interest in "making the job easier" -- that recruited these potential resources into the problem-solving process.

Product assembly problem-solving thus appears to involve the establishment of a fitting relationship among problem, person and object -- or, more precisely, the formal requirements of the problem, the purposes of the problem-solver and the conditions and means provided in the task environment. Analytic models confined to the "problem" alone would fail to capture the essence of the expertise that product assemblers have acquired.

Introducing the concept of problem-solver's purposes highlights certain limitations of this research, and, we will claim, of problem-solving research in general. Empirically, we established that a least-physical effort strategy, labeled optimizing, regulated skilled performance in product assembly. In what sense is this strategy "optimal" and why is it a preferred strategy? So long as we are engaged in evaluating product assemblers' on-the-job performance, no difficulty arises in making sense out of the least-physical effort criterion. Assemblers' use of this strategy on the simulation task requires a more extended explanation. Recall that the simulation task called only for moving empty paper cartons from one case to an adjacent case on the table. Recall, too, that experts followed a save-physical-moves strategy whether the savings were a negligible one container or six containers. Least-physical effort scarcely seems a compelling motive under these circumstances. Still, it is in accord with commonsense explanations that experienced assemblers would maintain their well-established strategies in a study directed at examination of their work; workers in other dairy occupations (see accompanying articles) also brought their on-the-job strategies to the simulated tasks.

Accounting for novice performance is more difficult. Why did student novices in the learning study tend toward optimizing, least-physical-effort strategies? They had no prior experience with this particular job; the simulation required little expenditure of physical effort. Nonetheless, students who became optimizers accounted for their change in strategy in post-study interviews in terms that echoed assemblers' comments that least-physical move solutions were "easier." Here are two representative replies to the interviewer's question: "Do you think that the way you went about filling the orders changed as you got more experience?"

Virginia: Yeah, cause at first I'd like, if you said one minus five I'd do, I'd just start with the whole order [case] and take out five from that order instead of seeing if another order [case] just needed a few more. . . .

Interviewer: [Eventually] how did you decide how you wanted to fill an order?

Virginia: Ah, like if I wanted, if it was the easiest to do, like if it [a case] had the most to it and I had to add the least to it in the fastest way.

. . . .

Michelle: . . . first, you know I looked at it I thought about what I had to do -- like take 5, like if it was plus five that means I got to just leave 5 in a cart or put in 5. [Then] when I walk in, I see. . . .

Interviewer: What do you see?

Michelle: If there's 3 in there, all I got to do is take 2, you know I look for the easiest way to do it.

As the protocols make clear, when these students referred to the "easiest" way, they had in mind a solution requiring fewer physical moves. Our analysis suggested that conversion from a literal strategy to use of nonliteral solutions increased the *mental* difficulty of the task; student optimizers ignored this aspect of the strategy change in their accounts. But the two students who remained *literal* throughout the sessions focused on the mental rather than the physical demands of the task. Both of them accounted for their use of literal strategies in exactly the same terms that optimizers accounted for theirs -- it made the work "easier."

Dinah: I used the fullest box . . . because . . . I'd prefer taking, just using the fullest box and taking whatever I needed from there [refers to literal solutions on minus problems which involve removing containers from a full case].

Interviewer: Why did you prefer that, I'm curious.

Dinah: I think it was easier.

Interviewer: Do you have any idea why it was easier . . . ?

Dinah: Uh, well, I didn't have to concentrate that much. It was easier for me just to take it out of the other box.

- -

[Ed has just described to the interviewer how he figured out a nonliteral solution. For the better part of the learning trials, he was a literal problem-solver].

Interviewer: How would you say that's different from when you first started doing the problems?

Ed: Because that way is more difficult . . . You got to figure out, you got to figure out . . . the numbers . . .

From a rational point of view, selection of a strategy that is intellectually easier seems no less appropriate than selection of a strategy that is physically easier under conditions of the experiment. Students also proferred other standards for good solutions, among them speed, accuracy and neatness. Given the range of possible criteria, it is not self-evident why the majority of student novices achieved a common construction of expertise as involving least number of physical moves. If we cannot account for this outcome in terms of prior personal experience with product assembly, how might we account for it? One speculation is that other work experiences may have led students to least-physical effort strategies. Occupational studies (which we cannot review here) suggest that physical effort-saving may be quite widespread in the workplace; a variety of jobs involving manual work might have fostered such a strategy. The student population in this study was too small to test a possible link between personal work experience and use of an optimizing strategy, but this hypothesis is potentially testable.

Another speculative (and non-exclusive) account of student performance would appeal to cultural factors rather than personal experience. The concept of "work efficiency" may be such a pervasive evaluative standard in U.S. culture at large that, with or without job experience, students in a situation in which they consider themselves evaluated, will attempt to meet this standard "as a matter of course." Moving the research, with appropriately modified tasks, to different cultural settings might be a first step in examining this possibility.

The interpretive issues we have been addressing point to a deep problem in problem-solving research in general: how to account for experts' preference for one strategy over another? More specifically, and in line with our concern with optimizing strategies, how to account for the emergence of more "efficient" strategies with practice? The scope of the problem can be indicated by reference to research in the formal domain of mathematics. In this domain, both mathematicians and researchers accept "fewer mental moves" solutions as self-evident indices of efficiency and skill (these strategies can be considered analogous to the least-physical-moves strategies in product assembly). For example, Polya (1957), a mathematician well-known for his analysis of problem-solving skills, holds that good math solutions should not only be accurate but "short and simple"; he recommends that "shortness" become an explicit objective in mathematics instruction:

". . . it can happen even in very elementary classes that the students present an unnecessarily complicated solution. Then the teacher should show them, at least once or twice, not only how to solve the problem more shortly but also how to find in the result itself, indications of a shorter solution." (1957, p. 64)

On what theoretical grounds are shorter solutions "better solutions"?

Even more enigmatic is the evidence that many arithmetic problem-solvers share this criterion -- that a solution should not only lead to a correct answer (be functionally adequate in a strict sense) but that it have an "economical" form as well. Such strategy preferences are not the exclusive achievement of adult experts. Resnick and Gruen's studies (Resnick, 1976) provide startling evidence that children as young as five or six years also prefer solutions with fewer mental moves. They taught first-graders an algorithm for adding two single-digit numbers and discovered that, with experience, the children went on to invent fewer-move solutions. Resnick's description of the pupils' pattern of strategy acquisition resembles the present description of product assembly learning:

> In the studies just reported children are taught a routine which is derived from the subject matter. After some practice -- but no additional direct instruction they perform a different routine, one that is more efficient. The efficiency is a result of fewer steps (not, apparently faster performance of component operations) which in turn requires a choice or decision on the part of the child. A strictly algorithmic routine, in other words, is converted into another routine which turns out to solve the presented problems more efficiently. (1976, p. 71-72)

Why do first-graders prefer fewer mental move solutions? And why, on a practical task such as product assembly, do *all* experienced workers and most student learners elect to go against the tendency for fewer mental moves and choose solution procedures that initially require more mental moves for the sake of fewer physical moves? Are there other practical tasks in which mental and physical "efficiency" during early learning stages are at variance with each other?

In pondering these questions, we enter into the relatively unexplored territory of the structural as well as functional adequacy of problem solutions. Specifying what makes one solution "more fitting" (shorter, simpler, easier) than another from the problem-solver's point of view is a challenging theoretical question. Since this criterial question arises with respect to problem-solving in both practical and formal domains, it is interesting to speculate on the possibility that achievement of some fit between solution structure and problem structure may be a fundamental adaptive property of human thought.

Notes

[1]Edward Fahrmeier collaborated in the conduct and analysis of the dairy studies. Researchers in the learning study include Dolores Perin, postdoctoral fellow, and research assistants Joy Stevens and King Beach. Thanks to Jay Seitz for setting up the data files.

[2]Actually, the assembler typically goes for two-four products at a time (see Scribner, Gauvain and Fahrmeier, this issue) and must keep quantities for all these products in mind. Our analysis greatly simplifies the cognitive demands of the task.

[3]Students received a reduced set in one session.

[4]This study is supported by NSF Grant BNS 82-8819.

[5]Dolores Perin contributed this analysis.

Pricing Delivery Tickets: "School Arithmetic" in a Practical Setting

Sylvia Scribner

The occupation of wholesale delivery driver in the dairy included several arithmetic tasks closely resembling those students encounter in school arithmetic classes. These tasks required drivers to find and write the answers to addition, multiplication or subtraction problems stated in numbers and presented in standardized written formats. In carrying out these tasks, drivers were, in a sense, doing "school arithmetic" outside of school. We thus had an opportunity to investigate whether formal problem-solving in the mathematical domain exhibits any distinctive features when it is carried out in a practical rather than in an academic setting. Note that the comparison of interest here is not between "school arithmetic" and "everyday arithmetic" such as that involved in shopping or cooking (cf. Lave, Murtagh and de la Rocha, in press), but between school-arithmetic-in-school and school-arithmetic-at-work.

Our studies concentrated on one school-like arithmetic task -- pricing delivery tickets, a job that every wholesale driver has to carry out routinely on a daily basis.[1]

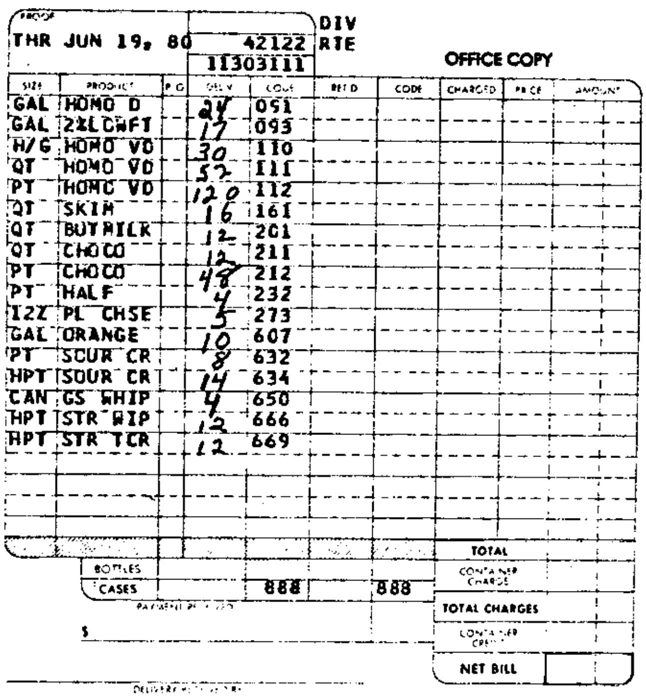
Pricing Delivery Tickets: A Job Description

Wholesale drivers are responsible for determining the cost of their daily deliveries to customers. For this purpose they use standard delivery tickets, preprinted with the customer's name and the products usually purchased (Figure 1 reproduces such a ticket).

When a driver completes a delivery, he enters on the ticket the quantity of each product delivered. Fluid milk products, the focus of our analysis, come packaged in containers of different sizes which we refer to as *units*: gallons, half-gallons, quarts and so on. As Figure 1 indicates, drivers always express product quantities on the tickets in units. Mr. G.,

Figure 1

Sample Delivery Ticket



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SIZE	PRODUCT	DELV	CODE
GAL	HOMO D	24	051
GAL	2%L CWFT	17	093
H/G	HOMO VD	30	110
QT	HOMO VD	52	111
PT	HOMO VD	120	112
QT	SKIM	16	161
QT	BUTMILK	12	201
QT	CHOCO	12	211
PT	CHOCO	48	212
PT	HALF	4	232
12Z	PL CHSE	5	273
GAL	ORANGE	10	607
PT	SOUR CR	8	632
HPT	SOUR CR	14	634
CAN	GS WHIP	4	650
HPT	STR WIP	12	666
HPT	STR TCR	12	669

BOTTLES — CASES 888 — 888

TOTAL — CONTAINER CHARGE — TOTAL CHARGES — CONTAINER CREDIT — NET BILL for example, delivered 24 gallons of homogenized milk, 30 half-gallons, and so on. After entering quantity delivered, the driver calculates the cost of the product and enters it in the columns provided; he proceeds down (or up) the ticket this way until all products are priced out and then he totals the dollar value of the entire delivery. Drivers use scratch pads, personal calculators or the dairy's calculating machine as aids.

Accuracy counts. Each man is responsible for the exact value of products he takes out of the dairy. Speed counts, too, for the driver's day begins at 3 a.m. and does not end until 1 or 2 p.m. To help the driver price out, the company provides a mimeographed price list for all major products sold wholesale. All prices are expressed in units on this list because the price structure consists wholly of unit prices. Since the size of each product is recorded on the delivery ticket in units, and prices are in units, the computation task seems straightforward: take the unit price from the price list or memory, multiply it by the number of units delivered and enter the result in the appropriate column. School-taught multiplication algorithms, if executed properly, could always produce accurate delivery cost figures.

Informal observations disclosed that drivers did not always use an algorithmic solution procedure. Mr. B., a driver I accompanied on his route, provided one of the first instances of an alternate pricing strategy. He read the line item "32 quarts skim milk" on the ticket, consulted a scratch sheet, found a price, doubled it and entered the result on the ticket. To understand his solution, we need to know that milk products in the dairy are stacked in standard-size plastic cases, that the driver's truck is loaded with cases, and that many of his high-volume sales are delivered in cases. The clue to Mr. B's solution is that he had converted the amount "32 quarts" into the amount "two cases" and he had computed the cost using price per case rather than price per quart. This solution can be characterized as indirect. Mr. D. interpolated a procedure -- translation of unit terms into case terms -- before carrying out the calculations. By taking this indirect route, he transformed a problem "32 x $.68" which might have required paper and pencil aids into a problem "2 x $10.88" which he was able to solve mentally.

This kind of problem transformation is clearly dependent on use of setting-specific symbols and knowledge. Consider the importation of "case" into the arithmetic problem. The milk case is a material object having instrumental value in the physical activities which comprise the dairy's production and distribution systems; it is used for packing, storing, carrying. But pricing-out is an activity occurring wholly in the symbolic mode. As a material object, the case is without significance for this activity. It achieves significance only when it has been stripped of its material properties and made to function as a number, or more accurately, a quantitative variable (see below). The company's price system does not make use of the case as a quantitative term; its construction is the outcome of the intellectual activity of drivers as a social group.[2]

A second aspect of interest is that translation of unit problems into case problems requires the individual driver to shift back and forth into different base number systems. This is a consequence of the fact that the fixed-dimension case holds a different number of unit containers of various sizes (e.g., quart, pint) and these numbers do not constitute a single base system. A case holds four gallons, for example, but nine half-gallons, and 32 pints but 48 half-pints. When confronting a given number of units on the ticket, say 32, a driver considering a case solution needs to select the conversion factor appropriate to the container size of the product, viz:

32 gallons = 8 cases
32 quarts = 2 cases
32 pints = 1 case
32 half-pints = 2/3 case

Given this complexity, questions arise: are case price solutions specialist or commonplace procedures? Under what circumstances do they offer an advantage over algorithmic or other arithmetic procedures?

Observations of Pricing-Out

From the population of wholesale drivers, we selected a random sample of ten drivers to observe and interview. We met with each man after work, and observed him pricing out some (on the average, four) of his day's delivery tickets. We requested each driver to price out his usual way but to do the arithmetic out loud. A second observer noted the driver's actions: whether or not he consulted a price list, used paper and pencil or calculator, and if so, how he represented and computed the problem.

We also collected copies of the driver's tickets, company price sheets and, for some of the drivers, "crib sheets" of case prices they had personally prepared. Documents and behavioral records provided converging (and, occasionally, disconfirming) evidence for the talk-aloud protocols.[3]

These observations provided the answer to the first question raised: use of a case price technique was not restricted to specialists but was common to the social group. With the exception of one new driver all others spontaneously used a case price technique on one or more problems. Even drivers using hand-held calculators resorted on occasion to case price solutions (see discussion below).

Observations also extended our knowledge of the phenomenon. "Case price technique" proved to be a set of varied procedures having in common only the fact that they involved some use of case terms. Most commonly a driver used a case price when the product quantity was exactly convertible to a single case, e.g., 16 quarts. Another common use involved conversion to cases of quantities equal to several cases (typically two to five, or ten). Most interesting were procedures which involved use of both case and unit quantities and prices; these reorganized the multiplication problem into one requiring only addition or subtraction. For example, one driver computed an order for ten half-gallons by adding a unit price to a case (nine gallons) price. On an order for 31 pints, another driver started with the case price (for 32) and subtracted a unit price.

These flexible solution procedures, selectively applied, suggested that the case-price technique served an effort-saving function, that drivers used it to make pricing-out arithmetic easier. To serve such a function, knowledge about cases would have to be readily available to the individual driver. If he had to figure out conversions or case prices on the spot, "savings" would be reduced or vitiated. We could assume that all drivers learned case conversion factors through their regular delivery activities. Knowledge of case prices, however, would have to be acquired in relation to the pricing-out task itself. The existence of driver crib sheets indicated that some men were prepared to invest some time and energy "on their own" to modify the delivery ticket chore. All these considerations led us to suspect a strong relationship between case price knowledge and case solution procedure. To test this proposition and confirm the effort-saving hypothesis, we assessed each driver's knowledge of case prices and then examined knowledge-procedure interactions on simulated pricing tasks.

Price Knowledge Elicitation

For the same sample of drivers, we elicited case price knowledge in the course of an individual interview session covering several topics. We handed each driver the company's price list after removing the unit price information. We asked him to read down the list and state the case price for each product from memory.

Nine of ten drivers knew some case prices from memory. Of twenty-five products to which case prices applied, the range of those known varied from five to 22. (This assessment understates driver's knowledge since many knew prices for multiple cases and for fractions of cases.) Price knowledge was highly selective; drivers made it clear that they primarily knew prices for products they handled by case on their own routes. For example, in reading down the product list, they rarely said they did not *know a price,* but often mentioned that they did not *handle the product* in question. S's comment is typical: "Gallons of chocolate drink, I don't even sell that. I don't even put that in my memory bank." (Transcript).

Simulated Pricing Task: Standard Tickets

With records on hand of each driver's price knowledge, we prepared five pseudo-delivery tickets using actual products carried by the dairy. Included in the 37-problem list were 17 problems devised to be diagnostic of case price use on quantities that were evenly divisible into a single case (7 problems), two to four cases (5 problems) and five or ten cases (5 problems). Recording procedures were those previously described. Drivers were asked to price out in their usual manner and were permitted to use customary aids.

In the analysis, we coded an individual driver as "knowing a case price" if he had given it in the formal elicitation task.[4]

The knowledge-use relationship was unequivocal (see Table 1): drivers only used case prices when they knew them; under conditions of the simulation, they did not pause to look them up on crib sheets if they had them. The converse proposition however, does not hold: when drivers knew case prices, they did not always use them. Frequency of use varied with product quantities: on single case quantities, drivers who knew the price used it on nearly nine-tenths of the problems; this level dropped off for quantities equal to two to four cases and declined more markedly for five or ten case multiples.

Did case price use "save effort"? The relationship between use of case price and engagement in computational operations supports this supposition (see Table 2). In this analysis, "computation" refers to some overt calculation on the driver's part, as indexed by use of paper and pencil or calculator aids. (Even with rich behavioral and verbal data, we cannot infer "no mental calculation.") When problems involved single cases, use of case price eliminated computation entirely; the answer was simply "plugged in." On multiple case quantities, the use of case prices eliminated computation two-thirds of the time. In contrast, when these same problems were solved by unit price procedures, they almost always involved paper and pencil or calculator arithmetic, principally the latter.

Even when case price use did not eliminate computation, it simplified it. Here is a representative example from Mr. B.'s protocol:

Problem		Mr. B.'s scratch sheet arithmetic
120 gallons	$2.33 per gallon	932 30 —— 27960

Mr. B.'s transcript: "Alright, it's nine thirty-two a case and we have, uh, four into one hundred and twenty is thirty cases. So I'll take thirty times nine thirty-two (writes). I figure that's the easiest way to do it."

Mr. B. was one of two old-timers who never used hand calculators and often used case prices and a variety of other short cuts. Drivers with calculators tended to go down a line of problems using an algorithmic procedure, entering unit price times number of units (or the reverse order) for most. The effort-saving utility of the case price technique seemed contingent on the method of computation which it displaced. For a clearer picture of the case-price calculator interaction, we designed another price simulation.

Simulated Pricing Task: New Tickets

To assess the effect of calculator use on method of solution, we controlled the variability of price knowledge by eliminating this factor altogether. We prepared tickets with products not carried by the dairy (e.g., iced coffee, 1% lowfat milk) and made available price lists setting forth both case and unit prices for these products. Participants had the option of selecting a price from either list. On some problems, case prices were appropriate, as above; on some, case and unit prices (e.g., 17 quarts = one case + one quart), on others, unit prices or general short-cutting arithmetic techniques (e.g., rounding out 99 to 100). In the first session, we allowed drivers either to use or put away their calculators as they preferred. In a second session, we presented the same materials but requested former calculator users to do problems without them, and the others to use their calculators if and when they wanted to. Eight drivers repeated both sessions, but two veterans who had never used calculators refused to try them out. We treat these veteran non-calculator drivers separately from the group of six men who did the task different ways on the two occasions. Outcomes with respect to case price problems are reported in Table 3.[5]

Although numbers are small, an orderly pattern emerges: veterans without calculators relied heavily on case prices, using them in imaginative ways; one driver displayed as many as twenty-five different case price solution modes. Drivers who normally used calculators showed greater preference for case solutions on more complicated problems (multiple cases and mixed case and unit) when they were computing without their calculators. When calculators were in hand, they overwhelmingly turned to unit solutions -- except for problems whose quantities equaled a single case. Their performance can be described in this way: when case price eliminated computation entirely (the single case problem), they used case price whether or not they had calculators; when case price merely simplified arithmetic, they used it on only a minority of occasions, and then, in a discriminating fashion.

Discussion

We began by raising a question about how performance on paper and pencil arithmetic problems in a practical setting might differ from problem-solving in a school setting. Here we have examined in detail only practical setting performance (for detailed comparison of work math and school math among workers and students, see Scribner and Fahrmeier, 1982). It is abundantly evident that a distinguishing characteristic of practical setting arithmetic is that its boundaries are "permeable" --

Table 1

Effect of Price Knowledge on use of case price

DELIVERY TICKET SIMULATION [Standard Tickets]

Problem Type	Case Price Known		Case Price "Not Known"[a]	
	Total No. Problems	No. Solved with Case Price	Total No. Problems	No. Solved with Case Price
Single Case	36	31 (86%)	27	1
2-4 Cases	39	28 (72%)	6	0
5 or 10 Cases	38	16 (42%)	7	2
Total	113	75 (66%)	40	3 (7%)

[a]A price was classified as "not known" when a driver failed to provide it on a knowledge elicitation task. On three occasions, such prices were retrieved during the pricing task.

Table 2

Relationship Between Use of Case Price and Computation[a]

DELIVERY TICKET SIMULATION [Standard Tickets]

Problem Type	Case Price Used		Unit Price Used	
	No. Problems	% Computed	No. Problems	% Computed
Single Case (63)[b]	31	0.0	28	92.8
2-4 Cases (45)	28	32.0	17	100.0
5 or 10 Cases (45)[b]	16	37.5	27	100.0

[a]*"Computation" refers to some form of overt calculation involving use of paper-and-pencil or calculator aids.*

[b]*Several solutions were problematic and could not be attributed to either case or unit procedures. Therefore unit and case problems do not always add up to total number of problems within classes.*

Table 3

Effect of Hand Calculators on Use of Case Price

DELIVERY TICKET SIMULATION [New Tickets]

Problem Type	% Problems On Which Case Price Was Used		
	Single Case (10)	Multiple Case (11)	Case-and-Unit (5)
Drivers who never used calculators (2)	100.0	95.5	78.6
Calculator Users (6)			
Without	65.0	59.0	45.0
With	66.0	32.0	17.0

real world knowledge enters the problem solving system, modifying its operations. The knowledge base drivers brought to bear on the pricing task consisted not only of number fact knowledge and procedural rules for combining numbers (Resnick and Ford, 1981) -- knowledge common to arithmetic problem solving in all settings -- but also setting-specific knowledge about the relationship of things in the dairy. They brought this setting-specific knowledge to bear even though it was not a constituent element of the problem domain as they confronted it. "Bringing real-world knowledge to bear" was a constructive activity of the drivers. This constructive activity had both social and individual aspects. On the social level, the community of drivers evolved and transmitted the concept of the case as an arithmetic term; on the individual level, each driver had to determine when case terms were appropriate in his own work and make the necessary translations. Re-representation of the problem in this way was only a first step; additionally, each driver needed to know and keep up-dated specific information about case prices, without which he could not operate within the new representation. Other studies (Carraher, et al., in press; Lave, 1977) suggest that this integration of arithmetic and real-world knowledge is a feature of problem-solving in a number of practical settings. Implications of this fact -- that the "problem as worked on" has been systematically changed from the "problem as presented" -- are only beginning to be explored.

In these studies, we found that one of the factors moving drivers to take the indirect, case-mediated route to problem-solving was the desire to find the "easiest way." We pushed the analysis far enough to demonstrate that the "easiest way" was not an absolute, but was contingent on an individual driver's case price knowledge and calculating device. Knowing these contingencies allows us to infer that, although school-taught algorithms for solving multiplication problems may be the same ten years from now, drivers' "easiest ways" are unlikely to remain unchanged.

Notes

[1]Edward Fahrmeier collaborated in these studies. Robert Russell and Elizabeth LaThorp coded data. Evelyn Jacob helped work out observational schemes and conducted additional observations not reported here.

[2]Individual drivers uniformly reported that no one had instructed them to use case prices, but the procedure was common knowledge. Drivers did much of their paper work in an office called the "settlement room," in plain view of and often socializing with each other. The one driver-interviewee in our sample who did not use case prices, knew and reported that many of the men did. Case price use is a good example of a problem-solving procedure that is part of workers' culture and is culturally transmitted (cf. Kusterer, 1978).

[3]Copies of data layouts which bring these various sources of information into accord are available on request. Behavioral observations help to test the strengths and limits of talk-aloud protocols. For discussions on the validity of verbal reports see Bainbridge, 1979; Ericson and Simon, 1980; Ginsburg et al., 1983.

[4]From a technical point of view, it is interesting to note that there was practically no discrepancy between "not known" case price knowledge in the formal elicitation task and in the use context of the pricing task. Two drivers each remembered one additional case price in the pricing task that they had not reported during the elicitation. We have no way of telling whether prices "known" in the elicitation task were also "known" in the pricing task but we think it highly likely.

[5]This study also involved other dairy occupations and students. Comparative results are presented in Scribner and Fahrmeier, 1982 and Scribner, in press.

* * * * * *

To be human and to work
appear as inextricably interwined notions.
To work
means to modify the world as it is found.
Only through such modification
can the world be made into an arena
for human conduct, human meanings, human society,
or, for that matter,
human existence in any sense of the word.
It is not surprising then
that the great revolutions
in the character of human work
entailed transformations of human existence in its totality
from the so-called neolithic revolution
on to the Industrial Revolution
that is still transforming
our own existence today.

Berger, P. L. (1964). *The human shape of work.*

* * * * * *

Organizing Knowledge At Work

Sylvia Scribner

It is a matter of conventional wisdom that a person entering a trade or beginning a new job needs to acquire knowledge of many kinds to meet performance requirements: knowledge of facts and things, of mental and manual procedures, of social relationships and etiquette. Conversely, every job, no matter how unskilled, requires the worker to integrate and employ information from many diverse knowledge domains (Kusterer, 1978; Singleton, 1978). In the workplace, knowledge is an integral aspect of practical activities.

The relationship between knowledge and action, however, has low priority in cognitive science (but for important exceptions, see Lave, Murtagh and de la Rocha, in press; and Nelson, 1973). As Mandler (1983) points out, the central questions investigators address today concern the mental representation of knowledge. Many have as their aim the construction of mental models that ostensibly serve as general representations of cultural domains of knowledge. These approaches to the study of knowledge have many accomplishments to their credit, but they leave largely unexplored such vital questions as how individuals use their knowledge to get about the world, or how they acquire knowledge in the course of getting about the world.

In an activity approach to cognition (Leont'ev, 1978) the relationship between knowledge and action has high priority. This approach holds that object knowledge is constituted through activities. All or a wide range of activities may be functionally equivalent in constituting basic object concepts (e.g., object permanence in Piaget's theory) and enabling the abstraction of essential object features. But over and above this level, acquisition and organization of knowledge about specific properties of objects will be influenced by the goals and conditions of the concrete activities an individual carries out with these objects. In turn, as experience accumulates, activities will be increasingly guided by the specific knowledge-about-the-object that the individual has acquired and mentally represented.[1]

In keeping with this orientation, we conducted two studies among dairy workers examining the relationship between different occupational activities in a common object domain, and workers' organization of knowledge about this domain.[2]

The Knowledge Domain

Just as many anthropologists investigate folk knowledge of objects that are important for valued cultural activities (e.g., plants, stars), we investigated knowledge about a domain of things crucial to the dairy business -- the products the company manufactured and/or distributed to its wholesale customers.

This domain had a number of advantages for research purposes. First, it was a closed domain whose contents could be exhaustively specified. The company maintained a master price list which served as the authoritative reference document for billing and other purposes. The price list enumerated all products distributed by the company, and was updated from time to time; during our research, it contained 212 products, each identified by a unique item code. Second, the company's own descriptions of the products provided us with emically significant dimensions of variability among products. (Consult Figure 1, in Product Assembly: Optimizing Strategies and their Acquisition, this issue, which reproduces a load-out form on which products are represented in a manner similar to their representation on the master price list.) Four categories of attributes are specified in product names. Products are divided into *kinds* -- fluid milk, cheeses, mixes, and so on, and are further distinguished by *size* or *quantity* (e.g., gallon, pound), *qualities* (e.g., fat content, flavor), and *container* (glass, P for paper, box). These attributes do not exhaust all the distinctions that are made in the dairy among products or that might be made by individuals. Just as any object can be described in an infinite number of ways, workers handling the products could extract an infinite number of characteristics to use as classifying dimensions, ranging from color of the cap on plastic containers to "products on Charlie's truck and products on Henry's truck." However, the existence of officially-recognized and culturally-common specifications provided us with an initial basis for assessing the dimensions workers actually used. Finally, dairy products are familiar to members of the larger culture in which the dairy functions, enabling us to compare the specialist knowledge of producers in the dairy with the common knowledge of individuals relating to these products solely as consumers.

Retrieving Product Information

The first study used a recall procedure. Participants were members of the three dairy occupations included in the major research design. Two consumer groups were included for comparative purposes: 24 9th grade students and 8 white-collar employees of a language research institute (LRI).

Work tasks of the occupational groups involved them in different kinds of actions with dairy products. Office workers processed company forms which required them to read or write product names; they did not handle the actual products. Warehouse workers read or filled out forms listing products but only as one step in an activity sequence of locating and assembling products in the warehouse or counting them for inventory. Drivers handled the products on their trucks and used a number of forms carrying product names. In short: office workers acted only with symbolic representations of dairy products; warehouse workers and drivers interacted with products in both their symbolic and material forms but they did so for different purposes and in different settings.

Workers were asked to name the products the dairy sold wholesale in any order that came to mind. Consumers were asked to name as many dairy products as they could remember. During recall, occasional probes were used. These included general encouragements ("Can you name some more?") and specific probes in response to the use of a generic term characterizing an entire group of products ("You said some products were (milk) (cheese). Could you be more specific about what these products are?"). The elicitation was terminated when informants were emphatic that no more product names came to mind. Each person's recall was hand and tape-recorded.

Amount Recalled

As might be predicted, workers under these procedures named more products than did consumers. Although group averages of product recall cannot be taken to represent "what people know" in any absolute sense, relative rankings accord with *a priori* expectations that specialist knowledge is more extensive than general knowledge: warehouse workers named 49 products on the average, office workers 36 and drivers 31; LRI informants named 21 and students 9.

Relational Attributes

Object attributes used to organize retrieval were identified in the following way: beginning with the first two items on each person's recall protocol (number 1 and number 2), and continuing with adjacent pairs (number 2 and number 3, and so on), we determined whether or not items in a pair shared one or more common attributes and we categorized these attributes into the dairy's system. The following analysis of a recall protocol (adapted for the purpose) illustrates the procedure.

Item	Pair	Analysis
1. chocolate *milk*		
	1st pair:	common term is milk, a kind attribute
2. skim *milk*		
	2nd pair:	none
3. *orange* juice		
	3rd pair:	common term is orange, a quality attribute
4. *orange* drink		
	4th pair:	none
5. *quart* buttermilk		
	5th pair:	common term is quart, a size attribute
6. *quart* sterilized *whipping cream*		
	6th pair:	common terms are quart (size) and whipping cream (kind), a compound attribute
7. *quart* fresh *whipping cream*		

In actuality, dairy workers' protocols were characterized by longer runs of related products than the above example suggests. Note that the longer the runs, the greater the number of related pairs. The proportion of related to non-related pairs in an individual protocol measured overall list organization. Identification of attributes was limited to the four descriptors used on product lists, and to various combinations of these.

This analysis was relatively straightforward (coder reliability was .90).[3] The organizational measure it produced, however, must be taken as an incomplete reflection of the associative links in each individual's recall list. A coding determination that there was "no common attribute" between items in a pair does not imply the total absence of a common term between them; it merely indicates that the pair did not exhibit one of the four classes of attributes explicitly marked in official product descriptions.

In spite of these limiting factors, the organizational measure is informative. All groups except students organized their retrieval predominantly by the descriptors derived from dairy lists (Table 1, Row 1). Dairy workers differed markedly from both consumer groups, however, in the diversity of attributes used as relational links (Row 2). Consumers' product relationships were restricted to three or four attributes and attribute combinations compared to at least twice that number among dairy workers. Note that warehouse workers had the most diversified ways of organizing their product lists, indicating a rich and complex knowledge base.

The particular classes of attributes serving as organizational features also differed by group (bottom half of Table 1). Consumer groups relied almost exclusively on the category *kind of product* to organize their recall. In contrast, only 42% of office workers' associations and one-fourth of blue collar workers' associations consisted of simple links by product kind. In all occupations, the majority of product links were multidimensional; they involved various combinations of size, kind, one or more qualities, and container, and occasionally all four of these simultaneously.

Metacognitive Strategies

In addition to scoring for product pairs, we examined dairy workers' protocols for evidence of higher-order retrieval strategies. Some informants followed a systematic procedure in their recall, ordering two attributes into hierarchical relations with each other. For example, some used quantity as a higher-order attribute; they started with "gallons" and named products packaged in gallons, then proceeded to half-gallons, quarts and so on. Others organized the list by kind of product and subsumed size under that, or by location (see below) and kind. We scored a protocol for presence of a metacognitive strategy if the majority of list items reflected a taxonomic organization of this kind. There were marked individual differences on this measure, but use of systematic retrieval strategies was more frequent among warehouse workers than among members of any other occupation. Figure 1 displays the protocol of one warehouse assembler who was outstanding in his list organization.

Sorting Product Names

The second study of product knowledge used a sorting procedure. We presented the same informants with the names of 25 products on cards, using the company descriptors (e.g., half-pint chocolate milk; 1 lb. lowfat cheese). The 25 items were selected in such a way as to allow for the application of different sorting criteria. Standard sorting instructions were used ("put together products that belong together"). We asked informants to talk out loud while sorting, and later to explain the groups they made.

As Table 2 indicates, consumers again relied mainly on *kind of product* to constitute similarity groups. Eighty-five percent of office workers' groups were also based on *kind,* but some of their groups were defined by *size.* Blue-collar workers made greater use of size as a grouping criterion. Warehouse workers were exceptional in several respects. They were the only informants who did not organize the majority of their groups by kind of product. They were the *only* informants to use, as a grouping principle, location. Location was not explicitly built into the experimental list, nor is it an attribute marked on company documents. As warehouse workers used it on this task, location refers to the area of the warehouse in which various goods are stored: fluid products of high volume ("Bigs") are stored at one end and goods produced in lesser amounts ("splits") are stored at another. Location is a critical thing to know about dairy products if one spends eight hours a night going to fetch them.

Observations we made of product assemblers at work in the warehouse (see, Use of Spatial Knowledge in the Organization of Work, this issue) disclosed that they routinely use product location as the basis for reorganizing computer-generated order forms and making their assembly task more efficient and less arduous. In using location to sort product names on cards, warehouse workers were employing a grouping principle important to their actual work activities. The occurrence of organization-by-location in the two contexts of experiment and work provides a connecting link between them, and suggests that, to some (presently nonspecifiable) extent, the experiment succeeded in tapping customary organizing principles. This is also the most direct evidence we have that knowledge employed in activities involving physical manipulations of objects is utilized in a task requiring purely symbolic manipulations with these objects (the experimental task). Note that, although occupations varied in the particular product attributes they selected as grouping principles, they all constituted groups defined by a single principle. In this respect, the organizations of office workers, drivers and warehousemen were equally "abstract."

Figure 1
Warehouse Worker's Recall Protocol
[75 Products]

Gallons of homo	Cupcreamers
Gallons of two per cent	Blendcreamers
Gallons skimmed	30 pounds cottage cheese
Gallons punch	Five pounds cottage cheese
Gallons orange	Two pounds cottage cheese
Gallons lemon	24 ounce cottage cheese
Gallons cherry-apple	12 ounce cottage cheese
Gallons apple drink	Gallons sour cream
Half gallons homo	Pints sour cream
Half gallons green valley	Half pints sour cream
Half gallons two per cent	Twelve ounce pineapple cheese
Half gallons skim	Chip dip . . . 12 ounce
Half gallons orange juice	Three gallon sour cream with chives
Half gallons ice cream mixes	Three gallon sour cream without chives
Vanilla mix . . . ten per cent	Five gallon blend boxes
Vanilla mix . . . three point five per cent	Five gallon boxes half and half
Chocolate . . . ten per cent	Five gallon boxes skim two per cent
Chocolate . . . three point five per cent	Five gallon boxes chocolate
Quarts homo	Half pints homo
Quarts skim	Half pints two per cent
Quarts chocolate	Half pints low fat chocolate
Quarts half and half	Half pints skimmed
Quarts fresh whip	Half pints buttermilk
Quarts guernsey milk	Half pints orangeade
Quarts of buttermilk	Half pints punch
Quarts blend	Half pints orange juice . . . paper
Quarts table cream	Seven ounce orange juice glass
Pints of homo	Seven ounce grapefruit juice glass
Pints chocolate	Half gallons and
Pints half and half	Quarts of egg nog
Pints lemon	Half pints whipped cream
Pints tea	Half pints table cream
Pints orange	Twelve ounce can whipped cream
Quarts orange juice in glass	Fifteen ounce non dairy whipped cream
__________ and paper	Half pints yogurt
Quarts grapefruit juice . . . glass	Pound butter
Quarts apple juice . . . glass	Pound oleo
	Tray butter . . . fifteen pound box

Table 1
Recall Organization by Product Attribute
(Means)

	Consumers		Dairy Occupations		
	Students	LRI	Office	Drivers	Warehouse
% recall organized by product attribute	40	63	62	69	77
No. different simple or compund attributes	4	3	8	8	12
% associative links of principal attributes					
kind (e.g., "milk")	92	95	42	26	23
quality (e.g., "choc.")	0	2	1	0	1
size (e.g., "qt.")	0	0	5	7	9
container (e.g., "carton")	1	0	0	0	1
compound (e.g., "choc.milk")	7	3	52	67	66

Table 2
Sorting Organization by Product Attribute
(Means)

	Consumers		Dairy Occupations		
	Students	LRI	Office	Drivers	Warehouse
% of Sorts[a]					
Kind	77	91	85	67	36
Size	2	0	11	31	31
Location	0	0	0	0	32
Other[b]	21	9	4	11	1

[a]*The average number of groups into which items were sorted was 5.1 (students), 5.4 (LRI), 4.6 (office workers), 4.5 (drivers), 4.8 (warehouse).*

[b]*This category includes groups organized by place of sale, season of greatest use, and idiosyncratic reasons.*

Discussion

These studies are exploratory and serve primarily as demonstrations of the fruitfulness of an activity approach to the acquisition of knowledge.

Taken on their face, findings confirm the initial expectation that, even within a common knowledge domain, organizing schemes will be diverse and related to functional activities. Consumers encounter dairy products in many of their variegated qualities and quantities in supermarkets and refrigerators, but they ignored such attributes in their organization. Specialists (dairy workers) took account of more product properties, finding distinctions and similarities unmarked by consumers. But among specialists too, the structuring of this domain of common knowledge took different forms for individuals who were functionally related to that domain in different ways.

One way to summarize differences among dairy occupations is to conclude that different work tasks provide opportunities for individuals to learn different things about the objects: *what* you learn is bound up with what you do. This truism applies here (e.g., office workers did not know product location) but, as stated, it is an incomplete account of the findings in two respects: 1) it ignores the distinction between what is "known" and what is "used"; and 2) it bypasses the psychologically critical question of the meaning of "bound up with."

We cannot assume that failure of some dairy workers to use particular product attributes as organizing principles always indicates lack of knowledge of such attributes; other distinctions are necessary. Consider the following. Most office workers encounter and use information about product size and quantity many times a day as they handle company forms, prepare bills and the like, but they rarely employed this attribute as a grouping criterion. Drivers are familiar with the general layout of the warehouse; from time to time they personally pick up items for their trucks and some "worked the box" before becoming drivers yet not one of them used location as a grouping criterion. Warehouse workers certainly know product kinds and named more of them in their recall than members of other occupations. But they did not use *kind* as a predominant grouping criterion on either the recall or sorting task. Occupational variations appear to reflect, not only differences in "what is known," but the differential salience of product attributes as organizing criteria in these particular contexts of knowledge use.

What is "salience"? In discussing children's selection of object characteristics as bases for concept formation, Nelson (1973, p. 228) lists *importance* as a motivation, adding that "one manifestation of importance is utility in a problem-solving situation." Drawing on activity theory, we can suggest a more specific formulation of this notion of problem-solving utility. In experiments on activity and memory spanning several decades, Zinchenko (1981) and associates found that information related to the goal of a task was more likely to be remembered than information related to the conditions or means of reaching the goal. This concept of goal-related information can be extended to the phenomena at hand. In the dairy, certain object properties are essential to the accomplishment of one job, and not another. The attribute *location* illustrates the point. Location is related to the goal of product assembly; indeed, warehouse workers could not perform their jobs without detailed knowledge of the distribution of products in the storage space. Moreover, information about product location plays a role in the way they organize their own work in the interests of their personal goals of saving effort. In contrast, for wholesale drivers, location may be useful information to have but it is in no way essential. Their ability to carry out their work would be little affected if they lacked knowledge of how products are stored in the warehouse.

If the goal-relatedness of information is one condition of salience, some of the experimental findings fall into place. Object properties essential to the fulfillment of well-practiced activities may be those most readily accessed as organizing principles when individuals in an arbitrary task are asked to organize a familiar domain. Location, as an attribute, would be more readily accessible to warehousemen than drivers; a similar, but more complicated analysis might be made for the salience of size among both blue-collar occupations.

The present research suggests, then, that the functional role of knowledge in significant activities such as work may be related not only to what is learned, but to how knowledge is accessed in other situations. These observations, though *post hoc* here, offer testable propositions for future research on the functional bases of knowledge.

Notes

[1]The term "object" has two meanings in this passage. In some contexts, it signifies any of the non-subjective aspects of action (as in epistemological discussions which differentiate subject and object as two poles of the knowing process). In other contexts, "object" is used in the ordinary language sense to refer to discrete material things in the environment. The research concerned knowledge of objects in this ordinary language sense. We hope this meaning emerges clearly in context.

[2]Edward Fahrmeier collaborated in the conduct of these studies. Robert L. Russell and Edward Wizniewski analyzed recall and sorting protocols.

[3]Coding instructions are available.

Use of Spatial Knowledge in the Organization of Work

Sylvia Scribner, Mary Gauvain and Edward Fahrmeier

Knowledge of large-scale space is essential for conducting many practical, everyday activities. Large-scale space is characterized as space which surrounds the individual and requires multiple vantage points to be understood since part of the space is obscured from immediate view (Acredolo, 1981; Ittelson, 1973). To examine the role of spatial knowledge in the workplace, we adopted a functional perspective focusing on how such knowledge is used to accomplish task requirements and workers' purposes.

Possessing a "cognitive map" of a large scale space implies the ability to use the environment flexibly to conduct a task in the space. Such flexibility can be evidenced by the ability to deal successfully with a detour or by the ability to devise and coordinate multiple routes to carry out sequences of goal directed activities in the space.

Informal observations of product assemblers filling dairy orders in the icebox (warehouse) suggested they were using their spatial knowledge of the box to organize their work. To test this proposition, we conducted systematic observations of two experienced assemblers during the first half of their regular shift. Their method of work was typical of how others with experience handled the job.

The Task

As is customary, the two assemblers worked as a team, consulting a single truck load-out order form. These forms, which are kept at a fixed, centrally located point, list all the products and their amounts needed for the next day's deliveries, one form for each wholesale delivery route. Proceeding independently, each assembler initialed the items (s)he would fetch on a single trip, located them and carried them to a common assembly area for conveyance to the loading platform. Then (s)he returned to the central location and repeated the sequence until all items on a single order form were assembled, and the team was ready for the next. The assembly task is thus a version of the traveling salesman problem in that one or several stops are accomplished on a trip, with each trip interspersed with a visit to homebase.

On a full shift, the team fills some 60 wholesale orders consisting of approximately 1200 items (plus additional retail orders). During our observations, the team filled 22 wholesale order forms consisting of 420 items. Of the 76 different wholesale products stored in the icebox, 73 appeared on the order forms during the observation.

The observer stood at the location where the order forms were kept. Using a duplicate set of forms, she initialed the same items that the assembler was initialing, and noted order of selection and trip information.

The Setting

The icebox measures 6525 square feet (145 feet x 45 feet). Products are arranged in an orderly fashion according to several considerations: size of inventory, volume of the product, proximity to the area in the plant where the item was packaged, proximity to similar items, and so on. Most items have the same general location night after night, but a few items manufactured at the end of the day might be stored in a variety of locations due to space limitations in the normal locations for these products. On their arrival at work, assemblers spend part of their first hour "putting the box in order" -- relocating and restacking items for convenience in filling orders.

Trip Organization

Inspection of observational records yielded the following conclusions about how assemblers organized their trips.

1) Although assemblers occasionally went to procure one item at a time (bulk products) they frequently signed off for two, three or more times in a single trip. Organizing trips to fetch a number of items increased the mental difficulty of the task. Making the warehouse rounds, the assembler had to keep in working memory not only the names of the specific products to be located but their quantities as well. Quantity expressions on the load-out order form are complex (see Product Assembly: Optimizing Strategies and their Acquisition, this issue), sometimes representing number of cases, sometimes number of units (e.g., quart, box) and sometimes a combination of the two. Several assemblers informed us that "keeping orders in mind" was one of the hardest parts of their job.

2) In organizing groups of items to be procured in one trip, assemblers sometimes followed list order. They initialed, located and assembled products appearing as successive items on the list.

3) On some occasions, assemblers departed from list order and reorganized products to constitute trips. For example, Mr. B., preparing for his first trip on one load form, selected an item in the last third of the list, then omitted the next three products, included the next two, omitted two, and ended with the last item on the list.

These characteristics of trip organization suggested that, as in another of their work tasks, (see Product Assembly: Optimizing Strategies and their Acquisition, this issue) product assemblers were engaging in mental work (organization and reorganization of list items, mental rehearsal) to save physical effort. Specifically, we hypothesized that assemblers chose items to group together on the basis of the spatial arrangement of the icebox, that their selection was based on proximity of the items to each other in the box, and that their goal was to reduce the total distance they had to travel during the course of their shift.

If this hypothesis was correct, the distance assemblers traveled on their actual trips would be less than the distance involved in collecting items as they were presented on the load-out order forms. This hypothesis could not be tested directly. The icebox was too densely packed and the assemblers too rushed for observers to follow them and measure the exact route of each trip, nor could they be required to make "hypothetical" trips. The analysis therefore proceeded by indirect measures.

Method of Distance Calculation[2]

E. F. drew a scale map of the warehouse on which he located all wholesale products. From this map, M. G. using Graph theory (Ore, 1963) devised a geometrical figure or diagram which permitted the calculation of approximate but adequate measures of distance traveled on each trip.

The graph consists of 14 points, called vertices and 39 lines, called edges, which connect the vertices. Each vertex marks the center of a 6 ft. x 6 ft. area in the warehouse; all the dairy products located within this area were targeted as located at this vertex. Homebase was located at the center vertex. The edges, ranging in length from 10 to 41 feet, indicate paths of travel between items.

Assume a worker fetched three items on one trip. The first step involved locating each item on the appropriate vertex. Then the distance from one item to another was determined by adding the edges connecting their vertices; edges connecting an item vertex to homebase were included in the total trip distance. Various orders of item procurement were calculated in this way (Item A, B, C; Item A, C, B and the like) until the shortest distance linking all items in a trip was determined. The shortest distance for each trip was used to calculate the overall distance for a complete load order form.

Alternative Trip Arrangements

Using the procedures described, M. G. computed distance in feet for all items the assemblers fetched during the observation period, under assumptions of different trip organizing principles. These trip simulations were then compared to workers' actual trips. In this analysis, observations for the two assemblers were pooled, since they worked in tandem from the same order form.

The first simulation assumed the worst case -- the distance traveled if assemblers accepted the list as given and went for one item at a time. The second simulation assumed that items were grouped, but that groups were restricted to adjacent items on the list. To carry out this comparison, M. G. tallied the number of single items and groups of different sizes (2, 3, and 4 items) represented in workers' actual trips. She then randomly assigned the same number of singles and various sized groups to the items as they were listed on each of the order forms, working sequentially from top to bottom. This procedure segmented the order forms into the items as they were listed on each of the order forms, working sequentially from top to bottom. This procedure segmented the order forms into groups organized entirely on a sequential basis. It should be noted that the order in which items are listed on the load forms already reflects some accommodation to the location of products in the warehouse. Bulk products, for example, are always listed first, one after the other, and certain "like products" (cheeses, for example) are also listed successively.

Final calculations measured the distance of workers' actual trips.

Results

The travel distance under the one-item-at-a-time assumption was 20,016 feet. The mean travel distance for the five random generations of sequential groups was 13,279 feet (individual calculations ranged from 12,632 feet to 13,942 feet). Assemblers' actual trips amounted to 10,993 feet.

A comparison of the one-at-a-time simulation with the sequential group simulation measures the savings resulting from workers' application of grouping procedures to a list incorporating some information about the spatial location of products. This savings amounted to 6,737 feet. A comparison of the sequential group simulation with workers' actual trips measures the savings resulting from workers' reorganization of the list and can be taken as an indication that workers' *own* knowledge of warehouse space was applied to the traveling salesman problem. This savings amounted to 2,286 feet. In all, workers' mental activities with the order list (grouping and reorganization) resulted in savings of more than 9,000 feet over the worst case of no constructive input.

These calculations underestimate actual savings. Graph measurements are made "as the crow flies"; actual routes are longer. Moreover, calculations were based on only one-third of a night's work (22 order forms). Extrapolating to the entire shift, we estimate savings over the worst case (least mental effort) as 27,069 feet or more than 5 miles.

Assemblers accomplished their trip organizations speedily. They did not linger over the load-out order forms nor did they engage in discussions with each other as to how they were going to divide up the list. Nevertheless, the distribution of work was exquisitely managed: one assembler (male) traveled 5,446 feet during the observation period; the other (female) traveled 5,547 feet. To work in such a coordinated and efficient manner, each assembler needed some internal representation of the warehouse which could be flexibly used to organize the items on hand. With such knowledge, assemblers were able to map the symbolic organization of the order form on to the spatial organization of the warehouse to shape their work so it was a little more adapted to human needs.

Notes

[1]Evelyn Jacob made these observations.

[2]Additional information on the distance analysis and a copy of the graph used in this analysis can be obtained from Mary Gauvain, Tillett Hall, Department of Psychology, Livingston Campus, Rutgers University, New Brunswick, NJ 08903.

Technical Note: Frequency Effect in Retrieval of Job-related Knowledge

Sylvia Scribner

In the study of memory, as in other cognitive domains, limitations of standard laboratory experiments occasion growing concern. One commonly acknowledged limitation is the exclusion from laboratory research of certain memory phenomena prominent in daily life (Neisser, 1982; Bahrick and Karis, 1982). Another limitation concerns the range of applicability of laboratory-based models and empirical generalizations. Are these valid only for the conditions of the experimental tasks from which they were derived? Or can they be extended to memory processes in a variety of life circumstances?

This note concerns the latter issue. No procedures are on hand to resolve validity and generalization questions entirely on an *a priori* basis. Nor does it seem reasonable to suppose that the relationship between laboratory accounts of memory and everyday memory phenomena will be captured in one all-embracing formula. Rather, it seems fruitful to consider these relationships as a set of open questions that can be pursued in research as well as in theoretical analysis. As investigators extend the sample of situations and activities in which they study memory, opportunities are present for field tests of specific memory models or empirical laws formulated in the laboratory.

A study of dairy workers' retrieval of product knowledge illustrates possibilities that arise in field research for empirical approaches to the ecological validity problem.

The Frequency Effect

One of the most durable regularities observed in laboratory recall studies is the word frequency effect. Other things being equal, subjects given a word list to recall are more likely to remember high than low frequency words. This result obtains under a wide variety of list learning conditions (Klatsky, 1980). For experimental purposes, word frequency ratings are derived from counts of the number of times a lexical item appears in a sample corpus of written (Thorndike and Lorge, 1944) or spoken (Hall, et al., in press) discourse. Investigators, however, use these ratings as though they measured the number of times experimental subjects had actually encountered the particular words on a learning list.

Several questions arise as to the generality of the frequency effect. Does frequency influence the retrieval of specific items of information when all items are members of a highly familiar domain of knowledge, or does it merely distinguish between domains of high and low familiarity? Does it apply to *things* as well as words? Does frequency influence recall only under list learning conditions or does it affect how individuals access their knowledge under "free report" conditions?

Testing the Effect

We addressed several of these questions through an analysis of protocols obtained from dairy workers in interviews about their work and the nature of the dairy business.[1] In one interview, we asked each worker to tell us the wholesale products marketed by the company in any order in which they came to mind. (See, Organizing Knowledge at Work, this issue.) A group of dairy workers, composed of twenty wholesale drivers, product assemblers and inventory men, are included in the present analysis. These men were all experienced employees whose daily jobs consisted of physical activities with wholesale products (e.g., taking them off trucks) and symbolic activities with product names on company inventory and delivery forms (e.g., reading a product list). "Wholesale products" was thus a knowledge domain highly familiar to all--one which constituted the "stuff" of everyday practice. Nevertheless, the nature of the dairy business is such that some wholesale products are more frequently encountered than others. More customers are likely to have standing orders for fresh milk products than for specialty items such as "vanilla mix" or "sterile whip." Some wholesale customers order certain items (e.g., gallon homogenized milk) on a daily basis while ordering others (e.g., half-pint tea) only occasionally. The company recorded these variations on order forms which listed the products and their quantities delivered daily to each customer on a wholesale route. We used these order forms to assign product frequencies in the following manner: we secured a set of forms for all wholesale routes (63) for two past delivery dates spaced four months apart (to encompass seasonal variations). From a master price list, we identified 140 products marketed on a wholesale basis. We then counted the number of routes carrying each of these products on the targeted delivery dates, averaging over dates.[2] Product frequency ratings obtained in this manner could theoretically range from a minimum of 0 (if none of the wholesale routes included that product on either of those days) to a maximum of 63 (if all routes included that product on both days). The actual range was 0 to 50.5. Next, product ratings were categorized into frequency intervals on a pragmatic basis, such as to yield classes with an approximately equal number of products except for the lowest frequency interval which had nearly twice as many as all other classes combined. These classes were used as the basis of analysis.

Results

Protocols from the elicitation interviews contained 713 product names, an average of 35.6 items per worker. Table 1 indicates that product frequency was an influential determinant of both the *what* and *how* of information retrieval from this highly familiar domain. Consider first the products workers most often named. Column 1, "Average recall per item" is a measure of the number of times products in each frequency class were named by the 20 informants, divided by the number of products in that class. To illustrate, protocols contained 169 mentions of the 11 products in the top frequency class or an average of 15.36 mentions per item. If all workers had mentioned all products in that class

Table 1
Effect of Product Frequency on Retrieval of Product Information

Product Frequency Class	No. Products in Class	Average Recall per Product (max. = 20) (Column 1)	% Products on First Half of Recall List (Column 2)
40 - 50.5 (top)	11	15.36	88.8
30 - 39	10	12.40	59.7
20 - 29	12	8.33	48.0
10 - 19	14	8.85	45.2
0 - 9	93	2.06	18.4

(or any other) the average would be 20. In spite of considerable worker-by-worker variation (no product was named by all 20 workers) an orderly pattern emerges: highest frequency products are mentioned more often and mention falls off (though not linearly) with declining product frequency; few workers named the occasional sellers (0-9 product frequency).

To determine the effect of frequency on *order* of mention, each person's protocol was divided in half and counts were made of the number of times products in the various frequency classes appeared in each half. Column 2 of Table 1 presents results in terms of percentages to facilitate comparison. Eighty-eight percent of mentions of products in the top frequency class occurred on the first half of each person's recall list; this percentage declined to 18% for the lowest frequency products. In other words, workers appeared to start their recall at the "top" of the frequency stack and work their way to the bottom.

Discussion

This outcome suggests an orderliness to the way we provide information to each other on mundane matters. Each person queried to "tell what she knows" is free to supply information in any order she chooses; but the present study suggests that such freedom may in fact be exercised in quite similar ways by participants in a cultural system. What might underlie this commonality? The "frequency effect" merely names an observed input-output relationship; it offers no insight into underlying mechanisms. Some investigators (e.g., Chi and Koeske, 1983) seek to account for the relationship between better known items and recall by distinguishing the organizational attributes of better and lesser known subdomains of knowledge. Extension of such research to different kinds of knowledge domains is needed, and studies among various cultural groups are needed as well. Is adherence to a frequency criterion a manifestation of the workings of "universal mind" or is it an indicator of a culture-specific conventional strategy? If it should prove that this same principle of orderliness characterizes information retrieval among different cultural groups, ethnographic inquiry might put this finding to good use. It would be helpful to cognitive anthropologists engaged in the reconstruction of folk knowledge if they could assume that, when querying informants about a knowledge domain, first mentioned items are more likely to represent most frequent. Many domains of knowledge are not amenable to the application of counting methods. But opportunities are present in bounded systems such as the dairy to identify domains of knowledge whose member items can be specified and enumerated. In these settings, the present study suggests, the use of methods borrowed from the experimental tradition may be useful in both extending this tradition and putting new tools at the disposal of ethnographic researchers.

Notes

[1]Robert L. Russell devised and carried out these analyses.

[2]Note that this measure of product frequency covers both *thing* and *word* occurrence. Each product named on an order form is also a material object that is produced, packaged, and distributed to customers.

Toward a Model of Practical Thinking at Work

Sylvia Scribner

One purpose of research in the dairy was to increase our understanding of the nature of thinking embedded in naturally-occurring work activities. Descriptions and task analyses generated in this research have been thick with particularities and job-specific content, ranging from the details of case conversion arithmetic to facts about the location of products in a warehouse. The question arises: does the research approach pursued here allow us to move toward the identification of general features of thinking at work, or does it lock cognitive science into an ever-increasing collection of task analyses of specific jobs?

This question is readily recognized as one version of a general theoretical problem confronting functional approaches to cognition. The problem of moving from specifics to the general is not peculiar to research in naturalistic settings, but arises as well in laboratory research when investigators attempt to base general statements about "human problem-solving" on process analysis of specific tasks (Simon, 1976).

We would like to advance the claim that the empirical analyses presented here have general implications for a theory of practical thinking. This claim rests on the finding that expert performance on all tasks, differing as they did in many basic properties (predominance of manual versus mental operations, for example), had certain characteristics in common. The appearance of common attributes of skilled performance suggests a route to generalization. We need not, for the time being, query whether the particular operational components of these tasks are bound to the tasks or are "general" -- that is, are constituents of many other tasks (a form of the question, "does the particular generalize?"). Rather, we can treat the common characteristics of expert intellectual performance on these tasks as candidates for general features of thinking at work. Future research can determine whether these features characterize cognition in a wide range of work settings and across tasks varying in their social organization, technical means and intellectual demands. At the same time, we can use these features to examine the limits of current theoretical approaches and to elaborate new constructs for understanding thinking. We might characterize this approach as an attempt to discover the general *in* the particular -- an enterprise that calls for reciprocal development of theory and research.

In this article we will briefly summarize common attributes we have identified. For exposition purposes, we will first consider these attributes individually and then we will move up a level of generality to integrate them around several core constructs in the psychology of thinking. In this analysis, we are extrapolating from dairy jobs to other work tasks, and in a concluding section we will describe the type of work activities to which the model we are developing best applies. By this activity-specific approach, we do not preclude the possibility that some of the characteristics of skilled thinking at work, now described in a circumscribed way, may in the future qualify as fundamental properties of goal-directed thinking in many different domains of activity.

Flexibility: Variation in Modes of Solution

Expert performance on problem-solving tasks was marked by diversity of solution modes.

Flexibility most clearly distinguished experts from beginners. Novices tended to rely on algorithms which produced correct solutions through repeated application of a single solution procedure; with increasing experience, they replaced all-purpose algorithms with a repertoire of solution modes fitted to properties of specific problems in changing task environments.

What is outstanding about the variability documented here is that it represents the use of different component operations to solve problems that on formal analysis are problems of the same kind. Jobs such as product assembly and pricing-out are prototypical examples of repetitive industrial work. It might have been supposed that, to carry out the recurring intellectual chores these jobs demanded, workers would enage in standardized, repetitive mental operations. Instead they brought different mental operations to bear on repeated problems, reaching the same end result now one way, now another. This pattern of change has nothing in common with trial-and-error modes of problem-solving which involve experimentation with many solution procedures until the correct procedure is found. In the dairy tasks, all modes of solution used by experts yielded results meeting conventional accuracy requirements. Solution variability was therefore unrelated to the objective *outcomes* of performance, and related entirely to the *how* of performance.

Though central to skilled performance on dairy tasks, flexibility in the how-to of problem-solving is a neglected aspect of laboratory-based approaches to thinking. Investigators concerned with rules and strategies of thinking make the simplifying assumption that these higher-level regulating principles generate consistent solutions to problems of the same kind or the same logical class. Whether or not this assumption holds for the problem genres investigated in the laboratory, models based on such an assumption would be inadequate to account for intellectual performance on problem-solving tasks in the dairy.

Fine-Tuning to the Environment

Skilled problem-solving in the dairy was finely-tuned to the properties of the external, material environment and to changing conditions within it.

The ability to exploit (that is, effectively utilize) resources in the environment for problem-solving purposes distinguished experts from novices and often provided the basis for their solution versatility. The term "exploitation" is used here to emphasize that the physical environment did not determine the problem-solving process but that it was drawn into the process through worker initiative. Task analysis illustrates a variety of ways in which things and settings in the environment were pressed into a functional role. On some tasks, the environment provided the terms of the problem-to-be-solved. Consider order filling on product assembly. A formal analysis would suggest that this task consisted of a written problem (the product order) which the assembler solved and later executed at the product array. On the job, however, an experienced worker interpreted the written order, not as "the problem," but as input to an, as yet unspecified, problem. On arriving at the array, he used information from the physical configuration of containers in a case, in conjunction with symbolic information stored in memory, to define the form of the problem (addition or subtraction). A partial case functioned as one term in the equation and the assembler determined the number that needed to be combined with it to satisfy the order.

Inventory provides a somewhat different example of experts' use of environmental properties to achieve an initial representation of the problem-to-be-solved. Dimensions and configurations of product arrays were primary determinants of how the inventory man represented the generic problem of enumeration on different occasions -- sometimes setting it up as a multiplication problem, sometimes as a jump-counting task, but each time constructing a problem whose form best fitted properties of the object-to-be-enumerated.

Skilled workers drew things in the environment not only into problem formulation, but into solution procedures as well. In inventory, properties of the given product array functioned as selection devices for the micro-steps constituting a given solution procedure. Counting routines were precisely adapted to the shape of the things to be counted: stacks five-cases high prompted counting by fives; six cases high, counting by six'es. Another aspect of fine-tuning was experts' adjustment of solution procedures to the various material means or devices available to their intellectual work. On the "purely mental" task of pricing-out, experienced drivers modified both their problem constructions and their arithmetic operations in conformance with the particular facilitating powers provided, on the one hand by calculators, on the other by paper and pencil. Modes of solution came into being around means of solution.

As these examples suggest, on many dairy tasks the environment was more than an external "context" in which problem-solving occurred; it was an integral component of the intellectual activity itself. Neisser (1976, p. 183) has argued that, because perception and action occur in continuous dependence on the environment "they cannot be understood without an understanding of the environment itself." In the dairy setting, this observation can properly be extended to the higher cognitive processes involved in many problem-solving tasks.

Economy: Effort-Saving as an Optimal Solution Strategy

Skilled thinking on dairy tasks was regulated by a "least effort strategy."

In the context of this discussion, "effort-saving" refers to the *psychological* reorganization of work tasks to reduce the number of physical or mental steps required for their accomplishment and/or to simplify steps that cannot be eliminated; it has nothing to do with efficiency of movement or other industrial engineering concepts. Product assembly provided two examples of least-effort strategies in which mental operations were reorganized to save physical effort; pricing-out and inventory provided examples of the organization of mental procedures to save mental effort.

The least-effort strategy commends itself as a basic organizing principle of thinking-at-work because of its ubiquity and because other characteristics may be derived from it. Flexibility in solution procedures, and sensitivity to resources in the environment, for example, follow from the consistent employment of a least-effort strategy under changing circumstances.

An outstanding characteristic of least-effort strategies is that they were the outcome of processes operating on a conscious level. Various classes of evidence point to this fact. In the dairy community at large, least-effort strategies were widely acknowledged as "cultural norms" for intelligent ways of working. Individual workers reported making a conscious effort to devise such strategies, often explicitly describing their active search for short cuts or easier ways to do a job. Once adopted, effective use of such strategies depended on processes requiring active attention and awareness -- processes involved in problem analysis, solution choice, and executive monitoring. Thus, the acquisition of skill on these intellectual tasks, insofar as it implicates a move toward least-effort strategies, cannot be accounted for solely in terms of automatization of procedures as a result of experience.

If least-effort strategies represent conscious constructions, their investigation requires going beyond the formal requirements of problems to a consideration of individual ideals and purposes, and of the larger institutional and cultural contexts in which these take shape. Only by such extension of the theoretical framework will we be able to determine whether adoption of least-effort strategies in the workplace rests on a particular configuration of institutional and personal goals or on more fundamental "norms of thought" held by people in many cultures and expressed in a wide range of mental and manual activities.

Dependency on Setting-Specific Knowledge

Skilled problem-solving strategies in the dairy were dependent on specific knowledge about the things and activities in the workplace itself.

Most dairy tasks required a fund of "general knowledge" -- background information of a worldly or academic kind, and some level of basic skills (numeracy, literacy). But the hallmark of expert problem-solving lay in the fact that the experienced worker was able to use specific dairy and job-related knowledge to generate flexible and economical solution procedures. Expert problem-solving procedures were content-infused, not content-free.

The relationship between job-related knowledge and expert solution performance cannot be encompassed in one general description. Analyses of dairy tasks disclose that critical job knowledge involved many classes of information and took many forms and, consequently, that knowledge-strategy interactions were diverse and complex. In some tasks, critical knowledge took the form of specific factual information: an inventory man drew on his knowledge of the dimensions of a storage area to construct an efficient procedure for counting a particular product array. Some forms of critical knowledge can be conceptualized as mental representations: product assemblers drew upon their spatial knowledge of the warehouse to organize their product-fetching trips in the most efficient manner.

Symbolic forms of knowledge were central to a range of jobs. As a social and cultural system, the dairy over generations had evolved system-specific alphabetic and numerical symbol systems adapted from those prevailing in the society at large but taking a form peculiar to this setting. Mastery of these institutionalized symbol systems was a necessary condition for minimal performance on most jobs. But, in addition, experienced workers invented and/or mastered the use of individual symbols which made possible a level of performance satisfying the "optimal strategy" criterion. Various material objects in the dairy were converted into symbols which workers used to achieve short-cut solutions in problem-solving. The principal, though not the only, example in this research was drivers' symbolization of the dairy case, which provided the basis for efficient solutions to many pricing problems.

Not only was setting-specific knowledge central to the psychological reorganization of work, but, we have some evidence to indicate, that goals and conditions of work activity in turn influenced the specific knowledge that workers acquired and the saliency of such knowledge for conceptual organization in non-job contexts. These findings suggest dynamic and complex interactions among particular working activities, specific knowledge, and expert problem-solving strategies, interactions which have scarcely begun to be explored.

Problem-Solving at Work: A Summary Description

We have described a set of attributes characterizing problem-solving activities in the dairy -- flexibility and economy of procedures, effective utilization of knowledge, fine-tuning to the environment. These attributes, of course, were interdependent and jointly defined skilled practical thinking. We might summarize their interrelationships in this way: Thinking in the dairy was goal-directed and regulated by a principle of economy which, operating under changing conditions and on the basis of knowledge and information in the environment, generated flexible solution procedures adapted to particular occasions of use.

The picture that emerges is of a dynamic, interactive cognitive system that departs in significant respects from the models of problem-solving proposed by information-processing theorists. In these models, problem-solving is linear and one-way, proceeding from a defined problem through a sequence of steps to a solution. In the dynamic system of problem-solving observed in the dairy, the movement of thought is two-way. In addition to going from problem to solution, thinking proceeds from "anticipated solution" to "construction of problem." Steps to solution are variable and modified in kind and in order by fine-tuning to the environment; they do not invariably follow a fixed or "one-best" sequence for a given class of problems.

These studies of how problem-solving occurs under actual working conditions thus are helpful in indicating the boundary conditions of laboratory models and in presenting new schemes for an enlarged psychology of thinking. They pose challenges, too, to certain well-established concepts in psychology. Two such challenges especially interest me -- one having to do with the course of learning and the other with the nature of "ordinary" or practical thought, and I will make a few observations about each.

Mastery of the Concrete

On the basis of our specification of the nature of skilled problem-solving at work, we can generate a speculative model of the course of acquisition of work-related cognitive skills. The conventional psychological model of learning assumes a progression from the particular and concrete to the general and abstract, from "context-bound" to "context-free" intellectual activities (see, for example, discussion in Brown et al., 1983). This progression undoubtedly represents one aspect of the course of change in individual learners as they increase their mastery in a particular domain of activity. But an opposite process may be occurring simultaneously and it is this process which is highlighted by the present studies: skill acquisition at work moves in the direction of mastery of the concrete. The novice enters the workplace with a stock of knowledge, some school-based and some experience-based, and with certain general problem-solving skills (e.g., mental rehearsal, means-end analysis). An important aspect of learning at work involves adapting this prior knowledge and these general skills to the accomplishment of the task at hand. Such adaptation proceeds by the individual's assimilation of specific knowledge about the objects and symbols the setting affords, and the actions (including cognitive actions) that work tasks require. Domain-specific knowledge reveals relationships that can be used to shortcut those stipulated in all-purpose algorithms; with domain-specific knowledge, workers have greater opportunity to free themselves from algorithms and to invent flexible solution procedures. What emerges through this process is a qualitatively different organization of problem-solving procedures from that initially brought to the job. Problem-solving skill in this model implies not only knowledge and know-how but creativity -- an attribute of the work group as a social entity if not of each individual within it.

Mastery of the concrete, of course, does not imply the absence of a reciprocal process of abstraction. We have drawn attention to the various forms of symbolization and mental representation involved in dairy tasks, and the present research also offers one candidate for a general rule that might be acquired in a variety of work activities -- the least-effort strategy. (McLaughlin, 1979, offers a detailed description of specific skills and general concepts acquired in the auto mechanic trade.) Without minimizing the abstract processes involved, it seems appropriate to describe the primary course of attainment of problem-solving skills at work as a process of "concretization." Because of the relative neglect of this process in theory and research, and its educational implications, it warrants emphasis here.[1]

Creativity at Work

Thinking at work is fitted to the functional requirements and resources of particular tasks, and seems aptly characterized as adaptive. Because adaptation is a concept that emphasizes the fit of human thought and behavior to an existing environment, describing thinking at work as adaptive would seem to preclude its characterization as creative. The notion of creativity stresses the human production of something new. Yet thinking in the dairy was *both* adaptive *and* creative. Adaptation of thought to its functional requirements had an active, not passive, character, and it proceeded on the basis of worker invention of new solutions and strategies. Invention is a hallmark of creativity and it played a major role in all the occupations studied in the dairy community. One might say that cognitive adaptation in the dairy occurred, not as a result of processes happening to the employees, but as a result of their continual creativity.

Since creativity is a term ordinarily reserved for exceptional individuals and extraordinary accomplishments, recognizing it in the problem-solving activities of ordinary people at work introduces a new perspective from which to evaluate working intelligence.

Boundaries of the Analysis

Although we have referred to target activities as work activities, the analysis presented here is limited to a subset of such activities. For one thing, tasks studied were components of blue-collar jobs; whether or not all the characteristics we have specified apply to clerical and other white-collar jobs is a speculative, but empirically testable, matter. The jobs we considered were individually executed, and analyses, accordingly, do not inform us of the social organization of intellectual operations when work responsibilities are distributed among two or more people.

Most important for the general significance of the psychological analysis is the fact that all tasks included in these studies permitted the worker one or more "degrees of freedom." Conditions of work allowed the individual employee some latitude in determining task parameters: a worker might select her own means for getting the job done (e.g., use a hand calculator or paper and pencil) or might reorganize the task sequence (e.g., regroup products on the order list) or change the specified operations (e.g., satisfy a minus order by adding containers to a case). Such latitude stands in sharp contrast to the restrictive conditions of work on routinized, mechanized and automatically paced jobs such as those symbolized by the automobile assembly line (Chinoy, 1964) and widespread throughout manufacturing. Detailed studies of the labor process on certain factory jobs (Lamphere, 1979; Shapiro-Perl, 1979) indicate increasing management efforts to bring all operations under automatic control and to hold to a minimum worker-introduced variation in the way the job is carried out. The intent of such efforts, spelled out at the turn of the century by Taylor (1911), is to increase worker output and profit, and to reduce the cost of labor.[2] To the extent such conditions are established, it will be increasingly difficult for workers to display the flexibility and ingenuity we have documented. Whether or not flexibility can be entirely eliminated, however, short of robotization, is an open question.

If individual latitude on the jobs studied here may limit the application of the analysis to some, not all, work activities, it opens up the possibility of extending the model to thinking embedded in other practical activities in which individuals have control over their own actions. Research and analyses by Lave and her colleagues (op. cit.) suggest such possibilities. Their studies reveal that problem-solving in the mundane pursuits of shopping, cooking and tailoring share certain family resemblances with problem-solving in the dairy. These congruences give us some warrant for assuming that practical thinking is orderly, that it exhibits certain common characteristics in a wide variety of purposive life activities, and that it is amenable to scientific understanding.

Notes

[1]Anzai and Simon, 1969, have also described the attainment of problem-solving skills on a task as the transformation of weak general strategies into more powerful task-specific strategies.

[2]The difference in interests between employer and employee is not considered in the present studies. What is being addressed is the ingenuity workers bring to the accomplishment of their jobs under conditions that allow them to exercise such creativity.

Work-In-Progress

The following are brief reports of several cognitive studies of work, conducted as independent research projects by graduate students in the Developmental Psychology Program, CUNY Graduate School and University Center. All are members of Scribner's research study group on work and practical thinking. At various times the group has benefited from the participation of Mary Gauvain, Reginald Gougis, William Hirst, Miriam Koivukari, Nancy Nager, and Dolores Perin.

The Role of External Memory Cues in Learning to Become a Bartender

King Beach

External aids to memory such as shopping lists, notebooks, photographs, and calendars play a key role in our everyday dealings with information. Yet the commonsense notion of the importance of external memory cues to our daily lives has only recently become a topic of interest within the psychological community (Ceci and Bronfenbrenner, 1983; Harris, 1978; Meacham and Colombo, 1980; Kreutzer, Leonard, and Flavell, 1982). The present study seeks to extend these findings: first by considering external memory cues to be materially-realised symbols and second, in light of this, examining the relations between the cue material, the representation of information in memory, and the goals of learning an occupation.

A school which trains adults 18 years of age and older to become bartenders was chosen as a promising site for examining such relations. Heavy memory demands are involved in learning to become a bartender. In addition, the to-be-remembered information (drink recipes) is a finite and specifiable body of information that permits a more precise examination than is possible in other domains.

The school's standard two week course in bartending entails formal lecture-demonstration sessions by the instructor as well as extensive student practice mixing drinks behind a series of working bar stations. A graduate is expected to be able to mix approximately 100 different drinks rapidly and accurately from memory. To investigate how students master this material, I designed a two phase study. I enrolled as a student in the school and carried out an ethnographic study of institutional and learning activities in the two week course. I then designed experimental studies to verify and develop the ethnographic findings further.

Ethnographic Study

Ethnographic research strongly supported a characterization of bartending as a socially-constituted practice in Scribner and Cole's (1981) sense of a "recurrent goal-directed sequence of activities" consisting of knowledge, technology, and skills. The ethnographic findings suggest that a useful distinction can be made within this framework between individual goal-directed actions and the relatively durable collectively-held activity which goes beyond the actions of any given individual (cf. Leont'ev, 1981). Individual actions both reflect and construct the activity. The activity of bartending in the school includes as part of the environment a bar station which provides a rich socially-organized potential source of external memory cues. It is also marked by motivations stemming from the economic reality of having to trade goods and skills for capital. In the case of the bartender's actions, this means having to mix drinks both rapidly and accurately.

The ethnographic findings also suggest that a useful distinction can be made between two systems of external memory cues. Drawing on Eco's (1979) semiotic theory, we have distinguished between secondary and primary cue systems. The secondary system in the school consists of verbal information in the form of a mixology guide which contains written recipes of all drinks, as well as oral instructions and comments made by others. The primary system consists of such cues as bottle arrangement, glass shape, and the color and amount of liquid in a glass. Secondary (linguistic) systems of cues are materially alien and arbitrary with respect to their referents and therefore tend to cut across various activities. Primary systems of cues bear a non-arbitrary material relationship with respect to their referents and are therefore relatively activity-specific.

As a student's knowledge of drink recipes increases with experience, the student appears to rely less and less upon secondary cues to recall drink information, and to increase his or her use of primary cues. Secondary cues allow for the early achievement of the goal of accuracy in mixing drinks. They may also provide a scaffolding for the use of the primary cues which, unlike secondary cues, permit the drinks to be mixed rapidly once a sufficient base of knowledge has been acquired. The ethnographic description, then, suggests that a choreography occurs between the potential cues of the activity and the student's actions which differentially construct and utilize some cues and not others in line with achieving the goals of accuracy, then speed. These goals, in turn, reflect the motivation of the participants in the activity.

Experimental Study of Primary and Secondary Cue Use

The experimental study now in progress uses an already existing school practice to 1) verify the ethnographic findings that bartending students use primary as well as secondary external cues to recall drink information and 2) examine in more detail the nature of the progression from secondary to primary systems of cues with increasing experience. The practice consists of speed drills in which the students are told to mix sets of drinks while being timed by the instructor.

Data are presently being collected on ten novice and ten expert students distinguished on the basis of 1) their mid-term written examination scores, 2) the time they have spent in the course, and 3) their instructor's rating. Each student receives six speed drills, each consisting of a combination of four drinks. For the first three drills students are asked to use the normal bar glasses. The second set of three drills requires them to mix the same drinks in a different combination, but in this case generic black glasses are used to eliminate the primary cue of glass shape and to reduce the availability of the primary cues of ingredient color and amount. All secondary cues -- the mixology guide and instructions requested from the researcher -- are available to the students. A distractor task separates the two sets of speed drills. Each student is asked to count backwards from 40 by threes during the third drill in each set after placing the glasses on the bar rail before mixing the drinks. This is done to assess whether verbal rehearsal is used to remember the drink combinations.

Experimental speed drills are conducted in the school at the bar station and are videotaped. Students' tapes will be examined for mixing errors, duration of mixing time, retention of drink names, and use of secondary cues. A post-speed drill interview is also being conducted to tap the student's knowledge of drink information and memory techniques.

A third research phase is planned in which a combination of ethnographic and experimental tracking techniques will be used to follow the progress of several students through the entire course of study. It will focus upon the relation of the students' changing representation of knowledge about drinks to their differential use of secondary and primary systems of external cues.

Videotape Analysis of a Carpenter at Work

Randal Blank

A colleague, Dolores Perin, and I observed and videotaped a skilled carpenter (Dan) doing renovation work in a basement apartment in a brownstone house. In approximately three hours of film, spanning three days, we see the carpenter engaged in a variety of typical renovation tasks: framing out a partition wall with a door entrance; measuring, cutting and mounting sheetrock on an already framed out wall; mounting pieces of heavy sheetrock on a ceiling where it was necessary to discover an optimal arrangement of the pieces. In the course of the work, sometimes spontaneously and sometimes in response to our questions, Dan gave verbal explanations for a number of the tasks he was performing.

The present analysis concerns the various types of measurement used to carry out each of the tasks. For example, in one situation a tape measure appears to be the best device to use, whereas other situations call for other methods and frequently various combinations of measuring tools. In studying the video tapes my two central concerns are: 1) to what extent do the task environment and the immediate goal structure of the task being performed determine the carpenter's selection from an array of possible ways to measure? 2) since measuring takes place as part of a larger activity which shapes the acquisition as well as the utilization of that skill, it will be of interest to discover the effects of the functional environment on the types of skills that Dan has acquired. For example, Scribner's working intelligence paradigm would predict that becoming skilled in measuring would involve the acquisition of "flexible strategies" as part of what might facilitate more efficient patterns of work. Thus I am paying particularly close attention to Dan's use of complex strategies of measurement which would not be at all obvious to a novice, and that are especially well attuned to the specific requirements of a task.

Knowledge Organization and Recall in a Work Place

Edith A. Laufer

Following Chi and Koeske (1981), this study seeks to examine the attributes which differentiate better and lesser known subdomains within one field of knowledge and to examine the implications of knowledge organization for memory and aging. The field of knowledge investigated is specific to the industrial fastening industry which manufactures bolts, nuts, screws and washers. These products can be related to each other in many ways, such as by length and diameter, shape, cost, material and use. Experimental materials consist of 48 high-frequency items and 48 low-frequency items drawn in equal numbers from four product categories. Frequency ratings were based on computer print-outs of annual sales volume, and corrected in interviews with management and employees.

Thirty telephone sales clerks in three age groups (ranging from 23 to 69 years of age) are asked to group fastening items that "fit together" to a criterion of two successive identical sorts. Sorting is followed by free recall using Mandler and Pearlstone's (1966) sort-recall paradigm. The stimulus material in one session consists of items frequently used. Another session is devoted to materials that are infrequently used. It is important to note that sorting and recall tasks are activities similar to those that these sales clerks engage in while performing their daily jobs.

Both intra and inter-subject differences will be examined. Specific hypotheses are 1) on a within-subject basis high frequency product items will have different organizational relationships than low frequency products; 2) on a within-subject basis, recall will be better for high-frequency products than for low; and 3) on a between subject basis, older workers will exhibit less complex organization and lower recall than younger workers in the low frequency subdomain but will have equivalent recall and organization for products in the high frequency subdomain.

* * * * * *

"It is of interest
that none of the increased
understanding of the psychology of skill
which has been won was started from a formal
analysis of laboratory situations.
The initial impetus came from direct,
and, as far as possible,
unprejudiced observations of practices and activities
that everybody would agree to call skilled.
It is equally true
and interesting that once the working ideas
had been suggested by direct observation,
further definite progress was achieved only
as it became possible to put these working ideas
into operations that could be built
for the laboratory and tested under
reasonably well controlled
conditions."

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Kusterer, K. C. (1978). *Know-how on the job: The important working knowledge of unskilled workers*. Boulder, CO: Westview Press.

Kusterer's study is one of the few research enterprises that goes beyond generalities and actually demonstrates in detail the complexity of the work-related knowledge of "unskilled" workers. In this sociological study, Kusterer also confronts and discusses methodological questions and raises theoretical issues which should be of interest to psychologists concerned with the relationship between objective social and practical activity and its internal reflection.

Kusterer first examines the structure of work organizations which determine the content and means of acquisition of working knowledge. He then looks at how working knowledge affect organizational structure and productivity, that is, how working knowledge becomes a principal means enabling workers to affect their work situations. This "dialectical" or "reflective" analysis treats working knowledge first as a dependent variable and then as an independent variable. Then, treating working knowledge as an intervening variable, he shows how the sources and content of working knowledge impact upon workers' alienation and autonomy or control over the work process.

Two case studies form the major part of this investigation, one of a work department in a paper products factory and one of a bank branch office. Data consist of brief observation sessions, at-home interviews with informants, semi-structured interviews with other workers on the job and various documentary sources of information about the companies.

Kusterer describes in detail the large body of working knowledge required by unskilled workers to carry on production, knowledge of which management is mostly unaware, and which is never formally taught, but rather acquired informally through each worker's individual experience and through the work community network. This knowledge covers both routine procedures and supplementary knowledge for overcoming obstacles to the carrying out of routine procedures. For example, machine operators in the paper factory acquire a great deal of integrated knowledge about the materials and machinery they use, and about quality standards. To carry on efficient production, these workers must also know when and how to make subtle and complex adjustments of their machines (never formally taught) to compensate for variations in the materials (paper, ink and glue) that offset machine functioning. This knowledge is acquired through observation of and interaction with other workers, and through experience, all in an interdependent productive process.

Another part of necessary working knowledge is knowledge about the work community. Workers need the cooperation of others to accomplish their tasks. The machine operators, for example, needed the help of workers who serviced and supplied their machines, and bank tellers shared information and divided responsibilities in order to complete daily reports more quickly and leave work earlier.

Kusterer's evidence suggested that participation in the working community and acquisition of working knowledge tend to ameliorate alienation. Working knowledge interprets the environment and places the workers' activity in a meaningful context, enabling workers to see the effect of their work on the overall work process, on other workers, on the organizational goals and on those who use or consume the product or service produced. In addition, each area of supplementary working knowledge represents an aspect of the work environment that workers are better able to manipulate and control.

Although alienation can be ameliorated, Kusterer agrees with the Marxist thesis that alienation has an objective source in capitalist social structure and, therefore, cannot be eliminated under this system. He explains and illustrates this concretely in the context of the work settings studied, and the ambivalent feelings and attitudes workers express about their jobs. In his view, although working knowledge increases workers' control over certain aspects of the work environment, that environment is under the ultimate control of the management, which views workers' labor not as an end, but as a means of profit.

In his final comments, Kusterer compares the notions of "skill" and "working knowledge." He points out that the term "skilled" applied to a job implies a combination of manual dexterity and know-how, and that this limits its usefulness for analyzing blue-collar jobs. The concept of working knowledge is broader, and it also embodies the social determinants of problem solving and skills development. This study, therefore, provides a potentially useful concept for psychological research on the social processes involved in "skill" or knowledge development in work and practical activity.

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Singleton, W. T. (Ed.). (1978). *The analysis of practical skills*. Lancaster, England: MIT Press.

This is a book about how people cope with the physical world as they perform occupational tasks. Both in order to cope and as they cope, they develop, in the editor's words, "specialized attributes which we call skills." Singleton was a student at Cambridge in the late 1940's when Sir Frederic Bartlett was a leading psychologist there, and, like Bartlett, considers skills to be the appropriate units for analyzing real purposive human activity.

In his introductory chapter, Singleton discusses the concept of skill and offers what he considers to be the main characteristics of skilled activity. Instead of distinguishing between bodily and mental skills, as did Bartlett (1958), Singleton says that "all skill is mental and all skill is physical," with cognitive skill being "input dominated" as opposed to "output dominated" motor skill. Like Bartlett, he conceives of skill as being characterized by economy: "The unskilled state is not to do nothing but to do everything" (p. 7). Skill is also characterized by organized patterns of activity which derive their meaning and direction from their purpose. Skills are learned, and develop with practice, and therefore vary widely within and between individuals. In this chapter and in Chapter 2, on laboratory studies of skills, Singleton provides a lucid and useful conceptual framework for investigations of practical activities.

Chapters 3 through 14 consist of studies of a variety of occupational skills. The contributions are uneven in their level of analysis, reflecting in part the different backgrounds of the authors and their differing objectives; about half, including Singleton, are psychologists. The volume includes studies of farm workers, metal workers, dentists and architects among others; or as Singleton would put it, skills investigated range from those which are output dominated to those which are input dominated. Not all of the studies make a distinction between task analysis and skills analysis. For example, a study on air traffic controllers gives a detailed description of task demands, and refers to the abilities required to do the job as skills. Other studies separate the two enterprises. Branton claims that task analysis contains implicit assumptions about the nature of the skill elements involved in the task, and he tries to make these assumptions explicit with respect to train driving. Lacey, in addition to providing a detailed task analysis of tea blenders, attempts to specify what a skilled tea blender is doing that a less skilled person could not do. Singleton's study of sewing machine operators offers both a task analysis and a skills analysis; it also reflects his belief that a skilled activity must first be closely observed in its natural setting. In this case as in the other studies, the natural setting for occupational tasks is the workplace.

In the last chapter, Singleton offers a recommended procedure for skill appraisal. In addition to being a useful guideline for anyone interested in skill acquisition processes or novice-expert differences, the skill appraisal procedure echoes a theme emerging from several studies in the book (and implicit in all of them): It takes an expert practitioner to assess another expert practitioner in the same field.

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Work as a fundamental human activity

The way in which men
produce their means of subsistence
depends first of all
on the nature of the actual means of subsistence
they find in existence and have to reproduce.
This mode of production must not be considered simply as being
the production of the physical existence of these individuals.
Rather it is a definite form of activity of these individuals,
a definite form of expressing their life,
a definite mode of life on their part.
As individuals express their life,
so they are.

Marx and Engels. (1846). *The Germany ideology.* (Reprint, 1970.)

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On Method

The search for method becomes one of the most important problems of the entire enterprise of understanding the uniquely human forms of psychological activity. In this case the method is simultaneously prerequisite and product, the tool and the result of the study.

Vygotsky, L. S. (1978). *Mind in society.* Cambridge: Harvard University Press. (p. 65)

Erratum -- October, 1983 issue: Several lines (in bold type) were omitted from pages 69-70 of the article "A socio-historical approach to re-mediation" by Michael Cole and Peg Griffin. The passage should have read as follows:

> An enormous amount of **human ingenuity went into figuring that out. Those rock pictures, like Stonehenge, regulated peoples' interactions with the world and with each other. To repeat, the basic character of literacy is that we create objects to regulate our interactions on the one hand** with the physical world, and on the other hand, with our social world.

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