DOCUMENT RESUME

ED 293 999 CE 049 897

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TITLE	Head and Hand: An Action Approach to Thinking. Occasional Paper No. 3.
INSTITUTION	National Center on Education and Employment, New York, NY.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	Apr 88
GRANT	G008690008
NOTE	20p.; Paper presented at the Annual Meeting of the Eastern Psychological Association (Arlington, VA, April 11, 1987).
PUB TYPE	Speeches/Conference Papers (150) -- Reports - Research/Technical (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Adults; *Cognitive Style; Experiential Learning; Learning Modalities; *Learning Processes; *Learning Strategies; Learning Theories; *Nonverbal Learning; Task Analysis; Work Experience

ABSTRACT

Much research has focused on cognitive skills in isolation from daily life and from action. However, memory and thinking in daily life are not separate from, but are part of, doing. This study is based on a theoretical framework that encompasses an integrated account of mind in action. This "activity theory" holds that neither mind as such nor behavior as such can be taken as the principal category of analysis in psychology. The starting point and primary object of analysis is the actual process of interaction in which humans engage the world and each other. This study used observation of assemblers carrying out their jobs of filling milk cases in a dairy plant under normal working conditions. Descriptions resulting from these observations enabled the creation of job simulations to observe performance under more constrained conditions. The observation of workers and later of secondary school students in simulated situations showed that the workers acquired nonliteral least-physical-effort strategies simply through doing. Many reached optimal performance without teaching. The study found that in some circumstances, the operations of the hand are functionally equivalent--the head takes over for the hand. The study suggests that practical thinking is orderly, that it exhibits certain common characteristics in a variety of life activities, and that it is amenable to scientific understanding. (KC)

HEAD AND HAND: AN ACTION APPROACH TO THINKING

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Occasional Paper No. 3

April 1988

Prepared for oral presentation at the Eastern Psychological Association Annual Meeting, Arlington, Virginia, April 11, 1987.

PREFACE

The National Center on Education and Employment is funded by the Office of Educational Research and Improvement (OERI) of the U.S. Department of Education. The Center is based at Teachers College, Columbia University, in New York City. The RAND Corporation of Santa Monica, California, and Washington, D.C., is a partner with Teachers College in this enterprise.

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This publication is based on work sponsored wholly of in part by the Office of Educational Research and Improvement, U.S. Department of Education under grant number G008690008. Its contents do not necessarily reflect the views of OERI, the Department, or any other agency of the U.S. Government.

In introducing my talk, I will ask you to imagine the following scenes: a warehouseman is moving quarts of milk from one dairy case to another; an expediter is tracing the whereabouts of a stock item; a bartender fills mixed drinks from memory.

Although this may sound like a list of random observations, they all have something in common. They are tasks which my students and I have been studying as instances of "mind in action." I use this term to index an approach to the study of cognitive processes which views them as embedded in human action in the world. My research aims at analyzing the characteristics of memory and thought as they function in the larger, purposive activities which cultures organize and in which individuals engage. In earlier research I studied cognitive aspects of literacy activities in a West African society. Recently, I have been investigating cognitive aspects of practical activities occurring in the world of work. To acquaint you with this research, and to exemplify it, I will describe in some detail a series of studies which examined how thinking and doing--head and hand--are integrated in an industrial work task.

Hence my title. I am using the expression "head and hand" in a double sense: literally, to refer to the use of both instrumentalities in practical action, and metaphorically, to indicate a theoretical approach that links thinking to action in the world.

It is evident that this position contrasts with dominant approaches to cognition today. The prevailing perspective views mind as a system of symbolic representations and operations that can be understood in and of itself, in isolation from other systems of activity. Researchers adopting this perspective typically study cognitive processes by analyzing performance on isolated mental tasks. If we study memory, we ask people to recall some information or event under conditions which we design. If we study problem-solving, we ask people to do calculations or talk aloud while they try to answer the questions we have set before them. In these tasks, remembering and problem-solving are goals in themselves; they are the ends to which all operations are directed. When research is well-developed, it is sometimes possible to specify the component operations in these tasks with sufficient precision to program them on a computer--a computer which sits in a room having no transactions with the external environment, a computer that is, so to speak, lost in thought.

This approach to cognition has important achievements. Without minimizing them, it is fair to say that the metaphor "mind as computer" fails to capture significant aspects of human mental functioning. We all know that memory and thinking in daily life are not separate from, but are part of, doing. We undertake cognitive tasks not merely as ends in themselves but as means for achieving larger objectives and goals, and we carry out those tasks in constant interaction with social and material resources and constraints. What are the characteristics of remembering and thinking as they occur in such activities? Can we discover them by means of theories and models which begin by treating them as isolated processes to be understood in themselves?

In these questions, we hear echoes of the great debate that has haunted psychology since Ebbinghaus' day. How can the tools available to our science be brought to bear on an understanding of the complex phenomena of everyday life? This debate is often couched in terms of methodological choices. But I do not think that we can make great progress in a contest that pits laboratory against field, psychology against anthropology, or, for that matter, computer against person. The relationship of models to the phenomena they purport to represent is determined in the first place, not by method, but by theoretical conceptions of the phenomena. The practice of studying thinking in isolation from doing is consistent with a Cartesian view of the world that orders these two sets of processes--mental and behavioral--to two different spheres of reality. So long as we adhere to that metaphysical position, we cannot rely on finding a clever method that will put the two halves together again.

I have adopted a theoretical framework which stems from a different philosophical tradition, one that I 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 the Soviet psychologists L.S. Vygotsky and A.N. Leontiev. It has been elaborated over the years by their successors in psychology and philosophy, initially in the USSR but increasingly among psychologists in Europe, and to some extent the United States. I cannot, of course, exposit this theory here. But since it informs my research, I will offer a few schematic propositions as an orienting framework, and then I will rely on my case history to put some meat on these bare bones.

Activity theory perspective

Activity theory holds that neither mind as such nor behavior as such can be taken as the principal category of analysis in psychology. The starting point and primary object of analysis is the actual process of interaction in which humans engage the world and each other. Such interaction represents a synthesis of mental and behavioral processes. Sequences organized around specific motives constitute activities. We can roughly grasp this concept if we note that play, school, and work have been proposed as classes of activities of special importance to intellectual development. Activities--whether carried out by one person or many--are always part of a system of social life: people strive to satisfy purposes that have meaning within their community, and, in their activities, they use tools, symbols and modes of action that are culturally developed and transmitted. For this reason, the concrete content of activities and the motives they satisfy are historically changing. And so too are the modes of thinking incorporated in these activities.

One other set of constructs is important to the analysis I will be making. Activities may be analyzed psychologically on a number of levels: on the molar level of activity as such, or in terms of the goal-directed actions which comprise them, or the specific operations by which actions are carried out. As we will see, action goals are changeable; and equally important, even when goals are invariant, the operations used to achieve them may vary with circumstance and time.

A methodological principle is implicit in this approach. If thinking is an aspect of concrete activities, and we want to understand its genesis and forms, we need to begin with an analysis of the activities and actions in which it is embedded. We need at least a two-way street, one in which we move from the world to the construction of models, as well as the other way around.

Research objectives

These constructs shape my research, which has three objectives. On the most ambitious level, I would like it to serve as a vehicle for elaborating the very general constructs of activity theory. I want to develop and test a method that integrates observational studies of naturally occurring phenomena with experimentation on model tasks. And most concretely, I want to discover something about the characteristics of practical thinking in everyday life.

What activities might be suitable for investigating practical thinking? I chose to study work activities 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 waking time, and, in many--certainly our own--it is a principal source of self-definition. Although we are not wholly defined through our participation in 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 also commended work as an object of study and led me to concentrate initially on industrial and service occupations and crafts. Many of these occupations are highly structured and involve tasks whose outcomes are predetermined. They are thus more amenable to analysis than activities in other domains and offer favorable opportunities for devising and testing research methods. An important advantage is that work activities, especially those carried out in institutional settings, are socially defined and organized <u>as</u> activities. We can start with classifications already existing in the workplace and allow the evolving research to test their adequacy. That is the course I took. In my analytic scheme, occupations such as assembler, waitress, or bookkeeper represent motivated activities and particular work tasks represent goal-directed actions.

Our studies begin with systematic observations of people carrying out their responsibilities under normal working conditions. These result in a first-level description of cognitive aspects of a particular job. On the basis of this description, we devise a job simulation that allows us to observe performance under more constrained conditions than those occurring in the ordinary work environment. Simulations function as model systems for investigating specific hypotheses about the factors regulating variability on a task and the characteristics that distinguish expert from novice performance. (See Figure 1.) From time to time, we set up special experiments using established laboratory techniques to probe questions on a more specific level of analysis than simulation studies make possible.

Now let me turn to an illustrative line of research. For this purpose I will take you to a milk-processing plant that was the site of our first work studies. The occupational activity we will be examining is that of product assembly, and I will present a case history of our cognitive analysis of the assemblers' principal work task. The manual components of this task could be grasped by eye but its intellectual intricacies required some time to ferret out.

Thinking at work: A job description

Assemblers are responsible for locating and sending out to a loading platform the milk products ordered by wholesale drivers for their next day's deliveries. Accuracy counts--each man is responsible for his errors; and so does speed--the work shift does not end until all orders are loaded.

Assemblers use a computer-generated order form to get information on the kinds and amounts of products needed on different delivery routes. This form expresses quantities in a metric system specific to the dairy, one composed of cases and units. Dairy products are stored and handled in cases of a standard size which hold a certain number of unit containers of milk. The number of units in a case varies with the size of the container. One case holds four gallons, nine half-gallons, 16 quarts, and so on. If a particular order involves a quantity that is not evenly divisible into cases, the order form represents it as a mixed number: "x cases <u>plus</u> y units" or "x cases <u>minus</u> y units." For example, 1-6 on the order form stands for "1 case <u>minus</u> 6 units"--the exact number of units required for the completed order depending on the type of container specified. After the assembler reads the order (in actuality he handles several at a time), he proceeds to the area in the warehouse where the product is stored and uses a long metal hook to pull out from the array as many cases and units as required.

Product assembly is classified at the lowest skill level in the plant, and the job I have just described is in many ways prototypical of repetitive manual work. Yet it has a number of interesting features which recommend it for analysis of practical thinking. For one thing, filling an order requires processing of quantitative information from both symbolic expressions--the orders as printed on the computer form--and from physical configurations--milk containers in cases. It is neither wholly a symbolic task nor wholly a material task. For another thing, filling an order can be considered a form of problem-solving. It has a number of formal features: it proceeds within a rule-regulated number system in a determinate universe of admissible problems for which there are fixed criteria for solution. It thus shares some of the characteristics of formal problem-solving tasks well-studied in laboratory experiments. Yet the job differs in crucial ways. Product assembly problem-solving takes place in continuous interaction with an environment that is socially organized and is in constant flux. Locations of products and numbers of full, empty, and partially full cases of milk change from night to night and momentarily during the course of the work shift. Moreover, while this job is performed individually, there is a common culture in the warehouse which shapes patterns of work activity.

We concentrated on the procedures that assemblers use to fill the mixed case and unit orders I have described. Informal observations revealed they had many different ways of going about it. On some occasions, they filled orders as written: they filled plus orders by adding the specified number of units to an empty case and minus orders by removing the specified number of units from a full case. Their operations--adding or taking away, and the number of units moved--were isomorphic to the symbolic expression of the order. I will refer to these procedures as literal solutions.

Assemblers frequently departed from these literal interpretations, however. Take the order, "1 minus 6 quarts." Remember that there are 16 quarts in a case, so that 10 are needed. On one occasion, an assembler filled this order by removing four quarts from a partially full case of 14 that was located nearby. On another occasion, he filled the same order by adding two quarts to a partially full case of eight. In this latter instance, he not only changed the number of units to be moved but converted a take-away operation into an add-to operation. I will call these nonliteral solutions. (See Figure 2.)

Solution variability to identical problems commands 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. 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 while walking through the warehouse to locate the product. Literal and nonliteral solution modes impose comparable memory demands of this nature. But, beyond these, nonliteral solutions require some additional mental manipulation of the numerical information in the order so that it can be mapped onto quantitative properties of different physical arrays. (See Figure 3.)

A nonliteral solution to the order, "1 case minus 6 quarts," for example, requires the assembler to search the product array for a partially full case, make a mental comparison of the distance between the number in this case and the desired end result, and determine how many units to move. Many subprocesses may be involved in such solutions, but all require search, comparison, and quantity judgments not required in literal solutions.

Interrelationship of mental and physical operations

Why did product assemblers choose to engage in such extra mental work? What regulated their choice of solution mode for a particular problem? We 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. We were postulating a trade-off between mental and physical effort.

To test the first hypothesis we conducted systematic observations of assemblers filling mixed case and unit orders on the job.

As a measure of physical effort we used the number of containers the assembler moved from one case to another to arrive at the final order. Applying this measure, 80% of all literal solutions and 100% of nonliteral solutions--everyone--satisfied the least physical effort hypothesis. That is, of all the possible ways of filling an order, the assembler chose just that mode of solution which required him to transfer the fewest containers from one case to another under the given set of circumstances.

We turned to the laboratory to test the second hypothesis about a mental effort-physical effort tradeoff, and to map the acquisition of such a strategy. For this purpose, we devised a task simulation, using dairy cases and empty milk containers and tested it with experienced product assemblers and novice groups of other workers and students. Although the simulation removed the task from its actual work context and involved little physical strain, assemblers continued to fill the orders with nonliteral, least physical effort strategies. Novice groups, and especially the students, tended to proceed algorithmically, carrying out literal instructions.

Since assemblers' simulation performance was consistent with their actual job performance, we had some confidence that our task captured and preserved essential characteristics of the job. We had the possibility then of using the simulation as a model system for experimental studies on the acquisition of least physical effort solution strategies.

Approximately 200 students, most in secondary school, assumed the role of novice assemblers in a series of learning studies conducted in our laboratory and in the schools.

Our first question was whether novices would acquire nonliteral least physical effort strategies simply through doing--filling orders of various kinds--without instruction. Over the course of a number of studies, the answer is that the majority did. As they gained experience, many students adopted nonliteral modes of solution spontaneously, and some reached the same level of optimal performance as experienced assemblers on the job. In all cases, the course of change in mode of solution was from predominantly literal to predominantly nonliteral. In the terms in which we have been analyzing this transformation, mental operations came to substitute for physical operations: the head replaced the hand, not the other way around. (Figure 4 illustrates one such transformation.)

We also learned that construction of nonliteral solutions is not an all-or-none affair but on a group basis takes the form of a learning curve. In line with our hypothesis that moving from literal to nonliteral solutions involves a tradeoff of mental effort for physical effort, it seemed sensible to suppose that the rate of appearance of nonliteral solutions would be regulated by terms of this exchange. In some studies we varied the number of physical moves that could be saved by nonliteral solutions, holding the problem structure constant. Amount of physical savings ranged from one unit to six. Counter-intuitively, this manipulation had no effect on rate of acquisition or level of nonliteral solutions. When a nonliteral solution saved a move of only one milk container it appeared as early as a nonliteral solution that saved six.

The situation is entirely different with respect to mental effort. Some transformations from literal to nonliteral optimal solutions are more difficult than others, and the evidence is unequivocal that it takes the learner longer to shift to nonliteral solutions for the more intellectually difficult problems. Several classes of evidence support this proposition.

A logical analysis suggests that <u>minus</u> orders (e.g., "1 case <u>minus</u> 6 quarts") require more mental work than <u>plus</u> orders since their surface form does not contain information about the actual number of units required in the final order. The assembler must compute a mental representation of that number.

Figure 5 shows acquisition of nonliteral optimal solutions in one of our learning studies. On Trial 1, only half as many <u>minus</u> problems received nonliteral solutions as did the <u>plus</u> problems, and acquisition on minus problems continued to lag over all the trials. These are averaged group data. In a subsequent large-scale study, however, we conducted within-subject analyses of solutions to plus and minus forms of the same problem types. There were 520 occasions in which an individual learner solved one form of the problem pair nonliterally and the other literally. Of these, 480 instances--92% of all mixed pairs--consisted of a nonliteral, least physical effort solution to the plus form and a literal, greater physical effort solution to the minus form.

The third class of evidence is most compelling. We undertook to reduce mental difficulty by extracting one known mental operation from the task and providing practice on it. Beginning assemblers must learn to interpret the numerical expressions on the printed orders regardless of what solution mode they employ. But use of nonliteral solutions requires in addition that the assembler attend to a partially full case and make a quick judgment of how many units are in the case. We set up a numerosity judgment task, using a T-scope to display the printed order, followed by a photographic slide of a partially full milk case. The informant was to judge whether the number in the case was the same or different from the number called for in the symbolic expression of the order. Students participating in this judgment task prior to experience with actual assembly gave significantly more nonliteral least physical effort solutions on their first learning trial than did a comparison group without that training. This suggests that when judgments of quantity in the partial case were easier to make, students were more inclined to use that case to save physical moves.

So much for objective factors. Subjective factors also regulated solution shifts in the experimental learning situation. Here individual variations are informative. In all studies, some student participants defied the law of averages. They began as literal problem solvers and over many trials continued to fill orders algorithmically, never adopting a least physical effort strategy.

But, in interviews after the sessions, these literal problem solvers justified their solution choices in exactly the same terms as nonliteral problem solvers. Members of both groups said: "The way I did it was easier." Most students claimed they found nonliteral solutions easier because they did not have to move as many milk cartons; others said literal solutions were easier because they did not involve numbers. From a rational point of view, both explanations are sensible. Selection of a strategy that is intellectually easier seems no less appropriate than selection of a strategy that is physically easier--if, as here, both lead to the same acceptable outcomes. In evaluating product assemblers' performance on the job. we are inclined to accept their adoption of a least-physical effort strategy as so appropriate that it needs no explanation. Yet when we encounter variability in the experimental situation, especially different interpretations of "easiness," the obvious becomes problematic and prompts us to reexamine product assemblers' performance which we initially took for granted. There were individual differences among assemblers. They differed in educational background and job history and in the extent to which they consistently followed a least physical effort strategy. But all followed a least physical effort strategy most of the time, and <u>not one relied on a literal problem-solving algorithm</u>. In the plant there was a clear consensus that trading head for hand was the better way to do the job. To account for this common aspiration, we have to move away from constructs such as personal preference or individual difference to consider the structure of the work activity in its broader institutional contexts. Our experimental analysis thus returns us to a new ethnographic enterprise, one which aims at identifying the social processes which give use to preferred modes of solution among members of a given work community. But that is beyond the scope of our present inquiry.

Concluding observations

My description has been thick with particularities. Let me summarize the product assembly studies in terms of the constructs with which we started. From the work activity known as product assembly. we extracted the job of filling an order to analyze as an instance of a goal-directed action. The aim of the analysis was to understand how manual and mental operations are coordinated in this action and how they changed with changing conditions and expertise.

The first finding was that goal is a multi-sided concept. It cannot be entirely specified from a task analytic perspective since it has its subjective as well as objective aspects. In product assembly the objective externally imposed goal is completion of the order with speed and accuracy. Assemblers' personal goal is to satisfy this requirement with the least physical effort. To a remarkable extent, given the conditions of work, they were able to maintain this goal as invariant under continually changing circumstances. To do this, they had to draw flexibly on a wide repertoire of constituent operations, organizing them into a smooth action system on each occasion of order filling. Others who have studied action systems--I think of Miller, Galanter and Pribram's classic book--have shown the essential role of mental representations and regulatory processes in manual actions. Such analyses emphasize the role of the mind in constructing a plan for action and monitoring its execution--the mind directs, the body does. Our analysis goes further in demonstrating, for one particular action system, that execution has its mental as well as manual components, and that mental and motor processes may substitute for each other. We might say that, in certain circumstances, operations of the head and of the hand are functionally equivalent.

Our learning studies suggest that such functional equivalence comes about through practice--the head takes over for the hand, first for the simpler problems, then for the more complex. What is achieved through practical thinking is intelligent organization of action, finely fitted to task demands and resources and to the intentions of the actor.

It is tempting initially to place the burden of explanation for this reorganization of the task on the demands of the assembly job per se; it is physically strenuous and monotonous. But the kind of reorganization we have described turns out to be one instance of a large class of instances that are not tied to physical features of work. In the two years we were in the plant, we analyzed six or seven key jobs in blue collar and office occupations. Some of these jobs were wholly symbolic in nature--pricing out customer deliveries, for example, or preparing bills; others were physically undemanding. Nonetheless, across all jobs, wherever working conditions allowed for optional modes of action, experienced workers displayed flexible forms of problem-solving that served to save effort. The effort saved on symbolic jobs, of course, was mental, not physical. In the factory 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 mental or physical shortcuts. Researchers in labor psychology laboratories in Paris, Dresden, and elsewhere report similar phenomena and refer to a least-effort "optimizing criterion" as a basic principle of workers' subjective organization of work.

In laboratory research on problem-solving, we tend to interpret goals solely in terms of the objective outcomes set by the experimenter, taking no account of the ends the problem solver has in mind. Laboratory conditions appear singularly unsuitable for yielding knowledge about personal values and understandings. Experimental records disclose differences in goals but give us little insight into conditions of their origin. To examine this aspect of human functioning we need to shift to a social level of analysis and a study of the larger institutional and cultural contexts in which individual ideals and purposes take shape.

I have given an interpretation of product assembly research within an activity theory framework. And this brings me back to the broader question that motivated these studies of practical thinking at work.

One purpose was to try to concretize and elaborate activity theory constructs. I may have made some small progress here. But it is obvious that the fit between theory and research evidence is not a close one. I could have presented the studies and their findings in other theoretical terms--there are action theories from other traditions--and much of what I have discussed can be translated into the more familiar conceptual frameworks we find in psychology journals. Activity theory is not in itself a theory of cognition.

It seems appropriate to consider it, rather, as a metatheory, offering certain basic categories and principles for theory construction in the various fields of psychology. These categories direct us to new questions, and, in the field of cognition, give us the possibility of enriching theories of thinking. I hope many will find these questions and this perspective worthwhile.

A second motivation for our research was a test of method. I wanted to see if we could bring sufficient rigor to the study of thinking in naturally-occurring activities to produce experimental models which preserve essential characteristics. Since the initial studies of five occupations in the milk-processing plant, my students and I have extended the framework and methodology to other occupations--sales engineers, carpenters, waitresses, bartenders. We are currently analyzing the impact of the introduction of integrated computer systems on the intellectual demands of jobs in material design and control. For some jobs, we have achieved fine-grained specification of the knowledge and skills required; for others we remain at the level of first description. I cannot offer a full assessment of how far we may travel with our approach, but the methodology does travel and can be given away. I have gained some confidence in the analyzability of practical thinking. As we go along, certain old dichotomies that have impeded an action-oriented approach to thought become increasingly irrelevant. Observation is not opposed to experiment, but may be the forerunner of it. Description is not opposed to explanation but may function as a first approximation to it.

Finally, what have we learned about practical thinking at work? I remember the first occasions on which I presented some of the dairy studies. "Very interesting, Sylvia," some said. "But what can we learn of these job analyses that is useful to cognitive theory? Does product assembly generalize?"

I see no reason to think that the specific operations involved in product assembly--or any other job--will transfer to or be identical with constituent operations in other tasks. But that is beside the point. We are interested, not in whether <u>particulars</u> about practical tasks generalize, but whether we can find <u>general</u> characteristics across a wide range of <u>particular</u> tasks. Our research offers some candidates for such characteristics, a number of them already exemplified in my description of product assembly. Common to expert performance in all jobs we have analyzed to date are a set of interrelated attributes: flexibility in modes of solution to formally identical problems, creative shortcuts to simplify and economize on mental and physical effort, fine-tuning to the environment, and effective utilization of setting-specific knowledge.

Future research can test the range and variation of these features. One limitation to generalizations about thinking at work, however, needs to be pointed out here. All jobs we studied permitted the worker one or more degrees of freedom in organizing the task. This measure of latitude stands in sharp contrast to the restrictive conditions of work on routinized, mechanized, and automatically paced jobs epitomized in the assembly line. On such jobs, I assume it would be difficult for workers to display the flexibility and ingenuity we have documented. Whether or not flexibility in practical thinking at work can be entirely eliminated short of robotization, however, remains an open question.

If individual latitude on the jobs studied here limits application of the analysis to only some 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. A flock of recent studies reveals that problem-solving in shopping, cooking, and other mundane pursuits shares certain family resemblances with the modes of problem-solving we have found in certain work occupations. These congruences give us some warrant for assuming that practical thinking is orderly, that it exhibits certain common characteristics in a variety of purposive life activities, and that it is amenable to scientific understanding.

Figure 1
Research Strategy for Cognitive Analysis of Work

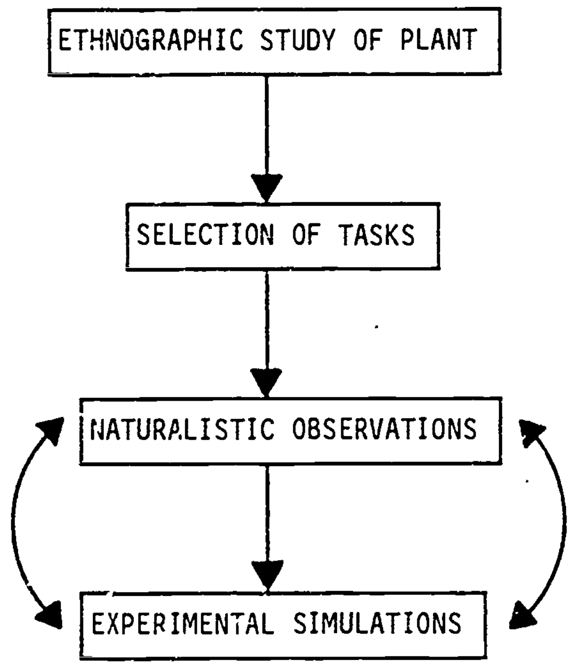

Figure 2
Example of Variability in Solutions To a Product Assembly Order

ORDER: 1 Case - 6 Quarts (or, in unit terms, 16 - 6)

OBSERVED SOLUTIONS

LITERAL SOLUTIONS	NONLITERAL SOLUTIONS
16 - 6 (take away from full case as instructed)	14 - 4 (take away from partial)
	11 - 1 (take away from partial)
	8 + 2 (add to partial)
	6 + 4 (add to partial)

Figure 3
Features of Literal and Nonliteral (Optimal) Solutions on Product Assembly Task

LITERAL	NONLITERAL (OPTIMAL)
1. No computations required	1. Computations required
2. Identical orders receive identical solutions	2. Identical orders receive different solutions in different contexts
3. Solution plan can be formulated *a priori*	3. Solution plan needs to be constructed from information in the problem

Figure 4
Product Assembly Simulation Learning Study
Example of a Student's Change in Solution Mode

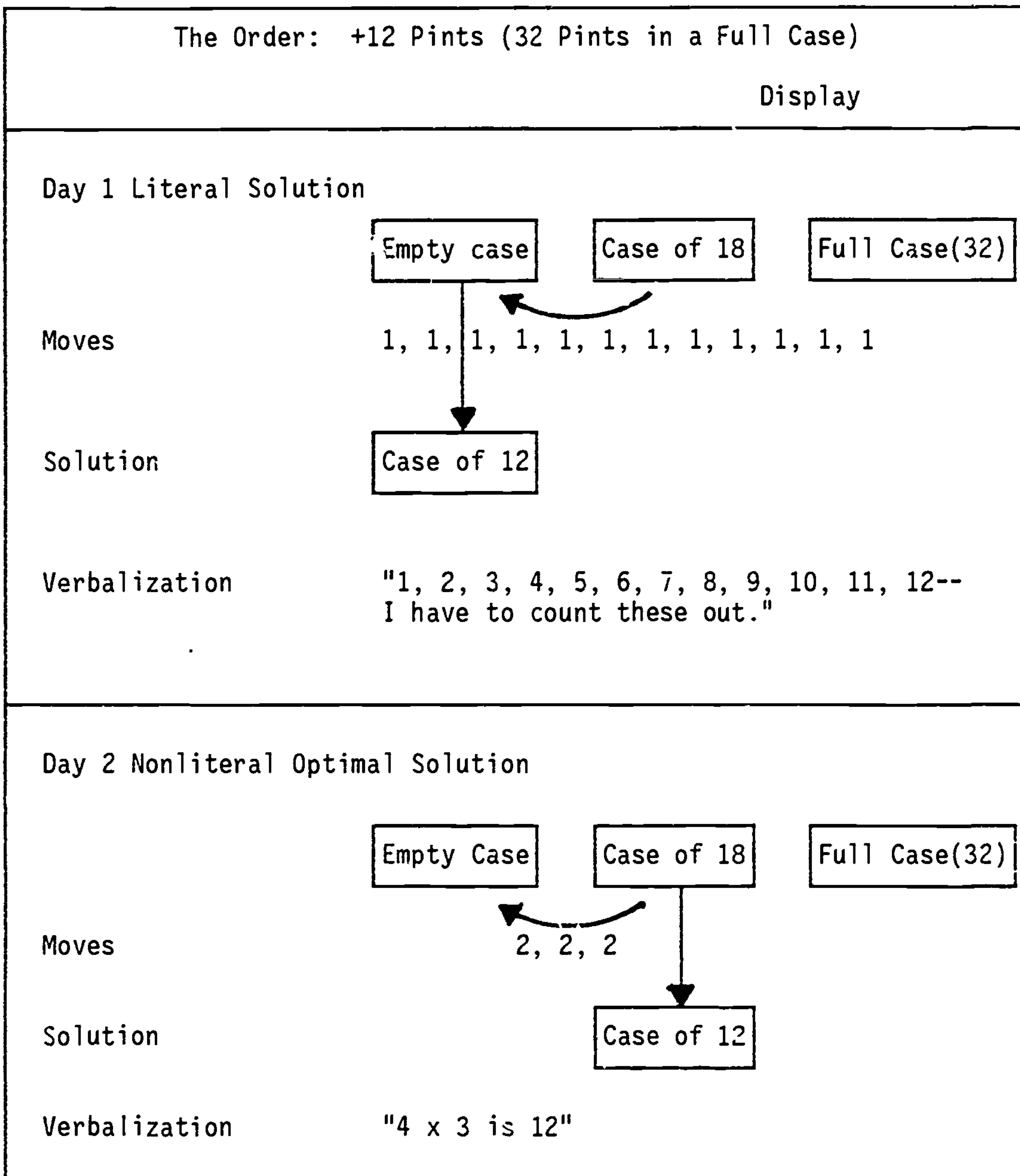

Figure 5
Acquisition of Nonliteral (Optimal) Solutions
on Product Assembly Learning Task