THE QUARTERLY NEWSLETTER OF THE

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TABLE OF CONTENTS

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THE QUARTERLY NEWSLETTER OF THE LABORATORY OF COMPARATIVE HUMAN COGNITION

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Introduction

Stephen Reder, Guest Editor

Roger Barker's treatise, *Ecological Psychology*, began with these words:

> The Midwest Psychological Field Station was established to facilitate the study of human behavior and its environment *in situ* by bringing to psychological science the kind of opportunity long available to biologists: easy access to phenomena of the science unaltered by the selection and preparation that occur in laboratories. The Field Station provided promising opportunities. But it also raised problems that were new to psychology: How does one collect specimens of behavior? What are the parts of the continuing stream of a person's behavior, and how does one enumerate and describe them? Among the limitless attributes of a person's surroundings, which ones are relevant to his behavior, and how does one identify and measure them? (1968, p. 1)

The field research of Barker and colleagues, which spanned several decades beginning in the late 1940s, developed theory-based descriptions of the naturally occurring environments of human behavior. In Barker's best known work, he and colleagues completed a detailed mapping and analysis of the behavioral habitats and settings of children in the town of Midwest (Barker & Wright, 1955). One important outcome of their line of work was its careful documentation of the finding that "... some attributes of behavior varied less across children within settings than across settings within the days of children" (Barker, 1968, p. 4). Among the many contributions of Barker and colleagues' research was the development of a rigorous "shadowing" methodology for carefully following, documenting and analyzing the *stream of behavior* on the ground.

The three articles in this thematic issue use variants of shadowing techniques to study selected behavior on the ground. In the first article, "Watching Flowers Grow: Polycontextuality and Heterochronicity at Work," I describe several shadowing studies of work groups collaborating on long-term projects. Members of these product design, executive management and public school teacher teams—were shadowed over weeks and months as they worked collaboratively on projects. It proved necessary to modify Barker and Wright's shadowing techniques in order to study the behavior of the work group, particularly the contribution of remote interactions mediated by written and electronic communication technologies. These studies describe work group behavior as a highly complex structure, being both *polycontextual* (members are typically engaged in several ongoing activities at once) and *heterochronic* (activities and their components are organized with respect to different temporal frameworks). This richly textured fabric of group behavior constitutes both a set of logistical constraints and creative resources for collective accomplishment of multiple tasks over time.

In the second article, "Shadows in the Soup: Conceptions of Work and the Nature of Evidence," Patricia Sachs explores two different conceptions of work, each of which takes a distinct approach to the analysis of work tasks and activities. She terms these two different approaches the *functional business view*, closely allied with the scientific management theory of Frederick Taylor, and the *work practices view*, which understands workplace activities in terms of problem-solving practices, social interactions and communities of practice. Despite overlapping terminology, each view approaches the analysis of work with different assumptions and goals. Sachs examines the nature of the evidence each approach takes as critical for its analysis of work, and illustrates each in the context of a company she has studied. She shows how shadowing data can provide critical evidence within the work practices view. She utilizes, however, quite a different shadowing methodology than the Barker-Wright technique. The article describes the shadowing technique she and Sylvia Scribner developed and illustrates its application in the analysis of a workplace.

The third article, "To Capture A Process: Hierarchical-Sequential Representations of A Computer-Based Activity," by Alan McAllister, reports a third approach to the shadowing of behavior. McAllister is interested in describing the goal-directed, problem-solving behavior of computer programmers during experimental programming tasks. In these experiments, the computer records details of the subject's interactions with the computer system. To analyze these fine-grained records of programmer-computer interactions, McAllister brings together the Barker-Wright approach to describing constituent units of goal-oriented behavior and Newell and Simon's (1972) conception of problem-solving behavior as goal-directed search through problem spaces. McAllister illustrates the use of his methodology with a study of young students learning to program in the LOGO language. He also discusses how his techniques might be usefully extended to analyze social interactions in cooperative work and instruction.

These three articles thus describe distinct shadowing methodologies, each tuned to a different range of theoretical and practical issues. Each suggests ways in which its approach needs to be broadened in order to be applied usefully in other types of investigations. Each tries to draw important relationships between theories of context and descriptions of behavior. It is hoped that together they will stimulate others to cast shadows in the streams of behavior.

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Watching Flowers Grow: Polycontextuality and Heterochronicity at Work

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An unbroken thread beyond description . . .
Stand before it and there is no beginning.
Follow it and there is no end . . .
- Lao Tzu, *Tao Te Ching*

Introduction

There has been increasing interest in how teams cooperate to conduct and accomplish their work. Cross-disciplinary attention is being directed to this problem in order to understand better the relationships among evolving theories and methods (Engeström & Middleton, in press; Galegher, Kraut, & Egido, 1990; Nardi, 1992; Resnick, Levine, & Teasley, 1991). In-depth case studies have been conducted of particular work tasks or processes (e.g., Cicourel, 1990; Egger & Wagner, 1992; Engeström, 1992; Heath & Luff, 1991; Hutchins, 1991; Saferstein, 1992; Suchman, in press). Two general empirical approaches are evident in these field studies of cooperative work: investigate and illustrate general principles from extensive analysis of small strips of observed behavior (e.g., Suchman, in press), or analyze structural properties of specific recurrent activities (e.g., Engeström, 1992).

There have been relatively few investigations of work groups, however, in which characteristics of the *full range* of a group's work activity have been systematically examined as they operate over days, weeks, or months. Such investigations potentially offer a broadly-based analysis of the dynamic properties of a group's tasks and work objectives, and possibly a bridge between micro- and macro-analytical approaches to the study of work. One of the striking characteristics of many work groups is the overwhelming complexity of their realized work: numerous tasks are carried out involving complex temporal, spatial, and interactional overlaps, usually contending for limited material and human resources. Hutchins and Klausen (in press) note the staggering complexity of a commercial jet flight: millions of parts flying through space in close formation with hundreds of passengers and crew. The complexity of a work group's "flight" through several weeks or months of activity is probably no less complex, and certainly no better understood.

Jerry Schwab, Sylvia Hart-Landsberg and I have been investigating such work group trajectories through complex activity spaces. We have been particularly interested in how patterns of group activity, stretched over time and space, themselves constrain, mediate and bring about the accomplishment of component tasks. Our work has utilized a *shadowing* methodology, in which participant-observers regularly follow work group members through their daily rounds, recording specified types of events, the corpus of which is then analyzed in terms of unfolding work group activities.

Shadowing Method

The basic method of our shadowing studies was to observe, describe, and analyze the macroscopic structure of work group behavior on common, goal-oriented tasks as they are carried out over long periods of time, (e.g., designing a new high technology product, developing a marketing plan for a new telecommunications service, writing a cross-disciplinary middle school curriculum). We studied teams ranging in size from 3-8 members from different organizations engaged in product engineering (Reder & Schwab, 1989a, 1990b), corporate management (Reder & Schwab, 1989b, 1990a, 1990b), and public school teaching (Hart-Landsberg, Schwab, Reder, & Abel, 1991; Schwab, Hart-Landsberg, Reder, & Abel, 1992).

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Our shadowing techniques are based on methods pioneered by Roger Barker and colleagues (Barker, 1968; Barker & Wright, 1955; Schoggen, 1989). They developed methods for observing and documenting continuous streams of naturally occurring behavior in given settings and extracting from those data sets *standing patterns* and distinctive features of behavior characteristic of those settings. The detailed written records Barker and colleagues collected through direct observation were called *specimen descriptions*, generated by closely observing and documenting "streams of behavior" taking place within ecological units termed *behavioral settings*. These specimen descriptions are transcripts of ongoing activity—temporally ordered, recorded, and annotated by an observer shadowing a given individual over the course of a spatio-temporally bounded interval, most often a day. Barker and Wright term the immediate constituents of the behavioral streams in the specimen descriptions *behavior episodes*. The strong influence of Lewin's (1951) field theory and concept of action is evident in Barker and Wright's definition of episodes: (1) they reflect a constant direction towards a goal, (2) they occur within the normal behavioral perspective of the actor (and observer), and (3) they manifest continual progress towards the goal.

Issues in workplace shadowing. We encountered two key issues in adapting Barker and Wright's methods—which are specialized primarily to study children in towns and schools—to our studies of project-oriented work groups. First, the teams we studied relied heavily on mediated (e.g., electronic mail, written documents, telephone) as well as face-to-face communication in carrying out their cooperative work activities over time and space. Contingencies and continuities in group work could not be represented without these remote interactions. The powerful ethnomethodological methods so useful in making sense of work group accomplishments over relatively short intervals of time (e.g., Lynch, 1991; Suchman, in press) were not helpful in this regard; many critical events in the unfolding of group activity were not bounded within what Goffman (1981) called "common focused encounters" (marked by participants' co-orientations in space). The essential role of mediated, remote interactions in the accomplishment of group work required that we document the use of other communicative media and the interplay of remote interactions in the accomplishment of specific work activities.

A second methodological issue was that, as a practical matter, we wanted (to the extent possible) to categorize and record observational data in real time as we shadowed workers in their daily rounds. Although we frequently, during shadowing, also tape recorded meetings and conversations and collected copies of electronic and hard copy communication for retrospective analysis of communication and interaction (Reder & Schwab, 1989), the immense volume of potential shadowing data required us to develop effective ways of recording significant features of behavior directly in real time.

Modifying the shadowing technique. These requirements led to two significant changes to the shadowing technique: (1) We introduced the concept of an event—a constituent of the Barker and Wright episode as explained below—as a device for explicitly recognizing relationships between interactive sequences dispersed over space and time by mediated communication, and (2) we did not distinguish among Barker and Wright's full range of actions. If, for example, during the course of some solitary activity, an individual engaged in a number of subtasks all supporting the completion of a given task (e.g., debugging a piece of computer software code), we did not distinguish transitions among its component actions (e.g., inspecting a section of code, tracing through it stepwise, making a temporary change to test the effects of a given step). We categorized such uninterrupted solitary activity as a unitary strip of goal-oriented activity: repairing a bug in the code.

Our shadowing approach defined *tasks*, from the perspective of the team member, as discrete work objectives (e.g., writing a project report, selecting a vendor, testing a prototype). Tasks are accomplished through one or more *events*, which are defined as observable actions directed towards a task or work objective. Viewed within the context of collaborative work, we discriminate between events which are *communicative* (e.g., speaking to a co-worker over the telephone about the use of a computer program) and those which are *non-communicative* (e.g., using a calculator to reckon a price estimate). Tasks may be comprised of a single event or a sequence of events scattered over time, location, and participants. Tasks and events cluster in particular ways; these clusters we refer to as *episodes*. Episodes are defined as units of temporally and interactionally bounded activity, and can be further divided into simple and compound forms. A *simple episode* is defined as a unit of temporally and interactionally bounded activity involving a single task and event which may or may not involve communication with other individuals. If the simple episode is communicative, it is restricted to a single channel. A *compound episode* is defined as a unit of temporally and interactionally bounded activity which may involve more than one task and/or more than one event (e.g., a face-to-face conversation with another teacher [the first event] pertaining to a management plan [the first task] in which the subject creates for the other interactant a pencil sketch of the plan [the second event] followed by further discussion of an unrelated design problem [the second task]). As this example shows, compound episodes may involve more than one channel (i.e., information is carried simultaneously through face-to-face conversation and documentation). Similarly, multiple tasks can be addressed through a single event (e.g., a face-to-face conversation may involve discussion of several discrete tasks).

To perform real-time coding in a valid and reliable fashion required highly trained observers who were quite familiar with the work group members' goals and activities and the ways in which they communicated about them. Observers typically spent months of time in given field settings becoming familiar with the studied teams and their work before beginning the intensive collection of shadowing data. Multiple observers were usually involved in shadowing members of a work group under study. Members were shadowed for a day at a time, with each observer shadowing each team member for several workday-long sessions. Numerous artifacts were collected in the course of shadowing, including samples of email, written and electronic documents, copies of diagrams and temporary displays, transcripts of meetings, and so forth.

This shadowing approach enabled us to *partially* track the accomplishment of particular work group tasks over time. Although the ideal shadowing for our purposes would be to shadow activities as they unfold within the group, we had to settle for shadowing individuals as they moved through a range a situations and activities. Having multiple observers shadowing multiple individual team members gave us a rich but nevertheless incomplete view of a relevant activity as it unfolded.

Further information about field settings, instrumentation, procedures, and samples of shadowing data are described in detail elsewhere (Reder & Schwab, 1989b, 1990b, 1991).

Some Shadows of Group Work

Group work is accomplished through an apparent mosaic of activity, dispersed over time, space, and interactants in highly complex ways. Some analyses of the shadowing data track the activity of specific individuals, tracing over time the range of tasks and interactants they engage; other analyses attempt to trace the accomplishment of given tasks over time through the engagement and interactions of team members. Using either lens, it is clear that both solitary and interactive episodes contribute regularly to the accomplishment of many spe-

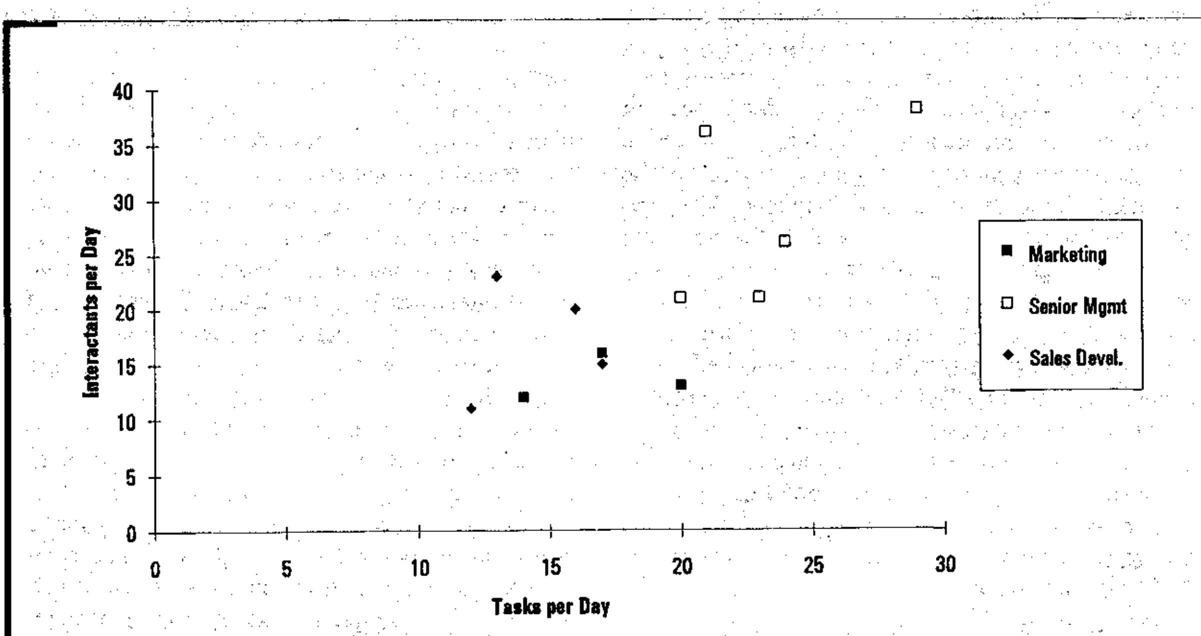

Figure 1: Scatterplot of individuals' average number of interactants and tasks per day. After Reder and Schwab, 1990b.

cific tasks. Several generalizations—which hold for each studied work group—can be drawn from an aggregate analysis of the shadowing data.

Standing patterns. To begin with, there are, using Barker's terminology, *standing patterns* of behavior characteristic of a given work group and its work. These patterns - involving such parameters as the number of ongoing tasks handled, the number of interactants in a task - the distribution of time among tasks, and so forth are highly stable for a group over time, yet vary markedly between groups (Reder & Schwab, 1990a). Furthermore, individual members of working groups adapt to such macroscopic yet group-specific characteristics: the profiles of an individuals' activity patterns shift adaptively when they move from one group to another. The average number of tasks and interactants encountered per day are plotted for each member of three selected management teams in a Fortune 500 company. Each point is aggregate data for an individual over many days of shadowing. Clear separation can be seen of individuals on the senior management team from individuals on the other teams.

Channel switching. When the accomplishment of particular tasks over time, space, and interactants is examined, a series of events and episodes is identified. In general, such episodic series are disjoint in terms of times, locations, and participant groups. Some episodes involve solitary work, others face-to-face interaction, and still others mediated interaction through electronic mail, telephone, hard copy and electronic documents, and so forth. When we looked at the sequence of episodes that involved the same interactants and the same task over a given day, interactions frequently moved from one communicative channel to another (e.g., face-to-face conversation to email). Such *channel switches* are ubiquitous in work group activity. Figure 2 illustrates the prevalence of intra-task channel switching among given interactants from product engineering work groups. As the length of the communicative chain of episodes increases, the likelihood of an intra-task channel switch increases.

Such channel switching occurs for a variety of reasons, including both logistical reasons (e.g., someone may not be accessible for a face-to-face conversation, so send email) and for reasons of communicative intent and strategy. Specific genres of work group communication themselves involve patterned channel switching as an integral feature (Reder & Schwab, 1989). For example, "walk-around management," a preferred style of informal staff monitoring and management in one organization, consists of periodic but unscheduled visits to staff work areas to "keep an eye on" what each person is doing; such visits are typically linked to follow-ups by electronic mail and later discussions in work group staff meetings. No one "link" in these episodic chains can be well understood

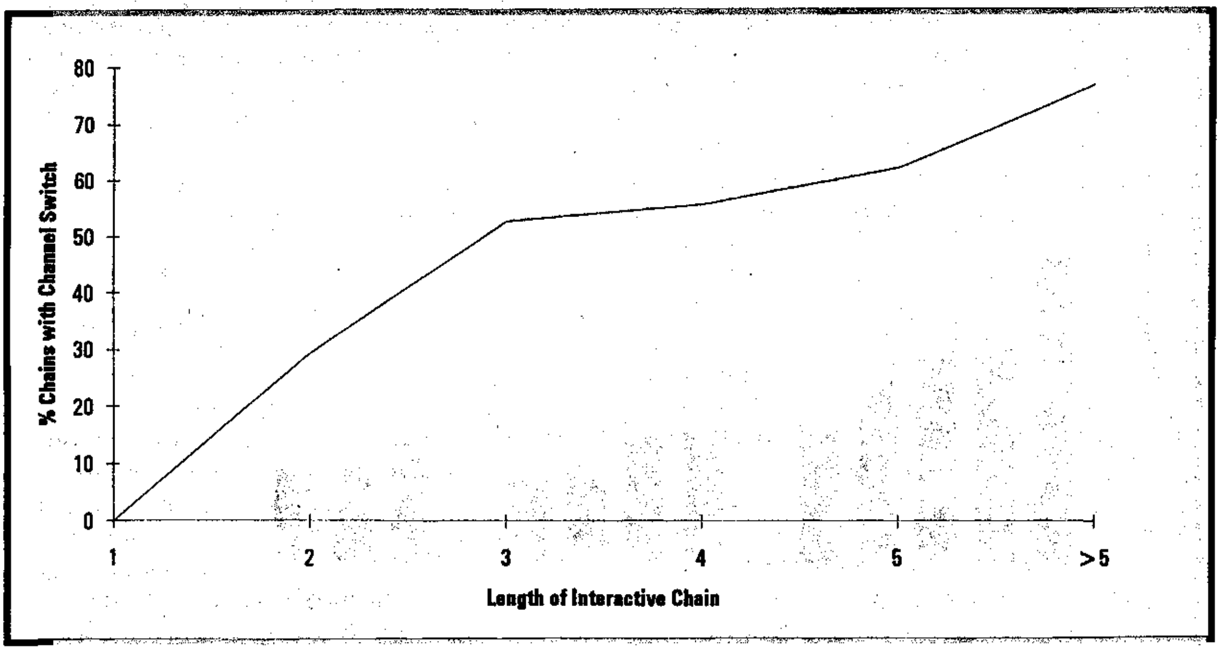

Figure 2: Mean proportion of inter-task channel switches within communicative chains by length of chain. After Reder and Schwab, 1990b.

without the larger (but temporally, spatially, and interactionally disjoint) patterned chain. Together they function quite effectively as a linked chain of episodes. Many of the strategic "choices" of media involved in such communicative chains are better understood as searches for mediational structures needed to accomplish individual and work group tasks; part of a system of socially distributed cognition (Hutchins, 1991).

Multitasking. Besides frequent channel switching, these shadowing data also contain significant amounts of *task switching* or *multitasking*. Both individuals and interacting groups frequently shift the focus of their attention and activity from one task to another. The crisscrossing of multiple ongoing tasks in the work of an individual and group can be tracked in the shadowing records. One summary measure of the richness of these intertwined strands of activity is provided by the computer science metaphor of a push-down stack. In analyzing the sequence of events in a shadowing record, we said that a task was put onto a "stack" when immediate activity on it stopped, but was resumed (by the same person) later that day. When it was resumed, it was "popped" back off of the analytical stack. We thus had an operational means to measure the number of tasks in the stack at each point in our record.

Figure 3 displays the mean running average and peak value (in terms of number of interrupted tasks) for individual work group members. Such a measure, of course, significantly underestimates the size of the stack, since intermittent activities last suspended prior to the day in question or next resumed after the day in question are not counted by this measure. Measures of the dynamics of task switching and of how individuals and work groups manage multiple ongoing tasks do reflect work group characteristics, especially styles of coordination and collaboration (Reder & Schwab, 1990b). Like some of the measures mentioned above, they reflect measures of work group activity that are relatively stable for the group but not so much for the individual member, whose values may shift if he or she moves to another work group. As with the channel switching discussed above, patterns of task switching may reflect both logistical factors (e.g., the relative priorities and timelines among contending tasks as well as among the resources necessary for their accomplishment) and social strategies for group work. Just as channel selection and switching may be integral to the accomplishment of certain tasks, task switching itself can allow individual and groups to not only progress on multiple inter-related tasks, it also provides adventitious junctures and juxtapositions between tasks for constructive exploration and mediation of inter-task relationships.

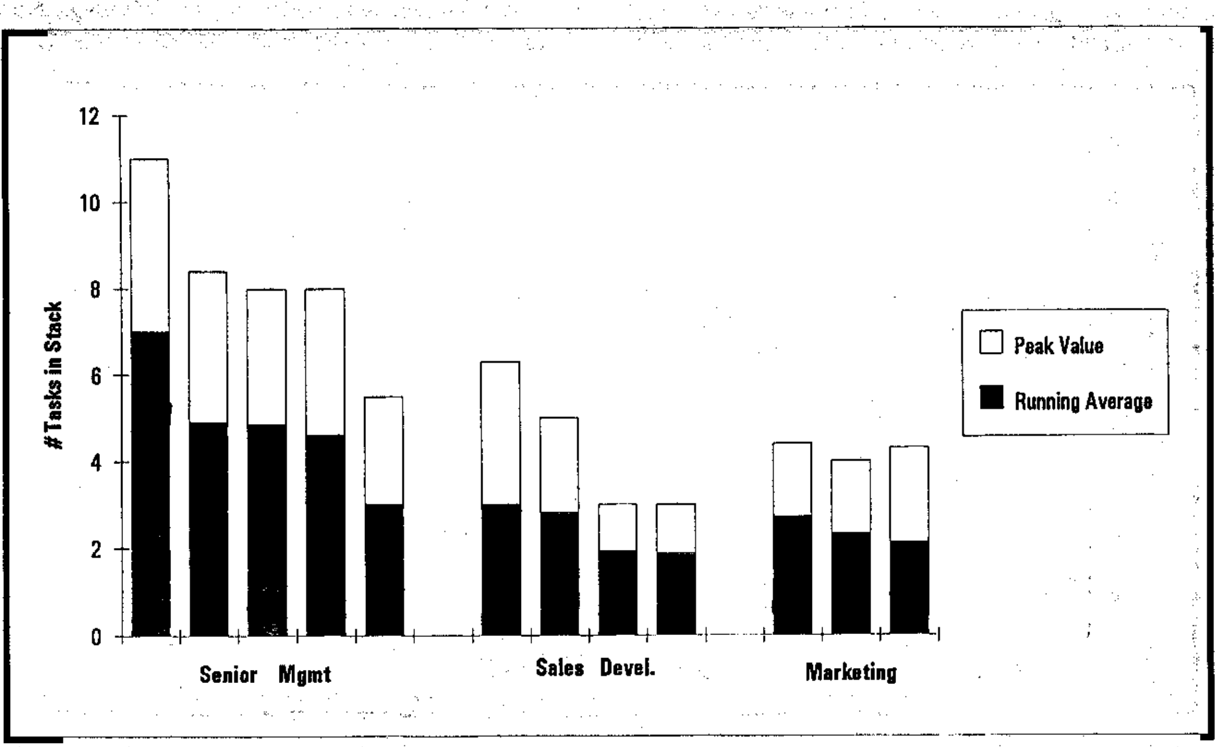

Figure 3: Mean daily running average and peak value of number of tasks in "stack" for individual members of three work groups. After Reder and Schwab, 1990b.

The texture of activity. The pervasive channel and task switching observed in the work of all studied groups generates a rich texture of interwoven activity, linking multiple ongoing tasks and chains of communication across disjunctures of time, space, and participants. This braided fabric of activity has two key properties essential to the understanding of work group behavior: *polycontextuality* and *heterochronicity*.

Polycontextuality. Polycontextuality means that the work group and its members are engaged in multiple ongoing tasks. This is more than a just global statement about how much an individual or work group accomplishes over a given period of time; it is also a *local* quality of ongoing activity that enables coordinated multitasking within the group. Suchman (in press) provides an elegant description of how airport ground traffic controllers, in constructing a shared workspace, maintain fluid relationships between individuals' focus on separate ongoing activities and a collective focus on restoring their local environment and social order following a disruption. The fine balance (which enables collectively structured shifts) of attention, orientation, and activity within their work group is here termed the polycontextuality of their activity.

Polycontextuality is also evident in the temporal cross-sections of the shadowing data. Recall that our shadowing technique breaks a Barker-Wright type episode into constituent events, which can partially overlap in terms of communication channels or tasks. Compound episodes are comprised of multiple events, usually compounded by threads of multiple tasks or communication channels. Reder and Schwab (1990, p.157) report approximately 47% of the workday for executive teams is spent in compound episodes, indicating the breadth of polycontextuality in these teams' work.

The notion of polycontextuality invites us to broaden the concept of a *meeting* as usually applied to the study of work. Workplace meetings are usually thought of as collocations of people engaged in concerted activities. The polycontextuality of work group behavior suggests that we also recognize *meetings of tasks*. Certain types of meetings were occasions during which teams dynamically (re)constructed a goal-oriented division of labor among multiple tasks in which they were engaged. On these occasions, team members frequently negotiated, coordinated, and synchronized their ongoing parts of the group effort (Reder & Schwab, 1989). Despite having marked temporal and spatial boundaries (i.e., they took place in particular settings with formal beginnings and endings), such meetings were, from another perspective, more diffuse in space and time. An impending meeting often served to funnel individual and group work on component tasks in its anticipation: reports and notes were prepared in advance, problems were documented, and conversations about possible outcomes were held as the meeting approached. Furthermore, ripple effects of the meeting could readily be seen in the individual and group task that followed. We are thus led to see, in a broader temporal framework, *meetings of tasks* rather than merely meetings of people.

Heterochronicity. The heterochronicity of the work group's activity refers to its organization with respect to multiple underlying time frames. Work group behavior is heterochronic in two senses. First, distinct tasks may proceed on different schedules and with varying pacing - this is *intertask* heterochronicity. Everyday work is replete with many familiar examples of this heterochronic mix of tasks. There is also *intratask* heterochronicity, which means that components of a given task are organized with respect to different time scales. Example: When two people are trying to finalize a decision, one may suggest that they "sleep on it" before finalizing it the next day. Another example: During a dispute, one party may request "some space"—that is, an opportunity to let feelings and reactions develop more fully—before proceeding with the face-to-face interaction. Both examples reflect the expected functioning of heterochronicity in an unfolding task. Work groups develop channel-switching and task-switching strategies for introducing heterochronicity into their processes, especially "planning," "decision-making," "learning," and other processes believed to "take time." We need additional evidence to determine the extent to which they actually "take" time (i.e., generate additional activity) or just develop on a different time scale.

Tension between individual and work group. Another feature of work group activity evident in the shadowing data is the tradeoff most work group members experience between having uninterrupted periods of time in which to get their own work done and being accessible for communication and interaction with others with whom they work (Reder & Schwab, 1990a). Workers were frequently observed attempting to manage and renegotiate this tradeoff, whether by closing doors or forwarding phones, or absenting themselves from customary workplace "territory." This interplay between social interaction and solitary activity in the accomplishment of work is very effectively depicted by shadowing data, as are corresponding differences in the "style" of a group's work and its coordination and collaboration patterns (Reder & Schwab, 1990b; Schwab et al., 1992).

Representation and mediation. Much emphasis has been placed on the role of notational systems and other tools in mediating the accomplishment of work, within the frameworks of both activity theory and distributed cognition. Within the complex texture of a work group's multiple ongoing tasks, such representations must evolve not only to support and mediate the component activities of the work, but also the varying *mix* of their activities as well. Systems of representation, tools and mediating devices are specialized not only with respect to the demands of specific kinds of tasks, but also with respect to the demands of specific combinations of tasks being carried out within a group's shared workspace. Patterns of interaction and of task interruption and switching among group members, for example, are reciprocally fitted to characteristics of the notational system and the physical work environment.

Within product engineering teams, for example, mechanical engineers tend to represent their work-in-progress with sketches, drawings, and other primarily visual (as opposed to textual) diagrams. These were often posted near the mechanical engineer's personal work area in a way that encouraged others to examine them informally as they passed by, perhaps ask a question or make a suggestion about it, and sometimes engage the designer in conversation about it even as other work continued. Software engineers and technical writers on the teams, however, tended to represent their work-in-progress with more textual media (program code, written documentation), which could neither be readily taken in at a glance nor discussed informally while other work continued. And the software engineers and documentation writers tend to arrange their personal work areas to discourage the interruptions which the mechanical engineers' personal work spaces encouraged.

Such relationships among representations of work-in-progress, patterns of interruption, and the arrangement of the work environment can be seen among other occupations as well. Those whose ongoing work can be represented visually (e.g., mechanical engineers, architects, artists) tend to prefer more open personal workspaces ("studios"); engage more often in informal conversation while conducting their professional work; and are less easily disrupted by conversation, radio, and so forth. Those whose work-in-progress is represented textually (e.g., software engineers, writers, academics, lawyers) tend to prefer closed work spaces ("offices") that minimize unplanned interruptions, engage less often in conversation while working, and are more easily disrupted by conversation and interaction. Devices for representing or mediating work in progress apparently evolve reciprocally along with characteristics of the social and physical work environment, and are specialized to patterns of collaboration and interruption within ongoing work. I have speculated elsewhere that the compatibility of various notational systems with group work environments and interaction patterns may be a critical factor underlying this patterning (Reder, in preparation).

Discussion

These findings and others—encompassing a range of work groups, occupations, and organizations—suggest that we need a broader understanding of cooperative workplace activities in terms of both theory and research methodologies. It is clear that work activities are situated not only in locally constructed and managed workspaces, but also in more globally structured ones whose fabric is temporally disjointed and whose component activities crisscross heterochronously in the accomplishment of group work. Although significant advances have been made in understanding how specific groups conduct given activities within small strips of locally situated and managed action, we know much less about how such activities are situated in these more globally structured and managed contexts. Bowers and Churcher (1989) have attempted to extend these approaches by modeling purposive action in terms of global constraints applied to sequences of locally managed strips of behavior.

With few exceptions, however, microanalytic and macroanalytic studies of work have generally remained separate in theory and research methods. Each approach is progressing well under this dichotomous arrangement, it might be argued, so there is little reason to tie them together. Tempting as it may seem to continue studying them as distinct sets of phenomena, however, there is increasing need to bring them together. The observed and experienced disjunctures of time, space, and communication media underlying group work performance—both within and across tasks—are integral to the fine structure of ongoing activity. The heterochronic and polycontextual patterning of a work group's tasks, so evident over longer expanses of time, penetrates the *local* management of activity. Team members continually take the larger pattern into account as they jointly construct shifts of focus among ongoing tasks and negotiate expectations about when and how activity will resume on a specific task. Sometimes such expectations are marked in discourse

("I'll get back to you about it early next week") as task junctures are constructed, at other junctures they are less explicit. In most cases such expectations are generally clear. At task junctures, team members and observers could usually anticipate the time (with varying degrees of heterochronic precision) when interactive work on a given task would likely resume (and often other details about what would likely happen when work did resume).

Little is known about how ongoing work group action is organized so that multiple ongoing tasks can be smoothly interrupted, suspended, later resumed, and eventually completed amidst a patchwork of other ongoing, yet intermittent tasks. Nor do we have a clear picture of the intricacies of a group "working on several things at once," even though it appears to happen frequently and may often be the norm for group (if not individual) work. Core features of the "style" of a work group's activity are carried in part by the macroscopic features of its activity patterns in time and space which enable it to deal effectively with the diversity of tasks it must carry out collectively. A work group needs flexibility not only with regard to how particular tasks may be accomplished, but also with regard to how a (changing) *mix* of multiple ongoing tasks, proceeding at different speeds and with varying priorities, can effectively be accomplished. This has been seen in both the micro- and macroscopic studies of work. Ethnomethodological investigations, such as Suchman's (in press) study of ground traffic controllers, Christian and Luff's (1991) study of underground train controllers, and Lynch's (1991) study of laboratory scientists, have revealed the management of such complexity in selected strips of behavior within microscopically observed attention shifting and focusing processes in shared workspaces and tasks. In our shadowing studies, teams of product development engineers, business executives, and schoolteachers exhibit characteristic and stable macroscopic patterns of collaboration, coordination, and communication as they shift among numerous ongoing tasks within constraints of available time, space, and communicative resources.

The polycontextual and heterochronic character of workplace activity appears to be a widespread feature of human activity and to have considerable historical and cultural depth within the behaviors we observed in workplaces. Barker and Wright's analysis of specimen descriptions of children's behavior characterizes the structure of their behavior in much the same polycontextual, heterochronic terms: "Behavior was more often like the interwoven strands of a cord than a row of blocks . . . overlapping episodes often did not terminate at the same time but formed an interwoven merging continuum" (1954, p. 464).

An anecdote from the product engineering teams casts further light on the pervasive cultural and historical embedding of polycontextuality in workplace activity. These teams relied heavily on the Unix multitasking operating system not only as a platform for developing and delivering the software components of products, but also as a medium of team communication and project information exchange. Electronic communication, automated bug reporting and tracking, software code exchanging, debugging, and product testing activities were all highly mediated by the network and operating system. On several occasions, a team member would arrive at another's work area, announcing his or her arrival and desire for attention with an episode-opening utterance: "push," a computer science term for suspending one task (by "pushing" it onto the top of a stack) in order to service another. When the visitor was ready to depart, the metaphor would continue as the visited person closed the episode by saying "pop" (thereby popping the interrupted task back off the stack and reactivating it). This exchange at first struck me as only another, albeit a quaint, usage of systems terminology to describe human interactions (as in "I'd like your *input* on that"). However, this particular push-and-pop usage may reflect the converse phenomenon, that is, the appropriation of ubiquitous features of human action into the design of computer systems. The notions of jobs being *interrupted*, of having too many jobs *stacked up*, and so on, appear to be deeply embedded descriptors of human workplace activity that have been appropriated into systems models and terminology.

It is essential that the polycontextual and heterochronic nature of work group activity be understood as a creative resource for the construction of work group behavior. For many readers all too familiar with the fragmentation and local inefficiencies of contemporary work life—the constant interruptions, meetings, and contending activities—it may be tempting to overlook the potentialities and contributions of the polycontextual, heterochronic fabric. This fabric, with its junctures and disjunctures over space, time, and participants, constitutes a medium through which work groups actually can work on multiple activities at once, and through which relationships among component tasks are continually negotiated and maintained.

The polycontextual and heterochronic texture of workplace activity is thus an important part of the environment in which group work itself is conducted. Although individuals' work is shaped by and shapes this pattern, we are not yet well tooled up to see details of the figural phenomena of group activity in sharp relief against this grainy, textured background. Important aspects of activity—including decision-making, learning, and planning—are difficult to locate behaviorally *in situ*, not only because of their emergent and contingent nature (Suchman, 1987; Lave, 1988), but also because they take place heterochronically. To understand heterochronic phenomena better, we need to develop appropriate research methodologies and observational technologies.

Just as time-lapse photography enables us to better apprehend the growth of living things, new behavioral lenses may be required to appreciate the unfolding of team work against a polycontextual and heterochronic background. We have tried shadowing the behavior of the individual members of a team as they conduct their group's work. This technique has helped us to follow the unfolding and carrying out of complex team tasks over time and space. But we need to develop even better techniques for *shadowing activity* itself. Without those special lenses, we may remain mystified as we try to watch flowers grow.

Note

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Shadows in the Soup: Conceptions of Work and the Nature of Evidence

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In this essay I examine some conceptions of work that reveal ways of looking at workers and their capabilities. I argue that conceptions of work have specific impacts upon workers and the workplace, which include the following: (1) *how jobs are designed*, and (2) *how technologies are designed.* Job design addresses such issues as whether a job to be performed requires expertise, and whether workers will be supported in their efforts to acquire such expertise. Technology design addresses such issues as what knowledge is, where it should reside (in people or technology), and what role people should play in its organization (as monitors of technology or as knowledgeable creators and analyzers of information).

These questions have become increasingly important in the last several years as global competition and swiftly changing products have led companies to reduce the size of their workforces and increase automation in order to become more competitive. The assumptions about work that underlie the decisions managers make as they automate and "re-engineer" companies are particularly significant since some of the consequences of reforging workplaces have included automation and job redefinition. In this essay I analyze a typical organizational artifact commonly construed as evidence about the nature of work within the organization. I then take a look at another sort of evidence, collected through "shadowing," which provides an alternative conception of work and an alternative view of workers' capabilities. These different conceptions of work have competing implications for job design and technology design.

Conceptions of Work

The analysis of work is an enterprise that has been undertaken in a number of different disciplines. I focus here on two distinct approaches which I dub a "functional business view" and a "work practices view" (see Figure 1). These two perspectives have developed within differ-

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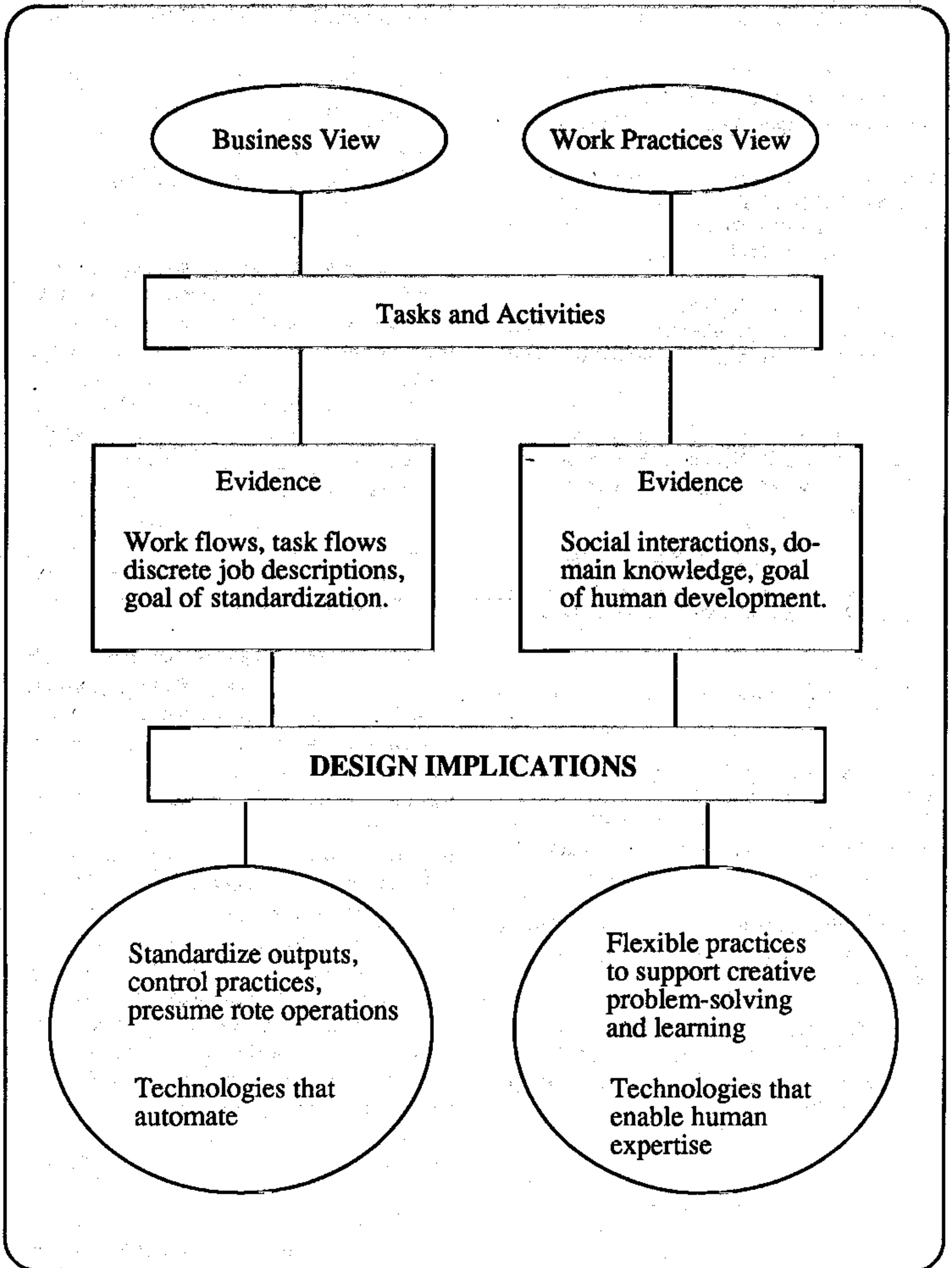

Figure 1: Map of conceptions of work and the nature of evidence.

ent intellectual traditions and have not significantly shared their perspectives with each other. Business views have grown over the course of the century based within the professions of economics and management science. Work practice views have emerged during the last century within the fields of anthropology, activity theory, and developmental psychology. Although these approaches are rooted in different disciplinary worlds, they overlap in their mutual interest in the nature of work, technology, expertise, and social organization.

The analysis of work is central to each of these enterprises, but each undertakes its analysis for different purposes. Business people focus on work flows and work processes as indicators of how business functions can be achieved. Work practice researchers focus on problem-solving practices, communities of practice, and social interactions to assess the nature of social organization and reasoning in the real-world contexts of how work actually gets done. Both business people and work practice researchers employ exactly the same terms—"tasks" and "activities"—in their analyses of work, and each uses these terms interchangeably. The meanings of these terms differ for each perspective, however, because their conceptions of work are based in different histories, arenas of interest, and goals for affecting the roles people and technologies play in society. Figure 1 illustrates this point.

In 1911 Frederick Winslow Taylor developed an approach to reorganizing workplaces he called "scientific management."[1] Under the principles of scientific management, work became segmented into small chunks, each of which was performed by a separate worker, whose speed, timing, and physical motions were defined by a manager. One of the first instances of this form of work design was Henry Ford's assembly plant, in which the social design (the division of labor, the use of people in machine-like fashion, the assumptions about the role of human thought) and technological design (the machinery as extended muscle) were explicitly intertwined. A key feature of Taylorism was the distinction between "mental" and "manual" labor. Mental labor, performed by engineers and managers, involved figuring out the most efficient way to do a job. Manual work, performed by laborers, involved carrying out the work according to the steps defined by management.[2] Mechanization moved human labor into machines. These features of work—efficiency through work steps and mechanization, mental managerial work, and manual labor—are clearly still present in workplaces and in rational analyses of work.[3] Today's updated version of these ideas include technologies designed not only to extend muscle, but mind, through information technologies that aim to put knowledge into the machine.

I retrace this brief history, no doubt familiar to many readers, to point out that unquestioned and unambiguous notions about work—efficiency and tasks—are in fact theoretically-generated concepts so well-worn they now appear as *common sense*.[4] Improving efficiency at work is the most widely-used rationale employed by companies when they decide, for example, to automate jobs.

Automation is often extraordinarily successful. Yet technologies do not always work the way they were intended. This is frequently explained as the failure of workers to carry out their tasks in the prescribed fashion.[5] This sort of explanation presumes that the workers have little or no understanding of what their work is about, or what indeed may be causing a failure. Studies of work practices reveal that the "workarounds" of workers, devised on-the-spot, are innovative forms of integrating the technology into the work world by tapping social interactions and local knowledge, effectively greasing the wheels of the organization so that the work can indeed "flow."

One of the artifacts of Taylorism in workplaces today is the notion that work can be adequately described in terms of tasks or activities that can be routinely performed. The concept of a task or activity in industrial settings connotes a simplified segment of work that takes little or no thought to perform. This conception of a task or activity differs sharply from the conception held by work practice researchers, for whom tasks and activities are units of analysis in which the skills and knowledge used in complex reasoning and problem-solving are clearly displayed. These different perspectives toward the same phenomenon produce different insights into what goes on at work.

An Artifact about Work from the Business World

Following is a representation developed by a consulting company to help managers understand the work process in sufficient detail to increase efficiency and improve performance at work (see Figure 2, next page).

Note that the most detailed level of analysis in this diagram is called "performer/job level," which defines workers in terms of a position ("a job"). The work process (designated by a set of linked boxes in a linear flow diagram) implies that process exists outside of any intervention or action by humans. People carry out the process, but they are not viewed as creating or producing the

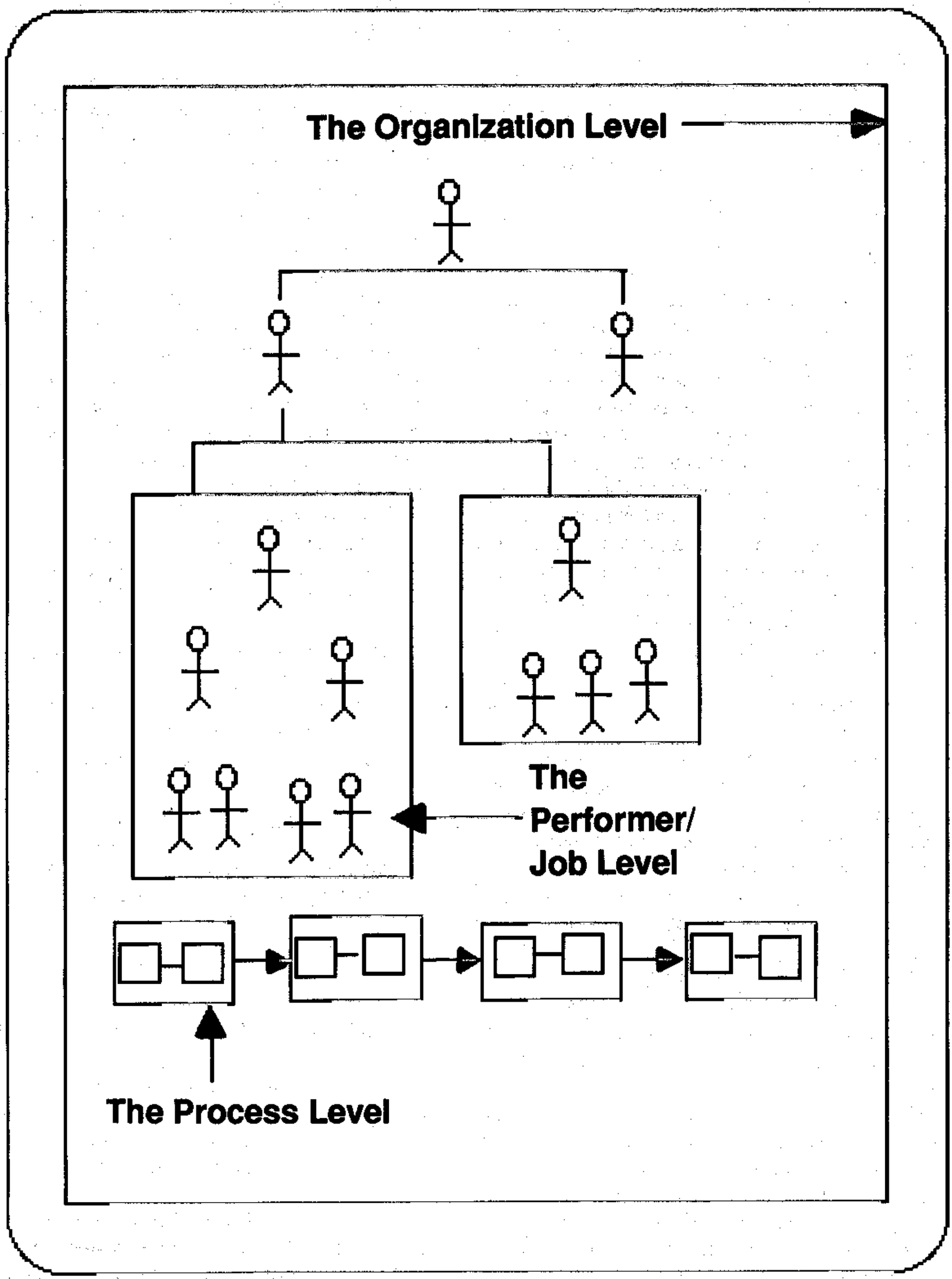

Figure 2: Three levels of performance. From Geary A. Rummler & Alan P.Brache (1991, Jossey-Bass). *Improving Performance: How to Manage the White Space on the Organizational Chart.*

process. Their role is to perform mechanistically rather than to reflect, discern, or discover. This distinction lies at the heart of the difference between business and work practice orientations toward work.[6]

People are hardly ignored in companies, I hasten to point out. The way they are thought about, however, tends to be in terms of their emotional rather than intellectual selves. Progressive managers put considerable time and energy into rallying workers, developing reward systems, and keeping enthusiasm up so that work will get done. Less progressive managers focus on controlling tasks, breaks, and conversations to achieve high volume productivity. In short, whether from a progressive perspective or not, the dominant view of the role people play in the performance of work is based on conceptualizing people as emotional beings whose path needs to be plowed, not as intelligent problem-solvers who help run the business.

Shadowing: Data about Work Practices

I provide a brief description of a detailed technique Sylvia Scribner and I developed in 1986 to gather fine-grained data. Our goal in capturing these data was to understand the issues, conversations, and activities that took place when one learner trained another in an effort to document intelligence in the course of everyday work. I then present some "raw" transcripts from our data.[7]

What is Shadowing?

Shadowing is a set of methods oriented toward collecting data about on-the-ground phenomena over some period of time (one or several days, several weeks, or months). Shadowing is most generally marked by an observer who tails after a worker or set of workers for a specified period of time, or through a specified series of events.

There are no absolute rules that govern this form of data collection. Rather, various techniques produce data of different granularity, each of which provides some insight into how workers (or participants in activity systems) perform their work in some specific context. Reder & Schwab, for example, developed a notational tool to aid an observer in capturing phenomena they designated "events" and "activities." This approach, less fine-grained than the one Sylvia and I developed, is extremely useful for getting a feel for how events and actions intertwine. Their method makes it easier to get a strong and grounded understanding of the way in which events flow, intertwine, disappear and reappear, and how these fit into the mixed activity systems existing at work. By contrast, our approach captured the way in which detailed conversations, actions, and activities intertwined, sometimes revealing that physical action was wholly dissociated from verbal communication, revealing how people are engaged in multiple and simultaneous activity streams. It was much harder for us to quickly capture primary events, whereas it was harder for Reder and Schwab to capture conversational subtleties. This only serves to point out that each technique has its own strength, and if used in combination, greatly enhances the data collected.

It is important to add that both these techniques provide insight on how individuals' activities are embedded in, and construct, communities of practice. The great advantage of shadowing is that at whatever level of detail it is carried out, it reveals through a combination of elicited, observed, and documentary data how participants sort through problems and become engaged in situations both on their own, and as part of a community.

I wish to emphasize that shadowing is best undertaken after spending time at a field site and gaining the confidence of participants there. We did not do any shadowing until we had spent several months in the plant, and then several full days in the stockroom where I ultimately shadowed workers, learning about the work and developing a relationship with the workers, union, and management. This more general ethnographic work is necessary for two reasons: first, horning in on the everyday work of people is basically a nervy thing to do; and it requires sensitivity at both personal and political levels. Second, interpreting data is an act that requires deep understanding of context. As the transcript below should illustrate, making sense of events that unfold both predictably and serendipitously can only be done by spending time in a place, and getting to know how it functions.

Our technique. We shadowed teams of workers for a period of several days, then over the course of several weeks. We affixed a small tape recorder to one worker and put a lapel microphone on him[8] as well, placing the recorder in a "fanny-pak," so the worker could keep his hands free in what was highly mobile and physical work. I wore a second recorder (same rig), and taped comments to capture what a video might record.[9] The workers' talk was highly deictic, so my commentary talk would define and contextualize what the workers said (for example: "when Joe says 'put this there,' 'this' refers to the bin of parts xx-11-22, and 'there' refers to the large scale in the receiving section of the stockroom.") We transcribed the worker tape as our "base" tape, and then created a "com posite transcript" by adding the commentary talk onto the same page as the worker talk. This was a very labor-intensive process, since we shadowed several workers over several days, creating a corpus of over 100 90-minute tapes. This form of shadowing permitted us to analyze the data in great detail.[10]

The following segment of transcript took place in the stockroom of an electronics plant. In it, I spent time with Joey, a stockroom worker working alone, so I used only one tape recorder. As Eddie, Joey's supervisor, became involved in the episode, I confronted the typical problems involved in shadowing (who do you follow around when they go separate ways? When do you intervene with a question?) which I resolved by sticking with the person manipulating multiple documentary systems, rather than the person physically moving materials, and by probing with questions to clarify their actions. I attempted to keep most of my side of the conversation non-directive ("umm, uh huh"), but there were times when it was imperative for me to intervene and ask some questions in order to make sense of what was going on. Not only did I need to understand the events myself, but I wanted the tape to capture the workers' own explanations of why they were doing what they were doing to get an idea of how they categorized the chunks of work themselves—evidence impossible to capture on the fly. I could use these detailed data to analyze the specific resources (computer screens, other workers, handwritten documentation systems, etc.) the workers utilized in solving their problem. At the time I recorded this particular episode, I had been doing research in the stockroom for one year, and had shadowed four teams of workers from two to four days, four to eight hours a day. This is important to know, because understanding what workers do in a highly detailed manner requires sufficient technical knowledge on the part of the observer so that she can analyze the situation later. It becomes clear in this episode that researchers must have copies of all documents (including printouts of screens as well as handwritten and computer-generated documents) in order to understand exactly what is going on. Those documents are not included in this essay.

The data. The full transcript from which this segment is taken is 44 single-spaced pages and captures a problem-solving episode that took 2.5 hours to unfold. In this episode, Joey and Eddie decided to double-check an order and discovered discrepancies they chose to resolve. The conversation begins as Joey completes an order.

Joey: Oh, seven, three, two hundred. It jibe, I just sign it in. Write my name and today's date. And I'm finished.

Eddie: Joe, on that . . . on those ones that we didn't have no stock, did you verify it? Being it's a hot issue it's supposed to be for Ladd [the president of the company], did you verify it on the tube—

Joey: On the tube?

Eddie: —to see that we had no stock?

Joey: No, I didn't.

Eddie: That's all right, let's do it, just—

Joey: I'm sorry, I should have did that since-

Eddie: No, that's all right.

Joey: —it was a hot order, you're right.

Eddie: I know, you ran right through it, I—

Joey: Right.

Eddie: —now, let me just make sure because I don't want this order to go up—

Joey: The(?) one part—

Eddie: —and them tell me, you know, that we have parts.

Joey: All right.

Eddie: You know, that's the only thing.

Pat: Eddie is checking to verify no stock, so he's take—taken this picklist right now and is going over to the computer and has pulled up the screen, item master file. What did you just hit, enter?

Eddie: Yeah, because I want to get to the item balance, that'll tell me whether I have stock or not.

Pat: Uh-huh.

Eddie: Which I hope I don't because if he's got zero there—two ninety-five, this better jibe.

Pat: So, Eddie—Eddie types in 1 dash—

Joey: You should have brought your glasses

Eddie: 1 dash 46 52. Yeah, I'm getting very, very careless that way.

Joey: There's one M99.

Eddie: This I can see. C'mon baby be right, three thirty-eight.

Joey: Three thirty-eight, right.

Eddie: You got two ninety-eight, two ninety-five.

Joey: That's the first?

Eddie: Yeah, see.

Joey: It said three thirty-eight but when I recount it-

Eddie: Recount it, terrific, okay.

Joey: —I got two ninety-five.

Eddie: I want that so I can adjust it.

Joey: I ... I put it in the bin, yes.

Eddie: Good, leave it on my desk, Joe. Let's see—you got the other one?

Joey: Yeah, I got b—I brought both bin cards.

Eddie: Very good, thank you, makes it much easier.

Joey: Hold on, here you go, I'll help you, one-

Eddie: Heh, shit, twenty-seven ninety-two dash one.

Joey: Twenty-seven ninety-two.

Pat: Now, Joey is typing this in for Eddie.

Joey: Dash one.

Eddie: AA.

Joey: M, A, A?

Eddie: Yeah, that's the code. I know ninety-nine would have zero on that one, thank-you. Nine fifty-five?

Pat: It shows up as nine hundred and fifty-five on hand, with three eighty-eight allocated is what it says on the screen. This is item balance detail all warehouses. Joey is now looking at the bin card.

What did they say? In this conversation Joey and Eddie checked the number of parts the computer reported as being "available," against the number of parts they actually counted. Since they found a discrepancy, they examined different screens (views) in the computer and various part identification numbers to see if the parts were either misplaced or incorrectly recorded. They were motivated to do this since the order was "hot" (urgent), and had been requested by the president of the company. They discovered the computer record didn't match the actual stock, so the transcript captures their conversation as they try to track down the discrepancies.

To accomplish this goal, Joey and Eddie had to identify discrepancies in multiple documentation systems, know the meaning of codes ("AA, 99") and relate them to the movement of parts in production, know how the computer handled and manipulated those codes, and compare the computer record to their knowledge of actual production processes, in order to (1) know there was a problem, (2) uncover what it really was, and (3) resolve it. These activities included understanding a number of elements in their work environment, and collaboratively making sense of them through conversation and testing of hypotheses using several resources.

If Joey and Eddie hadn't decided to double-check this order there would have been significant errors in the computer database that would have led co-workers in the planning department to order the wrong number of parts for future orders. That job - deciding what parts to order - is one that the computer system is designed to support by recommending how many parts a planner should order. Without human intervention in the workings of both the computer and the production process, the computer system would have made poor recommendations. This is an instance in which technology design has located "knowledge" in the computer, and job design, in which people are expected to do what are assumed to be physical, rote tasks.

There are several observations to make about these data and issues that are undoubtedly difficult to understand. It is, like all work, marked by technical occupational languages that refer to a specific technical, materialese when using a shadowing technique. This conversation is one example of an organizational world that is initially impenetrable to outsiders.[11]

The transcript here reveals a conversation with ideas thrown about to solve a problem. It does not look like a clean set of tasks to be carried out in automatic performance. That version of this job looks like this:

> A Material Handler [a stockroom worker] counts, moves, or otherwise handles materials, loads and unloads trucks, and performs various other simple duties as directed. Counts and packs parts or products in cartons, cases or other containers. Checks against packing lists for inclusion of all component parts or completed units, applies special labels or stencils where necessary, and performs other duties assigned by the supervisor.[12]

This description emphasizes the physical aspects of the job, and is officially listed as an unskilled job. Even though it is difficult to understand the details of the transcript, it is evident from it that the activities the workers engaged in (discussing problems, discovering problems, utilizing computer and other resources to find the cause of the problem and fix it, etc.) all point to workers needing to *understand* numerous elements in their work environment and interpret them.

Shadowing as a technique can capture this quality of interactions and behavior, coming up with a very different impression of "the work" from that conveyed in the official job description.

Discussion

Data that support the business view toward work can convey the message that work can be easily segmented and automatically performed. Data from the work practice view often convey the opposite message. Business people need overviews of the work in their organizations so they can run their companies effectively. A drawback of the abstracted, task-oriented perspective they ordinarily employ, however, is that it suggests work can be best carried out by simplifying it, specifying it in detail, and controlling it. Evidence based on actual interactions and troubleshooting of a job considered to be low-level and unskilled suggests that more intellectual activity than one might expect actually goes on in the process of "counting and moving parts."

Jobs conceived of as very simple and well specified are often designed for the perpetual novice: one who doesn't need to learn since the operations are laid out clearly. Evidence presented here suggests that such a job design may not be in the best interests of a company or the workers, all of whom would profit from understanding that the complex of details in the work environment are resources for troubleshooting, and which are gained on-the-job. An alternative design would be to assume workers should learn so that they can competently, if not expertly, handle troubles, exercising judgment as necessary rather than automatically going through prescribed motions.

Data collected through shadowing techniques reveal that even routine jobs require thoughtful intervention by workers. Designing jobs and technologies to support the exercise of practical intelligence would fundamentally respect what people have to offer, and provide an environment to fruitfully engage their minds.

Notes

[1] Frederick W. Taylor, *Principles of Scientific Management*, 1911, New York: Harper & Brothers Publishers.

[2] There exists a voluminous literature on the history of work and the role Taylor played in it. A readable history can be found in Marvin Weisbord's *Productive Workplaces.*

[3] There has been considerable energy devoted to moving away from Taylorism for a number of years, and practices such as "team-building" and"worker empowerment" are two such efforts. However, the fundamental structure of the mental and manual division of labor forms the essential skeleton of business today. Cartesian duality also primes much of our thinking on this. Wertsch, has an excellent discussion in "The Voice of Rationality," as does Scribner in "Studying Working Intelligence.

[4] See Geertz, "Common Sense as a Cultural System" in *Loal Knowledge: Further Essays in Interpretative Anthropology.*

[5] This explanation abounds in the technical literature of manufacturing, for example, which explains failures of technological systems as a failure to successfully "change the culture" of a company.

[6] Orr (1990) has analyzed how documentation such as "M&Ps" do not meet the needs of workers out in the field, pointing out that

the kinds of problems which emerge tend to be subtle and undocumented. That is, problems and situations arise in the normal course of everyday work that present new challenges for workers, which they need to figure out themselves.

[7] The research in the electronics plant was supported by the Office of Educational Research and Improvement (OERI) Grant number G008690008.

[8] The vast majority of workers in our study were male.

[9] It was not possible to videotape in this setting due to low light, and multiple aisles in and out of which workers continually traveled.

[10] "Thinking Through Technology" forthcoming, *Information Technology and People,* is an analysis based on some of this corpus.

[11] Researchers in workplaces must learn the language, the technology, and the production system in order to even engage in a conversation with workers, not to mention to be able to analyze their work.

[12] Documents collected in an electronics plant, Grade 2 job description, cited in Scribner & Sachs, (1990), *A Study of On-the-Job Training (pg. 13).* NCEE. NY: Columbia University.

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To Capture a Process: Hierarchical-Sequential Representations of a Computer-Based Activity

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It is relatively easy today to capture on-going human activity using the technologies of video and audio recordings and computer programs that track such things as keystrokes and system responses. The difficulty is transforming what is recorded into a meaningful, comprehensible form, whether it be verbal descriptions or symbolic and graphic representations. In this paper, I will describe the representations that I have developed and the perspective on goal-directed action that they afford. I will begin by tracing the lineage of these representations and, in doing so, provide a framework for an explanation of the approach I have taken. To illustrate the way in which the representations that I have developed work, I will refer to a study that I conducted with young students learning to program in the LOGO computer language. I will then make suggestions about how this approach might be extended to analyze collaborative work.

The Lineage

The representations that I have developed are a synthesis of two different approaches to representing

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process, that of Newell and Simon and that of Barker and Wright. Newell and Simon's *Human Problem Solving*, published in 1972, became one of the most influential works in the history of cognitive psychology, and its methods became the basis for many further studies of complex human performance. More than a decade earlier, Barker and Wright (1955) published *Midwest and its Children*, the results of a long-term study of the daily life of children in a small town. It was a landmark work as well, in this case in ecological psychology, but its methods were not widely employed outside of child studies. Although these two approaches were employed in different contexts and for very different purposes and had quite different fates, they have conceptually much in common. The two approaches can best be compared and contrasted by focusing in each on the manifestations of human activity that are recorded, the model that is applied to identify the significant elements in the records, and the representations of the process that make those elements salient. It is my contention that by focusing on the commonalities and synthesizing elements from each of these approaches, representations can be developed that capture aspects of on-going human activity that neither of these approaches alone would reveal.

In their studies of problem solving, Newell and Simon (1972) employed the method of *protocol analysis*, which involves recording the subject's verbalizations during performance of tasks and encoding the transcript in terms of a vocabulary of objects and relations defined for the task (Ericsson & Simon, 1984). In this approach, problem solving is conceived of as goal-directed search in problem spaces associated with a task (see also Newell, 1980). These problem spaces are symbolic structures consisting of states and operators that transform one state into another. The representations that are developed are called *problem behavior graphs* and take the form of flow diagrams in which the nodes in the graphs represent states of the problem space. The application of an operator to a state to produce another state is represented by a link between the states. To make these representations meaningful and abstract from all their detail, they can be segmented into episodes, "each of which is a succinctly describable segment of behavior associated with attaining a goal" (p. 84). These episodes are structured as simple sequences of steps or nested hierarchies. Figure 1 (opposite) shows an abstract problem behavior graph with circles representing states, lines between circles representing the application of operators, and brackets representing episodes.

Barker and Wright (1955) used the method of *specimen description*, which requires a trained observer to make detailed written descriptions of the activity of a subject. Their analyses of children's behavior employ Lewin's (1938) concept of action as intentional movement in a psychological space; actions are seen in the context of the relationship of the actor's intentions and the situations in which they evolve. Representations of the structure and dynamics of subjects' activities are developed by segmenting these specimen descriptions into episodes, which, although described in much the same terms as Newell and Simon use, have notably different characteristics.

According to Barker and Wright, an episode has three characteristics: It has a constant direction towards a goal, it occurs within the normal behavioral perspective of both observer and actor, and it has equal potency throughout its course. The concept of potency comes from Lewin (1938) and has to do with the continuity of behavior. A continuous segment of behavior can be seen as a whole and as having parts. In terms of the dynamics of the behavior or the view we have of it, the whole or the part may have relative weights or importance at any point in time. When I am walking to the local store, a conversation on the way with a neighbor may assume equal or even more importance than my progress towards the store. The activity of speaking to my neighbor may accordingly constitute a distinguishable episode, although still contained within the larger episode of going to the store provided my overall direction towards that goal is maintained. Episodes, conceived of in these terms, are not simple nested hierarchies, but have a variety of structural characteristics (see Figure 2, page 136); they are heterarchical rather than hierarchical, meaning that a given action can be assigned to different episodes without subordination of the one episode to the other (Broadbent, 1985).

Clearly these two approaches have much in common. In both, activity is painstakingly recorded, the models are based on the metaphor of movement in spaces, and the structure of activity is represented in terms of goal-directed episodes. In Newell and Simon's approach, the focus is on states of the problem space and the operators that change one state into another. In Barker and Wright's approach, the focus is on the structure of the directional continuities that are found in the activity. The approach that I have adopted for the analysis of computer programming draws elements from both of these approaches, but combines them in novel ways. Rather than recording

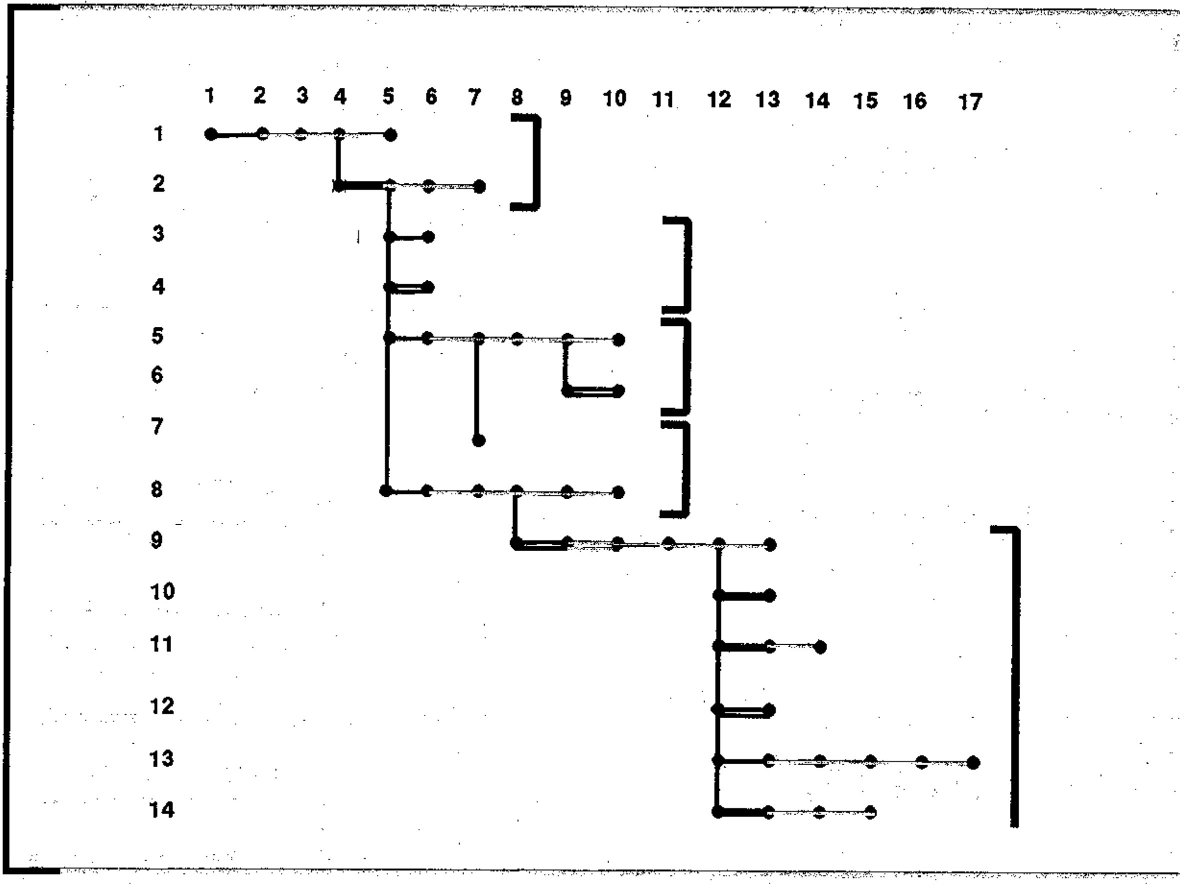

Figure 1: Problem behavior graph. Note: This is adapated from Newell and Simon (1972, pp. 171, 181). Circular nodes represent states and horizontal lines to the right represent operators applied to states. Double lines represent the repeated application of an operator to a state. Vertical lines between nodes indicate a return to a state. Time runs to the right, then down.

subjects' verbalizations or relying on verbal descriptions of their behavior, the interactions of the subject and the computer are recorded by the computer itself. The model it employs sees problem solving as goal-directed search in problem spaces, and automated encoding provides concrete references in the record for the states and operators of the problem spaces. This use of automated techniques avoids much of the tedium and costs associated with protocol analysis and specimen description and lowers the level of interpretation required to develop the representations. The representations that are developed identify the states and operators, provide descriptions of the actions in terms of their functions in creating a computer program, display the structural dynamics of the activity in heterarchical episodes, and form the basis for an analysis of goal-directed behavior in the programming environment.

The Representations of the Programming Process

The nine students in the study (ages 10 to 14) were trained to program in LOGO over 15 weeks and given three programming tasks at intervals to test their progress. The first task required them to develop a graphics program to draw a house and playhouse, for the second task they had to develop an interactive "High-Low" game to guess numbers, and the third task was to develop an interactive "Hangman" game with graphics. Their performance on these three programming tasks was the focus of the study. I developed software tools to automate the recording of the students' interactions with the computer and to assist in the analysis of these records. The objective was to construct representations of the programming process that could be analyzed to reveal the problem solving strategies that the students used. The specifics of the strategy

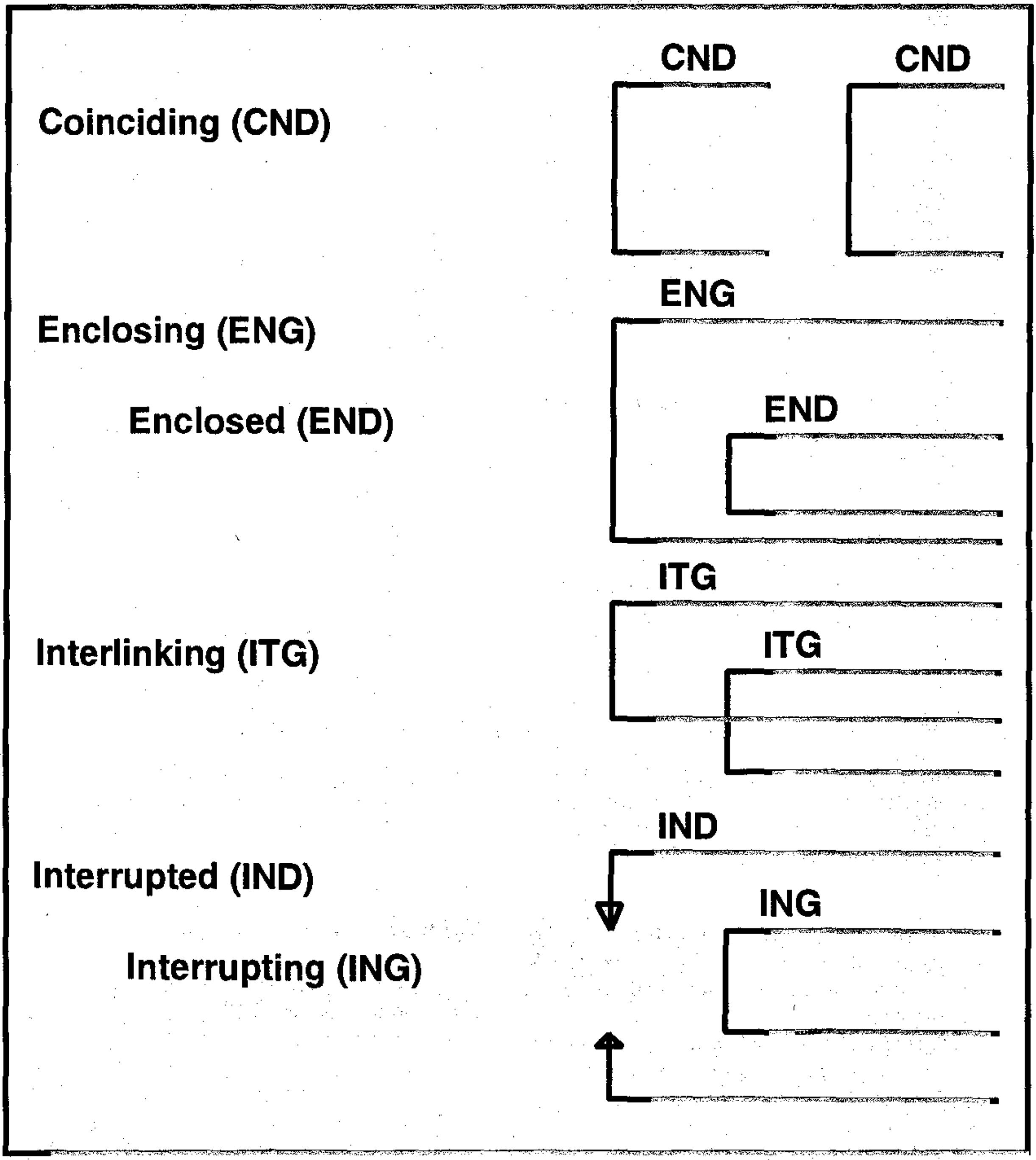

Figure 2: Episodal structures. Note: This is adapted from Barker and Wright (1955, p. 261). Coinciding episodes occur when different episodes intersect from beginning to end. Enclosing and enclosed episodes occur when a part of an episode intersects with the whole of another. The longer episode is the enclosing episode, the shorter the enclosed. Interlinking episodes occur when one part of an episode intersects with part of another. Interrupting episodes occur when an episode occurs in the context of another episode but has a different direction. Isolated episodes (not illustrated) occur when an episode occurs alone.

analysis have been detailed elsewhere (McAllister, 1993); the focus here will be on the representations themselves and what they reveal about goal-directed action within the LOGO task environment.

The elements of the representations are the states of the problem spaces, the operators that change those states, the functions of those operators in the evolution of the program, and the episodes that partition the process. Each of these elements will be explained and grounded in an analysis of the LOGO task environment and a model of goal-directed action within it.

Programming in LOGO involves writing procedures and can be conceptualized as taking place as a search in two basic problem spaces, a primary problem space (the "procedural space") in which procedures are developed, and a secondary space (the "trial space") in which experimentation, testing, and debugging take place. Search in these two spaces involves going back and forth between them; experimenting with instructions in the trial space and using the knowledge obtained to construct procedures in the procedural space; and constructing procedures, trying them out, and using the feedback that the computer gives to modify the procedures.

According to the model developed for this study, the search through these two problem spaces is a cyclical one in which the programmer begins by representing the problem based on the task instructions and establishes an agenda of goals. In this cycle, a comparison is made between the state of the problem and the programmer's goals, goals for fulfilling them are selected, and operators are implemented as actions on the system. These actions bring about changes in the system that, in turn, provide feedback to the programmer, and the cycle begins again with a comparison between the programmer's goals and the programmer's updated representation of the problem. Throughout this process, knowledge is being both developed and deployed, deployed when methods for achieving goals are retrieved and used, and developed when feedback from the system is used to obtain information for achieving goals.

In the IBM LOGO used in the study, these two problem spaces are clearly delineated. Procedures are developed in either a define mode (line-by-line) or edit mode (full-screen), and instructions are carried out in an immediate mode. The recording program developed for this study takes snapshots of the define and edit mode when they are exited and of the immediate mode each time a complete line of instructions is invoked. These snapshots are taken to represent states of the two problem spaces. I took the operators in these two spaces to be the manipulations of LOGO instructions that change states from one snapshot to the next. In the procedural space, states are changed by virtue of defining procedures and appending, inserting, and deleting instructional units. In the trial space, states are changed by invoking instructions. Another program that I developed generates a record of the states of the problem spaces and identifies the types of operators used to change the states of the problem spaces.

Since the purpose of programming is to create a program, the function of a set of operators in this environment is that the operators are intended to contribute to the construction of the program. For instance, when a programmer appends a set of instructions that draws a triangle for the roof of a house, the function of the operator is identified as drawing a roof. These functions are not isolated but related to a hierarchy of functions at various levels. For instance, in the above example, the superordinate function of drawing the triangle is drawing the house. These functions are presumed to reflect the programmer's goals: When a programmer appends instructions to draw a triangle to draw a roof, it can be assumed that drawing a roof was the programmer's goal and that this goal was a subgoal of the goal of drawing a house. This identification of task-specific goals provides the basis for the analysis of the programmer's goal-directed behavior.

I developed another set of software tools to generate a functional record that is the basis for the creation of a problem behavior graph. To create this functional record, operators are grouped according to their functions, the superordinate functions are identified for these functions, and then a hierarchically structured functional record is generated. These functional records are roughly equivalent to Barker and Wright's specimen descriptions, but in this case they are written in a language that specifies the functions of the actions taken by the programmer in terms of the on-going construction of the program. Using Barker and Wright's concept of an episode, the problem behavior graph is created by episoding this functional record.

The grouping of operators, the assignment of functions to operators, and the episoding are interpretive tasks performed by the analyst. These tasks require knowledge of the LOGO language and the effects of instructions in the language, as well as an understanding of the role of the operators in developing the program. However, unlike approaches that deal with subjects' verbalizations or observers' verbal descriptions, in this approach the interpretation is clearly anchored in reproducible actions that occur in the task environment and in artifacts produced through those actions.

Figure 3 (next page) illustrates all the elements of the representation. It shows the initial segment of a programming session in which a student was working on drawing a house. On the left, the states of the procedural space are represented, and on the right, the states of the trial space are represented. In the middle is the problem behavior graph itself. The operators are represented as are the functions, and the indentations show the hierarchical relations between the functions. The episode brackets on the left of the middle panel show the sequential structure of the actions. The major episode represented in the graph has as its goal drawing a square with a roof, and the three episodes it encloses have as their goals drawing the square, drawing the roof, and integrating the two components; this latter episode encloses three interlinked sequences in each of which the program is tested, a modification is made to the program, and the procedure is tested again. These feedback cycles, involving shifts from one space to another, constitute significant junctures in the programming process and provide useful clues for the limits of many episodes. Figure 4 (see page 140) is an episode abstract of the entire session for the same student and exemplifies the prominence of these interlinked feedback episodes in the records.

The two kinds of structures exhibited in these graphs, the functional structure and the episodal structure, are distinct, yet closely related ways of looking at goal-directed action in this task environment. The functional structure is a map of the programmer's task-specific goal commitments and their relationships at a given point in the process. The episodal structures link actions over spans of time that have unity of direction in terms of the goals that they are intended to achieve. In the representation of the process, the functional structure captures the static and hierarchical quality of the programmer's goals, whereas the episodal structure captures the dynamic and sequential quality of the movement towards the achievement of those goals.

The Perspective on Goal-Directed Action

Much of the literature on problem solving suggests that the goals that direct action are unitary and well-articulated and are stacked or otherwise organized in a hierarchical fashion to ensure that action is under the control of one particular goal until the goal is attained or abandoned (Broadbent, 1985). However, inspection of these problem behavior graphs suggests a somewhat different view: that the goals that direct action vary in their complexity, that they are not always clearly articulated, and that they evolve and are constructed in the process of problem solving.

While cycles of goal-setting, action, and feedback in which a single, low-level goal controls action are found in these records, it is far more common, especially in the later tasks, to have a sequence in which the goals controlling action are more complex. For instance, a programmer might construct a number of components of the program and then test it; in this case, the goals directing action within the cycle are complex and, in terms of the functional hierarchy, their unity would be at a very high level. Another example would be of a cycle in which a test of a program reveals a variety of bugs at different points in the program and an attempt is made to repair the bugs, and then the program is tested again. In this case, the actions within the feedback cycle may have a common direction in terms of the dynamics of the process (e.g., repair of flow of control problems), but they would exhibit great complexity in terms of the immediate functions they serve in the construction of the program.

Since the specifications for the programs in the tasks studied are sufficiently open-ended that they can be fulfilled in a variety of ways, the goals with which the programmer starts are not necessarily the goals that end up being achieved. Goals are likely to change as obstacles and opportunities present themselves along the search path. In other words, the search process is not merely a process in which goals are set, acted upon, and evaluated, but a process in which goals themselves are constructed and articulated. And the LOGO task environment supports and facilitates this formation of goals. The LOGO editor provides an external memory device that supports the programmer's representation of the program by allowing review of the procedures at any point in the development of the program, and feedback from invoked procedures supports the evolution of goals by concretizing them and providing a basis for their further modification and articulation. In short, action within the task environment supports the formation of goals.

Thus, goals are not static but undergo formation and articulation through action and the feedback received as part of the search cycle. The picture of the process that emerges is of dynamically evolving networks of goals at

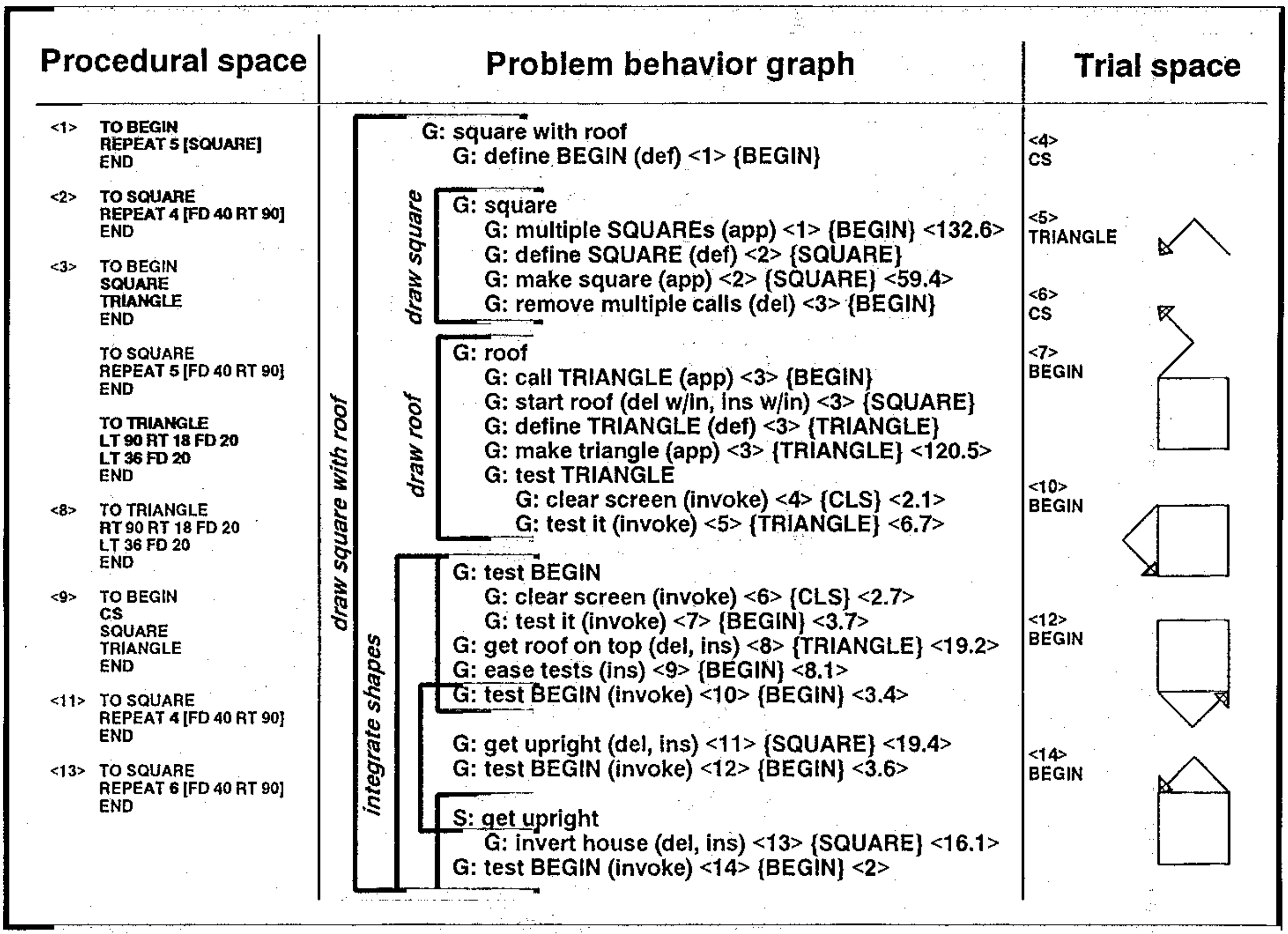

Figure 3: Episode 1 of s4's house-playhouse task session. Note: States of the two problem spaces are represented on the left and the right of the problem behavior graph and are keyed to the graph by line numbers in the record. In the left panel, changes to the programs are indicated in bold. The graph itself is an episoded functional record. The brackets demarcate the episodes. Seven episodes are shown; two enclosing, six enclosed, and three interlinked. The goals of the higher level episodes are italicized rotated lettering. Indentations in the functional description represent the hierarchical structure of goals and subgoals. "G" stands for goal; a previously set superordinate goal which is not adjacent to the subgoal is indicated by an "S" rather than a "G." The goals are briefly identified. The operators associated with these goals operate on instructional units; such a unit is defined as a LOGO primitive or defined procedure and its inputs. Categories of operators are indicated in parentheses. The procedural space operators are "def" for define, "app" for append, "ins" for insert, and "del" for delete (when a part of an instructional unit is the object of an opertor, "w/in" is indicted). Trial space operators are designated as "invoke," and operators that result in errors are indicated simply as "error." The numbers immediately following the operators indicate the line number in the record, and the action or procedure affected are indicated in brackets after the line number. Error messages follow in parenthesis. The time from the last action to the completion of the action is given for the last set of operators for the line.

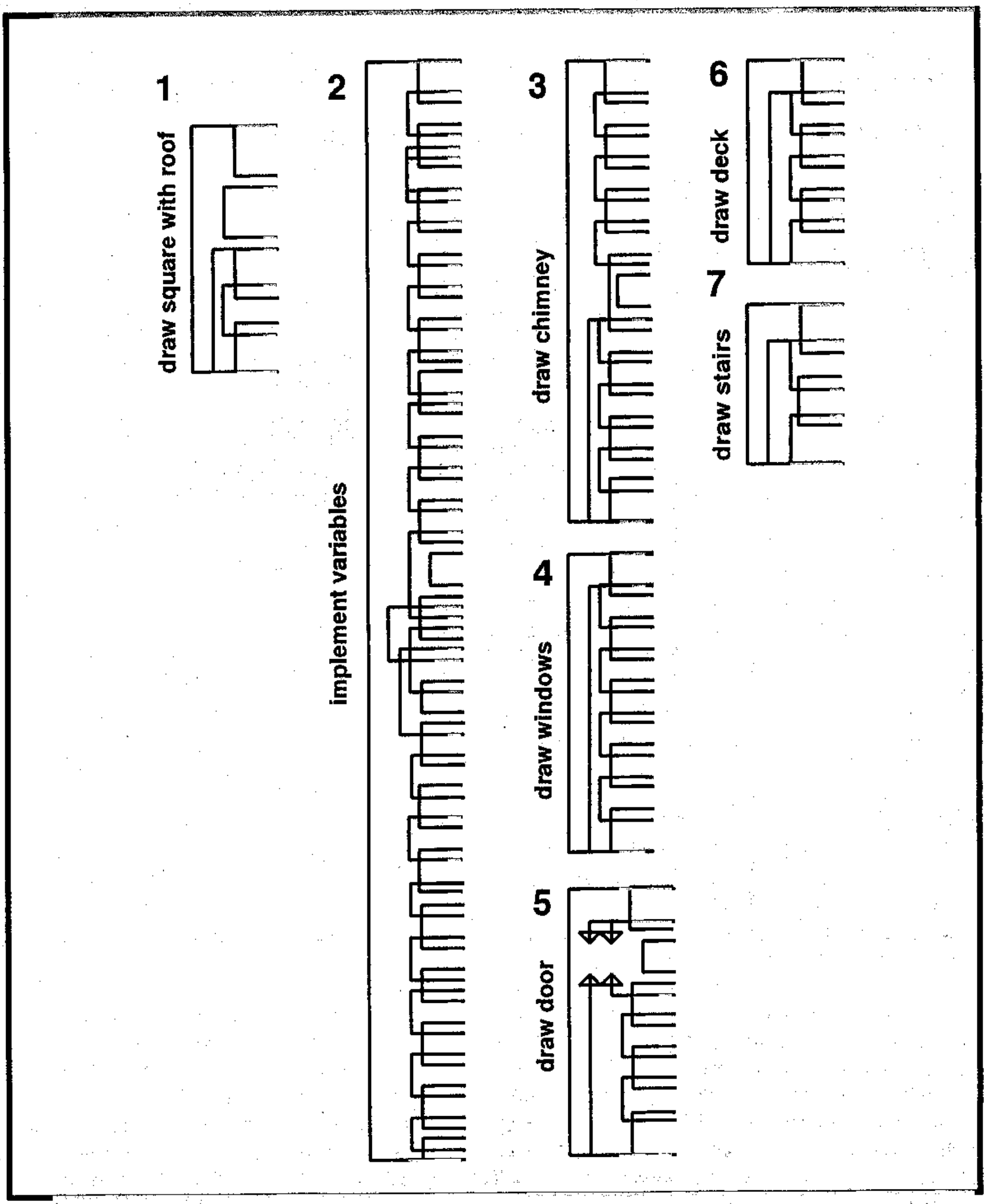

Figure 4: Episode abstract of S4's house-playhouse task session. Note: This shows an episode abstract for a complete session. There are seven major episodes in which components of the program were developed (indicated in rotated lettering): episode 1, house shape; episode 2, failed attempt to implement variables instead of constants; episode 3, chimney; episode 4, windows; episode 5, door; episode 6, deck; and episode 7, stairs.

various levels of generality and degrees of articulation, both determining action and determined by the results of action.

Limitations and Extensions

There are clear limitations to the approach adopted for this study. Even within the domain of the study of computer-based activity, its focus is quite narrow. Only that aspect of the programming process that can be recorded by the computer is represented, and the goals analyzed are only those that are specifically related to the construction of the program. Perhaps most seriously, the analysis is abstracted from all considerations of the social context of the activity. However, the perspective that emerges is very much in tune with descriptions of goal-directed action yielded by more context-inclusive approaches (see Valsiner, 1987), and there is no reason in principle why richer forms of data-collection and analysis could not be used in conjunction with the form of representations developed in this approach.

The major requirements for the use of this form of representation are that the step-by-step actions of those participating in the activity are recordable and that these actions are related functionally to something developed though the activity. Rather than relying on only one form of recording, a variety of forms (e.g., automated computer tracking, audio-video recordings, and unobtrusive observation) could be employed. The focus for the functional analysis could be any type of artifact, for instance, a written document or the design for a commercial product.

A study of social interactions in a design work-group could be conducted using automated tracking where some portion of the design activity occurs on computers. As well, work-group meetings could be videotaped during the phases of the evolution of the design, and email and other forms of document exchange and communication could be monitored. For each action, the author and time-frame would be recorded and the function of that action as it related to the evolution of the design would be specified. From this, the goal-directed behavior of the group would be plotted using hierarchical-sequential representations, as would each individual's activity. This would allow analysis of the distributed goal formation and action regulation of the group as a whole, as well as analyses of each participant's activity.

Conclusion

Understanding human performance as a process has long been an objective, and technologies are now available that make that objective realizable. Recording process is no longer a difficulty, but making sense of the records is. The form of representation that I have developed tries to make sense of records of on-going activity by looking at two dimensions of process. It looks at the functional aspect of process, what the actions taken contribute to the product under construction, and it assumes that these functions reflect the goals of the actor. It also looks at the dynamics of process, how actions are connected in time and the direction in which they lead. Fundamentally, it makes sense of human performance by focusing on indications of intentions in activity and by looking at how these intentions unfold in time.

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CUMULATIVE INDEX

ARTICLES PUBLISHED IN THE *LCHC NEWSLETTER* FROM JANUARY 1988 THROUGH OCTOBER 1993

(CODE: Author/Title/Issue and Pages)

(This is a condensed version of the *Newsletter's* Index. Copies of the complete index beginning in 1976 are available upon request. Back issues of the Newsletter are available for $6.25 an issue or $25.00 per volume. Send order to *LCHC Newsletter*, The Laboratory of Comparative Human Cognition, 0092, University of California, San Diego, La Jolla, CA 92093.)

Carraher, Terezinha, & DeLemos Meira, Luciano. (1989, January/April). Learning computer languages and concepts, *11* (1&2), 1-8.

Cazden, Courtney B. (1992, October). Does practice with specific "linguistic devices" matter?, *14* (4), 113-114.

Cintron, Ralph. (1991, January). Reading and writing graffiti: A reading, *13* (1), 21-24.

Cole, Michael. (1992, October). Sylvia Scribner at LCHC, *14* (4), 147-151.

Coyle, Brian. (1992, April). Oral tradition, visual media, and information transfer in an African development experiment, *14* (2), 44-57.

Delgado-Gaitan, Concha. (1991, January). Discussants' comments on preceeding papers, *13* (1), 25-26.

Di Bello, Lia. (1992, October). Looking for "What's leading": A legacy from Sylvia Scribner, *14* (4), 114-116.

Eckensberger, Lutz. (1990, January). From cross-cultural psychology to cultural psychology, *12* (1), 37-52.

Edgeworth, Matthew. (1992, January). Analogy as practical reason: The perception of objects in archaeological practice, *14* (1), 3-8.

Edwards, Derek. (1989, January/April). The pleasure and pain of mathematics: On Walkerdine's The Mastery of Reason, *11* (1&2), 38-41.

Edwards, Derek. (1989, July). Phase transformations as discursively occasioned phenomena, *11* (3), 95-104.

Engeström, Yrjö. (1988, January). Reconstructing work as an object of research, *10* (1), 21-27.

Engeström, Yrjö. (1988, April). Introduction. How to do research activity? *10* (2), 30-31.

Engeström, Yrjö. (1992, October). Toward an activity-based methodology for studying cognition at work, *14* (4), 116-117.

Engeström, Yrjö, Brown, Katherine, Christopher, Carol, & Gregory, Judith. (1991, October). Coordination, cooperation and communication in the courts: Expansive transitions in legal work, *13* (4), 88-97.

Engeström, Yrjö, & Kallinen, Timo. (1988, April). Theatre as a model system for learning to create, *10* (2), 54-67.

Farrell, Edwin. (1988, January). The formal thinkers among us, *10* (1), 7-11.

Feldman, Carol. (1992, July). On reading Paley, *14* (3), 73-77.

Fuhrer, Urs. (1993, January). Living in our own footprints - and in those of others: Cultivation as transaction, *15*(1), 23-29.

Gaskins, Suzanne, & Göncü, Artin. (1988, October). Children's play as representation and imagination: The case of Piaget and Vygotsky, *10* (4), 104-107.

Gaskins, Suzanne, & Göncü, Artin. (1992, April). Cultural variation in play: A challenge to Piaget and Vygotksy, *14* (2), 31-35.

Gauvain, Mary, & De Ment, Terri. (1991, July). The role of shares social history in parent-child cognitive activity, *13* (3), 58-66.

Ginsburg, Herbert P. (1989, January/April). The role of the personal in intellectual development, *11*(1&2), 8-15.

Glassman, Michael. (1990, October). Self, other and society: A Vygotskian view of creativity, *12*(4), xx-xx.

Glick, Joseph. (1992, October). Steps in the long march: From principles to practices, *14* (4), 117-118.

Greenfield, Patricia. (1992, October). On "The cognitive consequences of literacy" by Sylvia Scribner, *14* (4), 118-120.

Guerra, Juan C. (1991, January). The role of ethnography in the reconceptualization of literacy, *13* (1), 3-9.

Hakkarainen, Pentti. (1991, October). Joint construction of the object of educational work in kindergarten, *13* (4), 80-88.

Hanson, Vicki L., & Padden, Carol A. (1988, July). The use of videodisc interactive technology for bilingual instruction in American Sign Language and English, *10* (3), 92-95.

Hatano, Giyoo. (1988, January). Introduction, *10* (1), 2-3.

Hatano, Giyoo. (1989, January/April). Two microworlds of computation: How are they related?, *11*(1&2), 15-19.

Hatano, Giyoo. (1992, October). Comments on "The cognitive consequences of literacy," *14* (4), 120-122.

Hedegaard, Mariane. (1992, October). Reflection in honor of Sylvia Scribner's socio-cultural approach, *14* (4), 122-123.

Hirst, William. (1992, October). From tools to practice, *14* (4), 124-126.

Hundeide, Karsten. (1988, July). Metacontracts for situational definitions and for presentation of cognitive skills, *10* (3), 85-91.

Inagaki, Kayoko. (1989, October). Questioning and acquisition of knowledge in Japan, *11* (4), 142-145.

Jacobs, Suzanne E. (1990, April). Scaffolding children's consciousness as thinkers, *12* (2), 70-75.

Janikas, Kristen. (1993, July). Hand clapping games: Rhythmic recordings of girlhood socialization, *15* (3), 97-102.

John-Steiner, Vera. (1992, October). Scribner: Rigor and creativity, *14* (4), 126-127.

Kawatoko, Yasuko. (1988, July). The role of communication during classroom lessons in cognitive development, *10* (3), 76-85.

Kessel, Frank. (1992, July). Children's lives, stories, and literacy: The teacher-as-researcher, *14* (3), 64-65.

Khan, Farida A. (1993, April). Cognitive organization and work activity: A study of carpet weavers in Kashmir, *15*(2), 48-53.

Kindred, Jessica B. (1993, January). Comments: Sylvia Scribner as methodologist, *15*(1), 40-41.

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INTERNATIONAL CONFERENCE
LEV VYGOTSKY AND THE CONTEMPORARY HUMAN SCIENCES

September 5-8, 1994, Moscow

An international conference dedicated to the ideas of Lev Semenevich Vygotsky will take place in Moscow from September 5-8, 1994. The conference will be organized by the Department of Psychology of the Russian Academy of Education, Lev Vygotsky National Foundation, the Institute of Psychology of the Russian Academy of Sciences, the Institute of Psychology of the Russian Academy of Education, Moscow State University, and the Moscow Institute of Psychology and Psychotherapy.

The main goals of the conference are to bring together scholars from Russia and other countries to compare our understanding of Vygotsky's ideas, to share recent findings, and to organize a dialogue on research topics. We hope that this dialogue will result in future scientific activities and research cooperation. We also plan to publish a volume of papers presented at the conference in Russian and in English.

Among the topics we are planning to discuss are:

- Vygotsky and contemporary psychology: Vygotsky's heritage in Russia. Western Europe, Eastern Europe, Asia, Latin America, and the U.S.;
- The holistic approach to human nature and Vygotsky's cultural-historical theory;
- Vygotsky's ideas in cross-cultural psychology, political psychology, and studies of ethnicity and culture;
- Vygotsky and linguistic, psycholinguistic, and sociolinguistic analysis;
- Vygotsky and the humanistic perspective in psychology and related fields;
- Vygotskian ideas in education, literary analysis, and literacy.

DEADLINE FOR PROPOSALS: **May 1, 1994.** Anyone contacting us by this date will receive a preliminary program and an official invitation to the conference.

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