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AUTHOR	Barley, Stephen R.; Bechky, Beth A.
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ABSTRACT

Twelve technicians and research support specialists employed in two laboratories of a university biotechnology center were observed and interviewed for 1 year to compile data on their job duties, knowledge, and status. Although the university differentiated technician and research support specialist positions across nine pay grades that were supposedly calibrated to educational credentials and job responsibilities, there was little distinction between the work of laboratory technicians and research support specialists. Both groups viewed their work as waging a running battle with trouble and uncertainty by using various strategies to avert and resolve various mistakes, malfunctions, and enigmas. The technicians and research support specialists stood between the scientists who nominally ran the laboratories and the empirical phenomena that the labs investigated. The technicians used and elaborated a contextual understanding of materials, instruments, and techniques grounded in hands-on experience that most scientists lacked. Although the technicians' and scientists' jobs were interdependent, the technicians' contextual knowledge was not awarded the same status as the scientists' formal knowledge. The technicians and research support specialists attempted to cope with the status accorded them by the university either by embracing an almost blue-collar identity or, conversely, by seeking employment in laboratories where they would be treated as professionals. (MN)

EQW WORKING PAPERS

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In the Backrooms of Science: The Work of Technicians in Science Labs

by Stephen R. Barley and Beth A. Bechky

Program on Technology and Work
School of Industrial and Labor Relations
Cornell University

"In the Backrooms of Science: The Work of Technicians in Science Labs" by Stephen Barley and Beth A. Bechky
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Contents

I. Introduction

As defined by U. S. census categories, technicians represent the fastest growing segment of the labor force. Given moderate growth in the economy, by the turn of the century the employment of technicians and related occupations is expected to expand by 32 percent, a rate more than double that (15 percent) of the entire workforce (Silvestri and Lukasiewicz 1989). If forecasts prove accurate, professional and technical occupations will account for 18 to 20 percent of all employed Americans by the year 2000 (Bishop and Carter 1991).[1] At that point, professionals and technicians will compose the largest occupational sector, surpassing even operatives and clerical workers (Barley 1991).

At present, sociologists of work and occupations are ill-prepared for such a shift. Although sociologists have amassed considerable knowledge of the professions, aside from a handful of studies of engineering (e.g., Peltz and Andrews 1966; Zussman 1985; Whalley 1986; Bucciarelli 1988; Kunda 1991), we currently know little about technical work in general and even less about technicians. This lacuna is especially troubling with respect to science technicians, for unlike other technical settings, science labs have recently attracted the attention of a number of ethnographers (Latour and Woolgar 1979; Gilbert and Mulkay 1984; Lynch 1985; Traweek 1988; Amann and Knorr-Cetina 1989).

Neglect of the science technician cannot be attributed to the occupation's scarcity. According to the U.S. Department of Labor (1990), American laboratories employed 1.5 technicians for every scientist and engineer they employed in 1988. This ratio more than doubled since 1960 when the ratio of technicians to scientists and engineers stood at .70 (National Science Foundation 1961). Because the Bureau of Labor Statistics relies on census data which excludes students and other part-time technicians, the actual ratio is probably higher.

Shapin (1989) has argued that the technician's long standing "invisibility" stems from the scientific community's proclivity to devalue lower-status contributors. Although status differences may account for the invisibility of technicians in the writings of scientists, such an explanation is less satisfying for why sociologists have ignored technicians. Sociologists are usually keenly attuned to issues of status and, indeed, sociologists of science have often written about stratification in science (Hagstrom 1965; Zuckerman 1970; Cole and Cole 1973). A more plausible explanation is that sociologists of science have neglected technicians because they have been concerned with issues that are only tangentially related to the social organization of laboratory work.

Institutional analysis preoccupied the sociology of science in its formative years (Marcson 1960; Hagstrom 1965; Storer 1966; Cole and Cole 1967; Zuckerman 1968; Ben-David 1971; Crane 1972; Merton 1973). Consequently, early sociologists of science rarely concerned themselves with even the scientists' work and, when they spoke of scientific practice, they often did so in terms that mirrored the scientists' own vocabulary of motives. For this reason, a younger generation of scholars began to argue in the late 1970s that one could gain an accurate understanding of how science proceeds only by studying scientists in action (Collins 1974, 1975; Mulkay 1976; Bloor 1976, 1981; Knorr-Cetina 1981; Knorr-Cetina and Mulkay 1983; Latour 1987). Accordingly, younger sociologists and anthropologists of science took to the field and have since produced a burgeoning number of ethnographies of lab practice (e.g., Gilbert and Mulkay 1984; Latour and Woolgar 1979; Lynch 1985; Amann and Knorr-Cetina 1989; Traweek 1988).

Ironically, however, the movement to study the backrooms of science has left technicians just as invisible as they were in the eighteenth century (Shapin 1989). This is so largely because modern sociology of science fashions itself more a sociology of knowledge than a sociology of work. Although ethnographers of science have certainly had more to say about lab practices than their predecessors, their primary objective has been to speak contextually about issues of knowing.[2] The upshot has been that, with few exceptions (Collins 1974, 1975; Lynch 1985; Cambrosio and Keating 1988), most lab studies offer an anemic image of how lab workers experience their practice and an even paler image of a laboratory's division of labor.

We submit that the time is ripe not only for studying science as a form of work but, more specifically, for examining the work of science technicians. An appreciation of what technicians do is vital for several reasons. First, because technicians maintain materials, operate instruments, conduct experiments, and record data, they often preside over science's encounters with the physical world. Failing to understand the technician's role may therefore lead not only to an unrealistic picture of science's labor process, but also to a misrepresentation of the varieties and the distribution of scientific knowledge and skill. Second, because technicians provide "data to be used in the arguments of the scientists" (Latour and Woolgar 1979), their work ultimately grounds the very construction of knowledge in which modern sociologists of science are interested. To ignore the technician's contribution is to act as if scientific knowing begins only after scientists have come on stage and, hence, to perpetuate a cultural myth that sociologists of scientific knowledge hoped to transcend. Finally, there are pragmatic reasons for studying the technician's role at this particular point in history. In response to recent reports on the inadequacy of American scientific and technical education (Parnell 1985; Johnston and Packer 1987; Aerospace Education Foundation 1989), federal and state agencies have begun to draft policies for attracting young people to technical careers, especially those that do not require a doctorate (Committee on Science and Technology 1986; Committee on Science, Space and Technology 1991). Without detailed information on technicians' work, these policies, however well intentioned, risk consuming considerable public funds on programs that may miss the mark because they are fashioned on stereotypical images of what technicians know and do.

This paper aims to pierce the science technician's cloak of invisibility by examining the activities of technicians in a laboratory. Based on existing evidence, we first propose a general model of the technician's position in an occupational division of labor. We then draw on data from a study of two laboratories in an American university to contextualize the model by specifying more precisely the types of knowledge and skill that technicians command. The data lead us, in turn, to consider the status inconsistencies that mark the technician's role in scientific settings. We conclude on a practical note by suggesting how such inconsistencies may undermine policies designed to address the shortage of technical personnel.

II. Work at the Empirical Interface

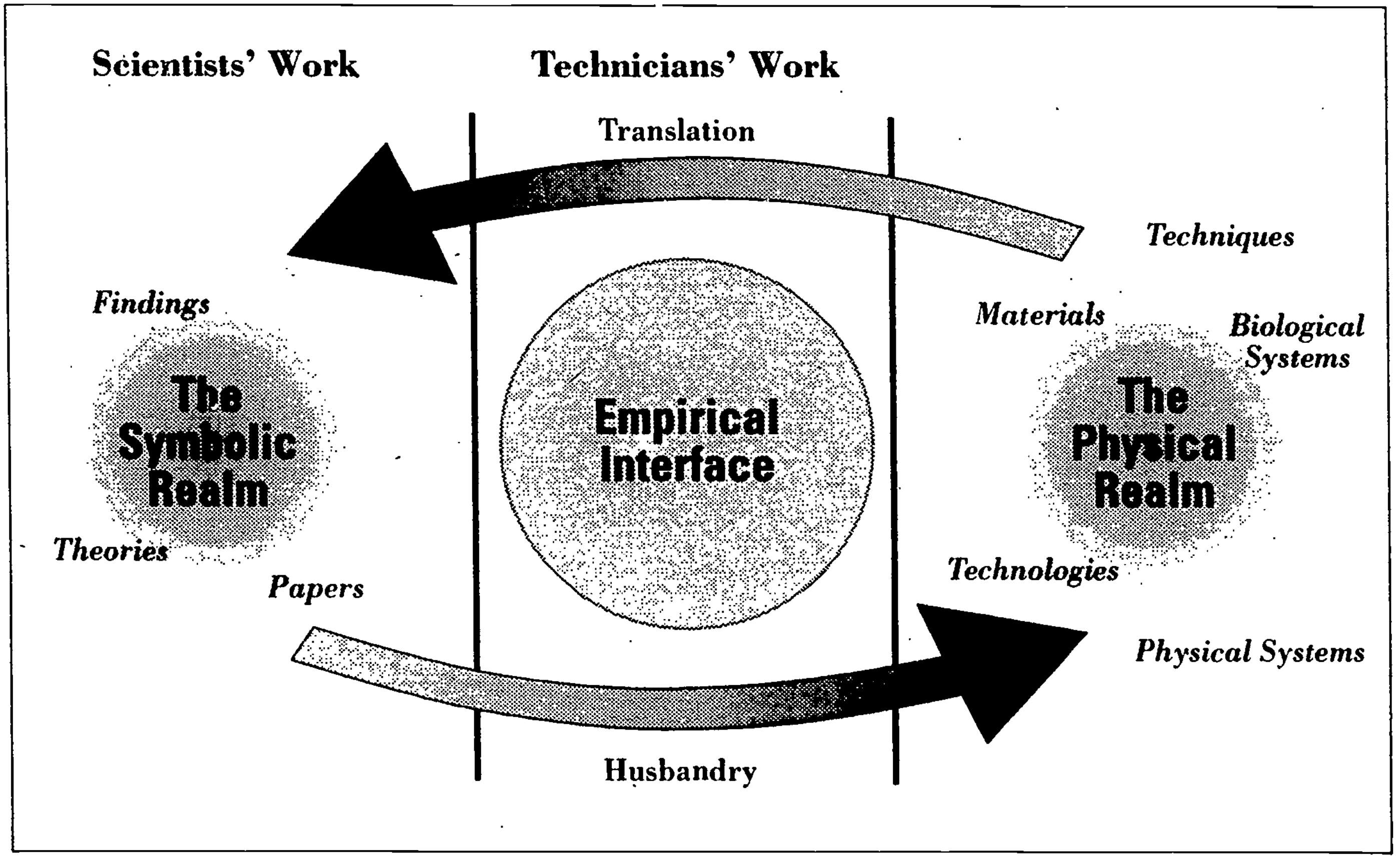
Although science technicians have attracted little sustained attention, hints of their role lie scattered throughout recent studies of lab practice (Collins 1974, 1987; Lynch 1985; Cambrosio and Keating 1988; Jordon and Lynch 1992). If we assume that technicians' work bears a resemblance regardless of context, then it is reasonable to draw on studies of technicians employed in other settings as well as ethnographies of science labs to propose a model of the technician's position in an occupational division of labor. Researchers attending a recent workshop held to synthesize existing data on the technical labor force concluded that technicians' jobs exhibit common attributes (Barley 1992). Persons formally employed as "technicians" usually work on, with, or through reputedly complex technologies or techniques. Those outside the occupations generally perceive the technicians' knowledge to be "esoteric." In many cases, technicians manage an interface between a larger work process and the materials on which the process depends. As a result, technicians usually enable the work of other occupations, especially professional and managerial occupations.

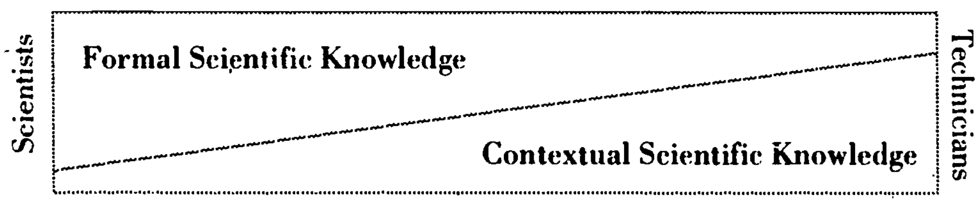
Figure 1 builds on these ideas, as well as the findings of published research to portray schematically the position of a technician in a serially interdependent occupational division of labor. Serial interdependence among occupations (Thompson 1967) implies that the "output" of one occupational group serves as "input" for another. Such divisions of labor are often (but not always) identified with the work of a profession.[3] The figure's premise is that technicians stand at the empirical edge of a labor process, where they mediate between a physical realm and a symbolic realm that consists of representations of the physical. Depending on context, the physical realm may encompass hardware, software, organisms, and other material phenomena. The symbolic realm, again depending on context, may be populated by findings, theories, designs, diagnoses, plans, or documentation—the inputs and the products of work often associated with higher-status occupations.

Work at an empirical interface pivots on two complementary processes. The first entails *translating* aspects of the physical world into signs, symbols, or information that phy-

Figure 1

The Social Organization of Work and Knowledge in a Laboratory





Relative Distribution of Knowledge

sicians, scientists, engineers, and other professionals subsequently use in their own work. For instance, sonographers (Barley 1990), emergency medical technicians (Nelsen and Barley 1992), and medical technologists (Scarselletta 1992) routinely produce images, counts, assays, and other data from which physicians construct diagnoses and prescribe treatment. Technicians in nuclear power plants (Hirschhorn 1984) and other automated facilities (Zuboff 1988) create and monitor flows of data about the production system that engineers and managers employ to make decisions. Pentland (1991) reports that a crucial part of software support involves converting customers' complaints into technical specifications that designers can use to fix "bugs," add "features," or develop "work arounds." Finally, Latour and Woolgar (1979) point to the translation function of technicians' work when they claim that technicians are responsible for the "inscriptions" from which scientists construct arguments.

As Figure 1 suggests, technicians usually do more than simply feed the symbolic work of others. Most are also responsible for *husbanding* the physical. Husbandry often requires technicians to employ theories, diagnoses, documentation, and other representations drawn from the symbolic realm they support. For example, programmers make use of abstract models of organizational processes when writing code (Kuhn 1989). To stabilize patients, emergency medical technicians make diagnoses that require them to be conversant with theories of disease (Nelsen and Barley 1992). Lynch (1985) has shown how electron microscopists draw on formal scientific theories to manage materials, equipment, and images as well as determine what is and is not an artifact. Even copier repair technicians must comprehend engineering schematics if they are to repair malfunctioning equipment (Orr forthcoming).

On structural grounds alone, Figure 1 raises several critical issues about the technician's role in an occupational division of labor. The first revolves around distributions of knowledge and skill and their implications for the labor process. Positioned as they are at the empirical edge, a large portion of what technicians do should consist of allaying troubles that might disrupt the link between the physical and symbolic realms. Existing studies largely support such an inference. Engineering technicians perform tests primarily to identify and correct problems that arise when designs meet use (Koch 1977). Copier technicians (Orr forthcoming), microcomputer support specialists (Gash 1987) and others charged with monitoring and repairing devices are, by definition, paid to troubleshoot key technical interfaces. Barley (1988) and Scarselletta (1992) have shown that technicians in medical settings routinely identify and eliminate glitches that threaten the work of physicians. In fact, it is difficult to think of a technical occupation that does not entail a significant amount of troubleshooting.

The dual processes of translating and husbandry imply that technicians must possess knowledge of both the physical and the symbolic realm if the interface is to function smoothly. Moreover, to the degree that technicians buffer those who work with symbols from empirical difficulties, they should develop a different, if not a deeper, understanding of the empirical world. Types of knowledge should therefore be differentially distributed: technicians should possess more "hands-on" or "contextual" knowledge of empirical phenomena, while the professionals' understanding of the empirical realm should be weighted toward the abstract and formal. This distribution (depicted at the bottom of Figure 1) should underwrite an emergent division of labor that may conflict with the images promoted by professional rhetorics. Sonographers therefore do more diagnosis than some of the radiologists they support (Barley 1990), and in the case of science labs, we might expect technicians to specialize in "empiricism" while scientists specialize in "theories."

The model also raises issues of power and status. If technicians mediate between the physical and the representational, their activity can be said to be structurally "critical" in the sense that their absence would decouple the larger labor process (Hickson et al. 1971). Their criticality should increase to the degree that they possess most of the contextual knowledge necessary for husbandry and translation. Thus, technicians should have considerable structural power (Crozier 1964). Because technicians often facilitate the work of more emminent occupations, their social standing should be incommensurate with their criticality. Technicians should therefore experience status ambiguity.

The foregoing considerations imply that technicians' knowledge and skill, and hence their value to the labor process, should be most visible when confronting trouble. Troubleshooting is not only central to the work of most technicians, but as ethnomethodologists have long argued, practical difficulties highlight reasoning practices that people take for granted under more routine conditions (Garfinkel 1967; Lynch 1985; Jordon and Lynch 1992; Suchman and Trigg 1990; Goodwin 1992). Studying how workers resolve problems is especially important when skills are primarily cognitive or perceptual, for on these occasions individuals are more prone to demonstrate, if not vocalize, what they know. For this reason we sought to study the skills and roles of science technicians by documenting not only the daily routine, but the problem solving practices of technicians in two laboratories at a large university.

III. Methods and Sites

The data were compiled during a year of observation in a monoclonal antibody (MAb) and a flow cytometry laboratory located in the university's Biotechnology Center. Although the activities of all members of both labs were examined, observations focused on the practices of the technicians. The goal was to explicate the broad contours of technicians' work, to document deviations from routine, and to record how technicians interpreted and handled those deviations. Given our interest in how technicians managed problems and the fact that problems occurred unpredictably, extended observation ensured that an investigator would be on hand when troubles arose.

Bechky recorded the majority of the data as jotted field notes which she expanded at a word processor immediately after each period of observation. She also conducted a number of structured and unstructured interviews with each lab's staff as well as with personnel officers and the director of the Biotechnology Center. To further extend the study's scope, in the last month of the research Bechky interviewed eight additional technicians from a variety of labs both inside and outside the Biotechnology Center. The interviews lasted approximately one hour and elicited information about the informants' duties, their careers, the social structure of the labs in which they worked, and their interpretations of their work roles. All structured interviews were taped and transcribed. Thus, the analysis draws on data collected in one form or another from a total of twelve technicians employed in ten laboratories. Table 1 displays the positions informants held, their genders, the substantive areas in which they worked, their highest degrees, the number of years they had worked in a research laboratory, and the methods used to collect data on their work.

Table 1
Technicians Observed or Interviewed

Job Title	Lab	Gender	Highest Degree	Time as Technician	Data Collected by
* RSS	Monoclonal	Female	MS	15 years	Observation
RSS	Flow Cytometry	Male	MS	3 years	Observation
RSS	DNA Synthesis	Male	BS	5 years	Interview
RSS	Biochemistry	Female	BA	12 years	Interview
RSS	Plant Science	Male	HS	26 years	Interview
RSS	Plant Cell Culture	Male	BS	10 years	Interview
Technician	Monoclonal	Female	BA	2 months	Observation
Technician	Flow Cytometry	Female	MS	6-12 months	Observation
Technician	Cell Biology	Male	HS	2 years	Interview
Technician	DNA Synthesis	Male	AS	8 months	Interview
Technician	Plant Pathology	Male	MS	8 years	Interview
Technician	Peptide Synthesis	Male	HS	>6 years	Interview

*Research Support Specialist

Observations began in the MAb lab, one of the few labs in the region that produced monoclonals.[4] Most of the lab's work stemmed from contracts with corporations or other university labs. The lab was headed by a director, a senior scientist who had worked in several biotechnology companies. The director also served as the Center's technology transfer specialist. Because administrative duties consumed most of the director's time, a "research support specialist," a seasoned technician with a master's degree and 15 years of experience in cell culture, ran the lab. During the course of the study, the lab hired a part-time technician as well as an undergraduate who assisted with lab maintenance. Near the end of the study, the MAb lab also took on a postdoctoral fellow.

The MAb lab relied almost exclusively on *in vivo* techniques to produce monoclonals. To start an *in vivo* fusion, mice were inoculated with the antigen for which an antibody was to be developed. Eventually, the spleens of the mice began to produce lymphocytes that secreted the antibody. At this point, lab workers "sacrificed" the mice and "rendered" their spleens to obtain a sample of cells, some of which produced the antibody. Under normal conditions spleen cells die quickly in culture. Cell death was circumvented by fusing the spleen cells, called "parentals," with the cells of a mouse myeloma to create "hybridomas," cell lines that could be cultured indefinitely. Fusion entailed simultaneously exposing both types of cells to polyethylene glycol which broke down the cells' membranes and allowed their genetic material to mingle. Sixteen years after its inception (Milstein 1980), technicians still considered *in vitro* fusion to be a "tricky" procedure.

After performing the fusion, lab personnel transferred the cells to wells of a culture plate filled with a selective medium or supernatant. Parental or myeloma cells that failed to fuse or that fused with cells of the same type died in this medium, leaving only hybridomas alive. Eventually, the hybridomas began to secrete antibodies. Tests or immunoassays, known as ELISAs, enabled lab workers to determine which colonies were producing the antibody. These hybridomas were harvested or "cloned" by diluting the colony and moving samples from plate to plate until a single hybridoma resided in each well. The single cells, in turn, produced colonies of their own which were assayed and cloned until lab workers found a colony that produced especially high concentrations of the antibody. The cells of this colony were cultured and then preserved in liquid nitrogen.

After five months in the field, observation began in the flow cytometry laboratory (FCL). The FCL's work and organization differed substantially from that of the MAb lab. By sharpening the contrast between sites we hoped to identify more easily the dynamics common to technicians' work. Whereas the MAb lab's activities revolved around a set of techniques, the FCL's centered on the use and maintenance of computerized instruments that generated data on cells.[5] Researchers came from all over the university to analyze cell samples on the FCL's devices. Thus, whereas the MAb lab produced products, the FCL provided a service. Moreover, because the work of the FCL's technicians focused more on the instruments than on the cells they analyzed, knowledge of optics, lasers, fluorescence, and computers was considered more crucial than knowledge of cell biology.

The FCL housed two flow cytometers, the largest of which was said to be "state of the art." The cytometers were used for karyotyping and making ploidy determinations, measuring membrane potential, and a number of other applications (see Sharpe 1988). Lab workers first stained the cells to be analyzed with a fluorescent dye known to bind to specific cellular structures or molecules. They then injected the cells into the cytometer where they were bathed in a liquid medium and passed at high speed though an observation region where lasers excited the dyes. Electrons (emitted as the dyes fluoresced) struck detectors that converted optical signals to electrical pulses which were, in turn, channeled though amplifiers to the cytometer's computer. The computer tabulated and displayed the signals as histograms that measured the intensity and scatter of the fluorescence, which in turn represented attributes of cells. In addition to the flow cytometers, the FCL housed a spectrofluorometer and a digital fluorescence video microscope.[6]

The FCL employed a research support specialist, who served as the lab's director, and a technician hired six months before the study began. The research support specialist had extensive knowledge of fluorescence, held a master's degree in chemistry, and was pursuing a doctorate in molecular biology. The technician held a master's degree in microbiology and had worked as a serologist for a commercial lab. Much of the technician's and the research support specialist's work involved setting up and aligning instruments, a time-consuming task that required adapting the devices to the study at hand. Although users were expected to run their own samples, in practice they often required both technical and scientific assistance from the staff. Because computers served as each instrument's "platform," the work demanded a facility with computational devices.

IV. Conceptions of the Technician's Work and Role

Conceptions of the science technician's role in a laboratory's division of labor varied according to whom one asked. Many people at the university used the term "technician" to refer loosely to all full- or part-time staff who were positioned below professors and postdoctoral fellows in a lab's authority structure and were not classified as graduate or undergraduate research assistants. More knowledgeable informants agreed that the colloquial usage was misleading because research assistants often did the same work as technicians and because persons formally employed as technicians were often graduate students. More importantly, some technicians did work similar to that of postdoctoral students and, at times, even professors. For example, experienced technicians designed their own experiments, taught classes, mentored postdoctoral fellows, and wrote research papers.

The University's Conception

The university attempted to order the diversity of technicians' work by calibrating titles to a compensation system assumed to reflect a hierarchy of skill. Personnel officers reserved the title of "technician" for "non-exempt" laboratory personnel, those who received an hourly wage. Technicians' positions spanned nine pay grades supposedly calibrated to educational credentials and job responsibilities. "Laboratory aide" was the lowest grade, reserved for individuals with little experience and no more than an associate's degree. Laboratory aides had narrow responsibilities and spent most of their time washing equipment and running errands. Higher grades officially required a bachelor's or even a master's degree and were credited with greater skill and responsibility. The university rewarded "exempt" laboratory personnel (of which there were five grades) with a salary and the title of "research support specialist" (RSS). Personnel officers claimed that RSS positions required a master's degree not only because they entailed supervisory and teaching duties, but because research support specialists often served as a lab's "second-in-command."

However, as the third column of Table 1 indicates, the university's classification system corresponded only vaguely with reality. Of the six RSSs observed or interviewed, only two possessed master's degrees and one had but a high school diploma. Conversely, of the six technicians, two held master's degrees although they were classified in the middle to lower grades. As in the case of the FCL, some research support specialists worked as full-fledged lab directors. Others (such as the MAb lab's RSS) were nominally second-in-command, but because the directors were usually absent, for all practical purposes they, too, ran the labs in which they worked.

Lab Staff's Conception

Such inconsistencies were not lost on the research support specialists and technicians, most of whom claimed that the university's personnel system carried almost no information about who did or knew what. In fact, many considered the system to be a bureaucratic device for using credentials to legitimize low salaries and inadequate benefits. However, lab personnel also recognized that being a research support specialist carried more status than being a technician. Bechky became painfully aware that lab staff attached negative connotations to the term "technician" when on the first day of the study she mistakenly called the MAb lab's research support specialist a technician. The RSS emphatically proclaimed that she was not a technician and "set the researcher straight." Technicians were also conscious of the status difference. For instance, one technician introduced himself sarcastically at the beginning of an interview by saying, "I'm just a lowly technician, low man on the totem pole." [7]

Yet, in the course of their work lab workers made surprisingly little of the distinction between technicians and research support specialists. Instead, they referred to each other by area of expertise or degree of experience. Specific individuals were said to do "cell culture," "peptide synthesis," and any of a long list of other specialties in which one could be "experienced" or "inexperienced." Within specialties, staff were known by the tasks they performed. In the FCL, the RSS's identity was bound to the larger of the flow cytometers and the video microscope for which he was solely responsible. The technician's identity was tied to her operation of the spectrofluorometer and the smaller cytometer.

The exception to the tendency to refer to each other by substantive roles was the widespread practice of distinguishing between individuals who were considered to be "scientists" and those who were not. In lab parlance, being a scientist had little to do with holding a degree, developing theories, publishing papers, or even being a professor. Instead, when technicians or research support specialists called someone a "scientist" they voiced a judgment about an individual's practice and his or her orientation to work. "Scientists," explained one technician, "are valuable, thinking persons. They are committed with their whole being and mind." Individuals who were considered "scientists" reputedly kept current in their fields, remained open to new ideas, valued experimenting with new techniques, and most importantly, acted independently. In short, to be a "scientist" was to demonstrate attitudes and behaviors that lab personnel considered critical for effective empiricism. Lab workers who were "not scientists," on other hand, were individuals who reputedly viewed their work as "just a job." Such individuals were said to be closed to experience, unwilling to act independently, and unable to admit mistakes.

Lab personnel claimed that even laboratory aides merited being called scientists if they approached their work appropriately. Conversely, most technicians and research support specialists could point to professors and postdoctoral students whose orientations they considered "unscientific."

In distinguishing between "scientists" and the "unscientific," technicians and research support specialists indexed their perception of a common denominator that cut across the diversity of lab work they otherwise embraced: the empirical encounter itself. The distinction between those who were and were not "scientists" was therefore a clue to how staff viewed their role in a lab. Technicians and research support specialists subscribed to the view that all science ultimately entails a confrontation with the material world. Out of such encounters come data for fashioning a body of thought or practice. Whereas scientific papers and handbooks may portray such encounters as the province of methods, lab personnel understood them as the province of technician's work. Although the methods sections of scientific papers imply that one can follow procedures as if they were recipes, lab workers were acutely aware that even routine encounters with the material world were unpredictable: instruments failed; researchers made mistakes, procedures went awry, and most importantly, biological and physical entities had an uncanny capacity for recalcitrance.

Thus, lab personnel valued independent thinking, flexibility, and the other attributes of a "scientist" not because these were the "norms" or even the accepted "rhetoric" of the scientific community, but because they believed that only by adopting such a stance could they outwit the unruly technologies and phenomena they were asked to master. Lab personnel viewed their work as a running skirmish with trouble and uncertainty, a battle that most suspected their superiors could no longer wage. Accordingly, technicians and research support specialists were always on the lookout for trouble. Vigilance at the bench ultimately rested on semiotic skill: an ability to recognize the meaning of a host of contextually generated signs and signals. The lab staff therefore took pride in their ability to see intelligible codes where novices (and even scientists) saw no information at all.

V. Trouble at the Empirical Interface

Recognizing Trouble

Talk in both labs routinely centered on the relevance of colors, shapes, patterns, and occasionally sounds and smells. For instance, the MAb lab's research support specialist routinely referred to the importance of "keeping the cells happy," an idiom she shared with other cell culture specialists. "Keeping the cells happy" meant ensuring that cells were healthy enough to endure manipulations and that they behaved as expected. To ensure healthy cells, cell culture specialists continually monitored differences in the cells' shape and color as well as changes in the visible properties of the media in which they grew. A sense for the semiotic nature of the work can be gleaned from the following notes taken as the MAb lab's research support specialist

(Sally) trained an inexperienced technician (Mary) to evaluate a fusion. The discourse turned on calling the technician's attention to the meaning of visible cues:

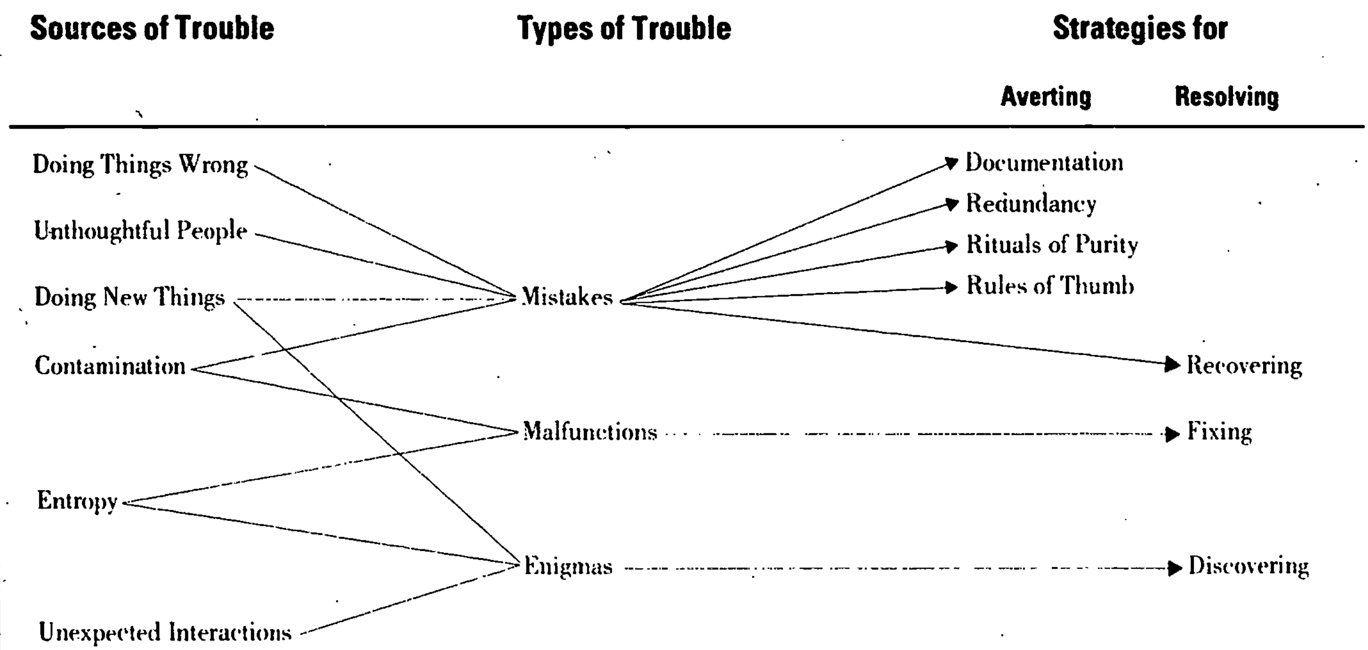
> [Sally and Mary took turns peering through a microscope. Sally looked first. Then, as Mary looked, Sally told her what to notice.] Sally asked Mary to look at the cells. As Mary peered into the microscope, Sally explained that there were many dead cells in the wells, but that the debris would eventually be cleaned away by macrophages and by refeeding. Sally assured Mary that the first time she looked at the results of a fusion she thought it hadn't worked. "But," she continued, "you can *see* that there are some live colonies beneath the dead cells." Sally called Mary's attention to a well in which the *medium had turned dark yellow*, a sign that the well probably contained many hybridomas. As Mary examined the well, Sally noted that the "*stretched out*" cells on the bottom of the well were fibroblasts. Mary asked how you could tell if a cell was a hybrid. Sally responded that if it weren't, it would eventually die and that dead cells "*look dark and grainy.*" Sally continued, "the *groups of round cells* are the hybrid colony. The *round single cells* are fibroblasts in the process of dividing, so they *don't have that stretched-out shape yet.*" Sally explained that fibroblasts aren't a problem until they start to *take over the bottom of the culture*, in which case you need to aspirate and move the cells to a new well. Next, Sally called Mary's attention to a well with mostly dead cells. She explained, "*Live cells look transparent and are very round.*" (Italics added to emphasize visual indexicals.)

In addition to reading naturally occurring signs, such as the shapes of cells, lab workers relied on an arsenal of instruments and procedures designed to produce or amplify visual signals and numerical codes. MAb lab personnel regularly used ELISA readers and a variety of stains and solutions to make cellular and sub-cellular states visible. Artificially generated signals were even more important in the FCL, where the work revolved almost entirely around reading images displayed on computer screens. For instance, to align a flow cytometer, technicians repeatedly examined histograms displayed on the monitor while adjusting such properties as the "tightness of the scatter." Alignment entailed iteratively "tweaking" a variety of controls to obtain a histogram whose shape the technicians deemed optimal for the task at hand.

Although instrument manuals and textbooks discussed many of the signs crucial to the practices of both labs, the staff claimed that only by experience could one become an accomplished interpreter. Experience was deemed critical for two reasons. First, considerable information was carried by subtle differences in shading and pattern that could not be adequately described or depicted. Second, like spoken languages, technological codes exhibited "dialects" or local variations. These variations were often tied to peculiarities of specific cell lines, machines, and experiments. Hence, experienced research support specialists and technicians made use of signs that could be found in no textbook and that were difficult to define except ostensibly. Partially for this reason, practices successful in one lab often failed in another unless technicians from the first trained technicians from the second (for similar observations see Cambrosio and Keating 1988; Jordan and Lynch 1992).

Interpretive finesse enabled lab workers to recognize when something out-of-the-ordinary had occurred. In the course of monitoring manipulations, lab personnel routinely compared what they saw to what they thought they ought to see. When signs deviated from the expected, lab personnel began to fear what they called "trouble." In some instances, signs of potential trouble were blatant, as when the MAb lab's research support specialist discovered that ascites drawn from the peritoneal cavity of a mouse appeared white instead of yellow. The RSS became concerned because she had never "seen this before." In other cases, signs were

Figure 2
Structure of Science Technician's Theories of Trouble



subtle and equivocal. On still other occasions, lab personnel were not even sure to what signs they responded: they could only say that something didn't "look quite right." Nevertheless, over time the co-occurrence of signs and events led lab personnel to formulate situated theories of why things went wrong. These situated theories shaped routine laboratory practice, informed the lab staff's strategies for managing difficulties, and constituted a considerable component of their knowledge.

The lab staffs' theories were composed of three constituents: sources of trouble, types of trouble, and a set of strategies for averting or resolving troubles. Figure 2 enumerates (and the following discussion elaborates) the constituents of theories that had currency in the labs we studied, as well as the relation between the constituents. In general, technicians typed troubles on the basis of their perception of the trouble's source and then acted accordingly.

Sources of Trouble

Doing Things Wrong. The staff of the two labs regarded their own foibles as the most prevalent source of trouble. From time to time, technicians and research support specialists created problems for themselves by forgetting, by working too quickly, or by misperceiving information. Lab personnel believed that such errors stemmed from several causes. Chief among these was lack of concentration. Being preoccupied or interrupted during a crucial task was said to enhance the likelihood of forgetting and, therefore, of either repeating or omitting steps in a procedure.

The inherent variability of biological processes was also considered a common cause of error. For instance, during log growth cells sometimes divide more rapidly than expected, thereby depleting their media of nutrients unusually quickly. If cells are not fed or cloned at this point, they die. Lab personnel routinely courted disaster by assuming, however reasonably, that specific cultures would grow at a normal pace. Bolstered by such an assumption, lab workers sometimes took what proved to be unfortunate risks, such as failing to monitor a culture over a hectic weekend.

Technicians and research support specialists contended that sensory-motor error was probably the most subtle cause of error. Personnel in both labs claimed that "having a feel" for one's instruments, materials, and techniques was crucial for successful practice. Although the idiom was at times synonymous with simple familiarity, in most instances technicians used the phrase to refer to tactile skills or what Harper (1987) called "ways of the hand." Many procedures in both labs required delicate manipulations. Too heavy or too light a touch could literally destroy what a technician or an RSS had achieved. The MAb lab's RSS was particularly conscious of the cost of sensory-motor error: "Fusions will not work if cells are touched wrong," she claimed. A variety of acts constituted "touching the cells wrong." Pushing a mouse spleen too vigorously through a screen designed to separate normal cells could damage an unnecessarily large number of cells and thereby lower a fusion's yield. Pipetting too forcefully into a test tube could destroy a cell colony at the bottom of the tube. Feel was also critical in the FCL, where clumsiness with an instrument's controls virtually precluded aligning the instrument effectively.

Unthoughtful and Unaware People. Technicians and research support specialists universally claimed that persons who were unaware of the implications of their actions enhanced the probability of error. For this reason, lab personnel watched outsiders and newcomers vigilantly until they departed or proved worthy of trust. Lab personnel were wary of two types of outsiders: visitors and collaborators with a reputation for "sloppiness."

Visitors were common in both labs. From time to time, each hosted high school biology classes as well as students enrolled in college courses. Salespersons, equipment repair persons, and clients also frequented both sites. Lab personnel had learned from experience that visitors could damage equipment or disrupt an experiment out of ignorance or happenstance. On one occasion, students from a neighboring high school unwittingly misaligned the MAb lab's phase microscope. The research support specialist spent two hours correcting the damage. On another occasion, a salesman from the company that manufactured the smaller of the FCL's two flow cytometers incapacitated the instrument for several days by "blowing a board" while demonstrating a product enhancement.

Although visitors could disrupt a lab's work, their stay was generally brief and lab personnel had authority to limit their access and activities. Far more troublesome were scientists and graduate students who were "unable to admit their shortcomings." Not only were such persons difficult to control (because they had higher status), but they also posed a more perpetual nuisance. Whereas lab workers might excuse a visitor's mistakes, they held careless collaborators accountable. Colleagues who repeatedly proved untrustworthy were said to suffer not from ignorance but from an "attitude problem."

Informants agreed that colleagues could prove troublesome for one of two reasons. First, scientists and postdocs who undervalued even an experienced technician's expertise and therefore ignored advice were said to "confuse status with knowledge." Second, acknowledged experts in one field sometimes overestimated their abilities in areas where their experience was limited. Lab workers viewed both shortcomings as a form of hubris that enhanced the probability of performing tasks carelessly, if not incorrectly. The tension generated by audacious and overconfident colleagues was routine in the MAb lab where the RSS was required to work with postdoctoral fellows from other labs, some of whom were widely known among lab personnel to be arrogant and "sloppy." On one occasion, a postdoc told the RSS that a particular sample was a positive control when in fact it was a negative control. The RSS did not discover the error for several weeks. Meanwhile, assays had revealed that the sample produced no reaction. Because the RSS believed the sample was a positive control, she concluded that the reagents were faulty and had already ordered new ones before another postdoc told her that she was misinformed.

Doing New Things. Practices in both labs changed constantly. At times, change was as minute as varying the proportion of an ingredient in a solution. At other times, change involved adopting an entirely new procedure. Reasons for doing new things were multiple. Technicians and research support specialists routinely modified their techniques to "optimize" procedures. Vendors continually updated the devices and materials they supplied. Over the course of the study, both labs purchased new machines and software and began new lines of research that required the staff to experiment with new procedures. When doing new things, even long-competent technicians became temporarily inexperienced and, hence, more prone to blunders.

Contamination. Knowing precisely with what materials one was working was generally considered a precondition for effective lab work. New procedures and new equipment violated this certainty, as did "contamination" by the presence of extraneous entities. Contamination could cause an experiment's failure, or worse, false or ambiguous results. Although contamination was of concern in all labs, those that cultured cells deemed the threat particularly acute. Cell culture specialists claimed that contaminants were not only omnipresent and hard to detect, but that it was often difficult to know whether a microorganism had invaded a culture until the culture was ruined.

Contaminants sometimes invaded a culture by "natural" processes, as when a mold released its spores on an air current. Supplies and reagents were another source of contamination. Thus, the research support specialist became concerned whenever she discovered that a shipment of fetal bovine serum contained flocculent, even though flocculent was common and generally benign. Finally, lab personnel themselves might contaminate a culture by being insufficiently careful. In such cases, contamination was viewed as the result of doing something wrong.

Entropy. Lab practice was predicated, in part, on the assumption that tools and materials possessed specific capacities. In time, however, all physical and biological systems degrade, tools and supplies being no exception. Lab personnel therefore considered entropy to be a particularly insidious source of trouble precisely because it exacted its toll gradually and imperceptibly. Materials and equipment that worked well today could go awry tomorrow without warning. When materials or equipment lost crucial properties, a procedure might not simply fail, it might return false results that the technician could misinterpret as valid, thereby triggering a chain of fruitless action.

Entropy wore many guises. The wear and tear of friction on moving parts disabled mechanical equipment. Chemical reactions gradually degraded critical reagents. Even the very techniques that enabled the staff to do their work often exacerbated the rate at which entropy occurred. For instance, in the MAb lab cryogenics were crucial for preserving cell lines, yet each round of freezing and thawing increased the probability that cells would perish. Similarly, centrifuging allowed technicians to separate cells from their media. However, if spun too quickly the cells would die and if spun too slowly they would remain suspended. Passaging (splitting and expanding) cell colonies was integral to culturing a cell line, yet with the trauma of each passage an increasing number of cells expired.

Unexpected Interactions. Iatrogenically generated entropy was not the only path by which routine lab practices engendered trouble. Laboratory work almost always entailed juxtaposing materials and machines in unnatural combinations. To the degree that materials, machines, and techniques were incompletely understood, such juxtapositions provided grounds for unexpected interactions.[8]

Unexpected interactions occurred with surprising regularity. Some proved frustrating but caused little trouble, as when the MAb lab's RSS discovered that using a homogenizer to blend small amounts of a substance was counterproductive because too much of the substance stuck to the blades. Other unexpected interactions proved more difficult to recognize and unravel. An example occurred in the FCL during an experiment designed to identify viable and nonviable bull sperm. Although the two types of cells were stained differently, the technicians discovered that the cells' optic qualities varied by their orientation at the time they were struck by the cytometer's lasers. Specifically, the paddle-shaped sperm cells reflected light differently depending on whether the laser struck their broad or narrow sides. The differential response led to an unexpected overlap in the distribution of optical frequencies being monitored. The trouble was eventually understood to have been caused by the fact that the technicians had sent the sample though the cytometer using a symmetric insertion rod which allowed the cells to orient themselves randomly to the laser (a problem that would have been irrelevant if the cells had been symmetrical). To obviate the interaction, the technicians replaced the symmetric with an asymmetric rod which forced a common orientation onto the entire sample.

Types of Trouble

Although technicians and research support specialists claimed that the troubles of a laboratory were legion, they recognized most troubles as being of one of three types: mistakes, malfunctions, and enigmas. As Figure 2 indicates, lab staff associated the three types of trouble with specific sources of trouble in a more or less orderly fashion, even though the specifics of a case could influence the mapping. For instance, technicians and research support specialists might label an instance of contamination as a mistake or a malfunction depending on how they constructed the chain of events that led to the contamination.

Lab workers spoke of *mistakes* when they thought that they had caused the trouble or that others had caused the trouble for them. Although lab personnel believed that most mistakes were unwitting, the degree to which they held the perpetrator culpable depended on whether the individual could be said to have "known better." In general, technicians and research support specialists greeted their own mistakes with annoyance and reserved stronger emotions for the mistakes of others. Mistakes might arise because lab personnel had committed sins of omission or commission, because someone had been "unthoughtful," or because new procedures or machines were being tested.

Malfunctions were troubles that arose when tools and materials ceased performing or performed counter to expectation. Malfunctions were particularly common in the FCL, where instruments were not only delicate but complex. Malfunctions were not, however, confined to electronic and mechanical systems: supplies could also fail. For instance, early in the study, a new stain marketed to the MAb lab for serum protein electrophoresis by a supplier of biologicals destroyed the layer of acetate across which the stained proteins were to migrate.[9] Technicians and research support specialists usually thought of malfunctions as the upshot of entropy and other natural processes.

Finally, lab personnel recognized a class of troubles that were neither mistakes nor malfunctions. Although the staff had no specific name for these difficulties, they were indexed by the technicians' occasional conclusion that some difficulty probably reflected properties of the physical systems or the technologies with which they worked. Lab staff readily admitted that much was still unknown about the materials they used, the phenomena they studied, and the techniques they employed. Therefore, procedures sometimes yielded results that the staff could not explain and organisms or devices sometimes behaved in ways that the staff found mysterious. Most lab personnel viewed such troubles, although frustrating, as an opportunity to push forward the frontiers of their science and technique. For lack of an insider's term, we shall label such difficulties *enigmas*—a noun that captures the consternation that attended such events as well as the staff's belief that all troubles could, in principle, be explained.

Although technicians and research support specialists recognized general types of trouble, they did not classify specific instances of trouble with finality. Instead, lab workers formulated a classification gradually as they tried to resolve or circumvent a difficulty. A classification had the status of a practical conjecture that allowed the staff to act (also see Barley 1988). If actions based on a classification proved useless, it could be revised. Hence, a problem initially attributed to a mistake might later be viewed as a malfunction only to be later reformulated as an enigma. Conversely, enigmas might eventually resolve into mistakes or malfunctions. Precisely because accounts of trouble shifted and because classifications were both a stimulus for and a result of action, lab workers rarely sought classification of problems as an end in itself, but rather as a means of containing problems as quickly as possible in order to keep their work on course. As Figure 2 indicates, strategies for averting and recovering from mishaps were linked to the lab staff's current understanding of the specific type of trouble they faced.

Averting Trouble Through Routine Practices

Lab staff premised their efforts to contain uncertainty on the dictum, "Avoid trouble when you can, confront trouble if you must." Accordingly, they had parlayed their theories of why trouble occurred into an arsenal of tactics for averting problems. These tactics comprised most of what passed as routine lab practice and were targeted primarily at avoiding mistakes.

Informants claimed that accomplished technicians were obsessively organized. "Being organized" carried many of the idiom's everyday connotations. Lab workers spoke of maintaining orderly records, scheduling activities, and keeping supplies in their proper place. Yet, in the two labs, "being organized" connoted more than working efficiently. Lab staff viewed "being organized" as the primary weapon in their war against uncertainty. Thus, to say that a technician was highly organized was to say he or she was adept at a work style that lab workers viewed as largely independent of procedure or scientific discipline.

Documentation. Central to this work style was an unrelenting concern with documentation. Technicians and research support specialists wrote incessantly. Some of what they wrote had a short life span. Lab workers routinely jotted notes to themselves about what they intended to do and what they had accomplished. These notes served as place markers in a flow of activity and were discarded as tasks were completed. Other forms of documentation endured for longer periods of time. For instance, technicians and research support specialists typically wrote experimental protocols. The staff regularly revised the protocols, but retained each version for years. Lab workers claimed that documentation was the backbone of an organized lab, not simply because it forced one to be explicit about what one had done, but because it provided a multifaceted defense against error.

First, documentation reduced the odds of forgetting. Most procedures required close attention to detail and unless lab workers remained focused, they could easily lose track of what transpired. By recording the flow of activities in forms ranging from log books to hastily jotted marks on scraps of paper, lab workers ensured that they would remember what they had done moments or days before.

Documentation also averted mistakes by forcing lab workers to rehearse before acting. For instance, when cloning hybridomas the MAb lab's RSS routinely created "maps" of the plates from which and to which she would passage cells. Each map consisted of a matrix representing the wells of a culture plate. Within the cells of the matrix, the RSS inscribed codes indicating the condition of the colony that lived in the corresponding well and the actions she intended with respect to that colony. Because the RSS developed her maps as she examined specific wells, the mapping forced her to make decisions and, hence, to think through the procedure before she performed it.

More permanent forms of documentation, such as protocols and lab notes, enhanced consistency across time and personnel. In both labs, key procedures were frequently reenacted. The validity of each enactment often required precise replication. Because most techniques encompassed a family of permutations geared to specific materials and objectives, without guideposts even experienced personnel risked performing procedures differently on separate occasions. The odds of inconsistency were further exacerbated when different individuals performed the replications. By employing protocols, notebooks, and other records as loose recipes for action, lab staff sought to eliminate inconsistency.

Protocols and programs served not only as recipes, but as templates. Even slight differences in materials or research objectives often meant modifying a technique. Faced with the need to modify practices, technicians and research support specialists almost always used existing protocols as baselines for accommodating new situations. By modifying existing protocols and programs, lab staff not only reduced the amount of work they had to do, they increased the probability that they would include crucial steps and alter only those parts of a procedure or program that needed to be altered.

Finally, as discussed below, documentation provided insurance when troubles occurred. Lab workers occasionally employed documents to support their claim that a specific problem was not their fault. More commonly, documentation allowed technicians and research support specialists to retrace their steps when seeking the root of a difficulty. Documentation therefore offered both a prospective and a retrospective defense against uncertainty.

Redundancy. Redundancy was a second tactic for circumventing mishaps. Technicians and research support specialists reasoned that they could recover from most mistakes if they had backups. Backups did not so much avert mistakes as obviate their relevance. Redundancy had several variants. One was to use a parallel system. If the main system failed, lab personnel could use the second to achieve their objective with minimal delay. Thus, the MAb lab's RSS routinely held some portion of the products of each step of a procedure in reserve until she was certain that the next step was successful. When freezing a cell line, for example, the RSS froze more cells than she needed and kept a sample of the cell line unfrozen in the incubator. After several days, she revived some of the cells to ensure that they had survived in sufficient numbers. If so, she simply discarded the sample in the incubator. If not, she cultured the incubated sample and repeated the procedure until revival produced an acceptable yield.

Overcompensation was a second variant of redundancy. Because lab workers recognized their proclivity for mistakes, they routinely double checked their actions. For instance, when calibrating flow cytometers and other instruments the FCL's staff took several readings to assure stability. The MAb lab's RSS also performed error-prone tasks in duplicate or triplicate. Calculations were a case in point. At numerous junctures in the course of cloning, one must calculate titrations. The RSS regularly calculated such values twice and sometimes thrice before recording the results on paper and doing the titration. The logic of redundancy also warranted the widespread practice of using several different sources of data to ensure the accuracy of an inference. Thus, when uncertain of their results, MAb lab staff used several immunoassays (ELISAs, Westerns, etc.) to ensure that hybridomas were secreting sufficiently high concentrations of an antibody.

Rituals of Purity. Out of the fear of contamination grew an almost obsessive concern with cleanliness. Tactics for ensuring cleanliness were especially prominent in the MAb lab. Sections of the lab were actually designated as "dirty" or "clean." Activities associated with the "dirty lab" were barred from the "clean lab" and vice versa. Routine paperwork, for instance, was performed in the dirty lab as was any aspect of a procedure considered impure, such as the sacrificing of mice. The clean lab was reserved for operations on cells, and the integrity of its boundary was carefully observed. The door connecting the two areas remained shut at all times and the staff shed lab coats worn in the dirty lab before entering the clean.

Within the clean lab, a panoply of practices for averting contamination enveloped the production of monoclonals. Taken together these practices defined the style of work that cell culture specialists termed "careful." All glassware was routinely sterilized in an autoclave before it was used and all procedures involving the preparation of cells or solutions occurred under a sterile flow hood that protected the materials from airborne contaminants and that siphoned fumes out of the building. When passaging or feeding cells, the RSS used pipettes with disposable tips. A tip used in one well or flask was never used in another. If the RSS accidentally touched a pipette tip against the side of a test tube or flask, she discarded it.

Rules of Thumb. Personnel in both labs further sought to avert mistakes by incorporating into daily practice rules of thumb derived from past experience. Rules of thumb were difficult to systematize not only because they were numerous, but because they pertained to particular instruments, materials, or steps in a procedure. Rules of thumb were rarely written down. Instead, they circulated among technicians as stories or snippets of advice. Rules of thumb did not dictate what tasks should be done (this was the role of protocols), but rather how tasks should be performed. The heuristics that shaped laboratory practices were of three general types.

"Cautions" were admonitions of vigilance that lab workers generalized from past mistakes. For instance, the MAb lab's RSS cautioned that if the phone rang when passaging cells, one should place the culture in an incubator and dispose of used pipette tips before answering the phone. The first act ensured the cells a hospitable environment should the call be lengthy, the second ensured that one would not absent-mindedly insert a pipette in the wrong well upon returning to the task.

Another body of heuristics pertained to ways of the hand, which lab personnel could not articulate except by example. Thus, when training others to perform fusions, the MAb lab's RSS monitored how deeply the trainee inserted the pipette tip into the wells and corrected faulty technique by demonstration. From experience, the RSS knew that if one inserted the pipette too deeply, one might disturb the cells on the bottom or even suck the cells into the pipette.

A third class of heuristics derived from formal scientific knowledge. In fact, such rules of thumb were a primary avenue by which the lab workers' knowledge of their science influenced their practice. Temperature, for example, was known to affect not only the metabolic rates of cells but the properties of reagents. When passaging cells, the MAb lab's staff therefore kept the hybridomas on ice not only to slow the cells' metabolism, but to mitigate against the possibility of a change in pH that could not be attributed directly to cellular processes.

Strategies for Resolving Troubles

Although technicians and research support specialists preferred to avert trouble, problems nevertheless occurred. Troubles typically heightened tension in the labs and evoked a flurry of activity intended to put derailed work back on track. Precisely how lab personnel resolved problems varied from case to case. In general, however, technicians and research support specialists employed three broad strategies for resolving troubles. Which they used depended on how they defined the problem at hand.

Recovering. Lab personnel viewed mistakes as indictments of their practice since, by definition, mistakes were problems that could have been avoided. Fortunately, most mistakes had limited effects. Technicians and research support specialists therefore sought to recover from mistakes by inserting corrective actions directly into the procedure's unfolding. Correctives put work back on track; they did not identify sources of error.

Lab workers used different tactics for recovering from mistakes depending on when they realized a mistake had occurred.[10] During the flow of work, staff periodically noticed that they were performing (or that they had just performed) an action incorrectly. Such mistakes ranged from pushing the wrong key on a calculator to passaging the wrong cell colony. Technicians and research specialists usually verbalized immediate recognition of an error with an "Oops!" or a more colorful synonym. Recovery often entailed no more than disregarding a result, repeating an action, or discarding ruined materials. Because instantaneous recoveries consumed little effort and quickly localized mistakes, they neither caused lab workers much difficulty nor seriously impaired the workflow. In fact, unless a lab worker called attention to the matter, a casual observer might not notice that an error had been neutralized.

More troublesome were mistakes that eluded the staff's attention. When technicians or research support specialists did not catch themselves in the act of making a mistake, they often did not suspect a mistake until they obtained unanticipated results. By this time, the staff may have performed additional operations, any of which could have gone awry. Consequently, lab workers now had to determine not only whether, but when, a mistake had occurred. Determining "what went wrong" was often a time-consuming task and might occupy hours, or even days.

Lab workers had little choice but to retrace their steps to recover from a temporally distant mistake. Here, documentation became crucial. To pinpoint what might have occurred, lab workers backtracked through programs, protocols, notebooks, and recorded calculations for an indication that someone had misinterpreted a cue, overlooked a critical detail, or acted carelessly. Combing the paper trail also helped the staff isolate the last step at which the procedure was on track. When their sleuthing uncovered an identifiable mistake, lab workers altered or annotated documents to reduce the odds that the problem would recur, and then resumed the procedure at the point where they believed it had gone awry. So long as one could identify a point where the procedure was on track, partial repetition often enabled lab workers to salvage their work even when they could not determine the source of the trouble. Inconclusiveness, however, left the staff uneasy, since an unexplained deviation raised the specter of a malfunction, or worse, an enigma that might someday return to haunt the lab.

Fixing. When lab workers believed that trouble stemmed from malfunctioning supplies or equipment, they usually sought to repair the problem's source rather than simply re-establish the workflow. Most lab workers took pride in knowing how their instruments worked and how to troubleshoot breakdowns. In fact, experienced technicians and research support specialists often enjoyed a reputation for being technical as well as scientific experts. A research support specialist in the DNA synthesis lab illustrated the extent to which some staff developed mechanical acumen. On the day of his interview, the RSS was overhauling a synthesizer. He explained with enthusiasm how he had already enhanced the efficiency of the lab's other synthesizers by modifying their design. Not only did he fully expect to do the same for the machine he was dismantling, but he claimed that many advances in scientific instrumentation arose from the tinkering of persons like himself.[11]

Although this individual's ability to "break a machine down and put it back together again" was perhaps extreme, most lab personnel had considerable knowledge of their equipment. Especially prevalent was a working knowledge of computers. Computers were critical not only because they were essential for analyzing data, but because they often controlled complex equipment such as the flow cytometers. The FCL's research support specialist's knowledge of computers was representative. Over the course of the study, he replaced several boards, solved several printer problems, and wrote a number of programs to enhance the cytometers' operation.

Although malfunctions caused delays and frustrations, technicians believed that malfunctions, unlike mistakes, did not reflect on their skill. The decision to repair a malfunction also occasioned a "time out" from the main flow of work as attention turned to the technical infrastructure that otherwise remained in the background. It was when confronting a malfunction that the staff momentarily ceased being scientists and assumed the role of mechanics or programmers.

Discovering. Enigmas consisted of unexpected results that lab workers had difficulty explaining as malfunctions or mistakes. As with malfunctions, lab personnel felt no blame for an enigma's appearance. However, because enigmas stymied lab work, perhaps more seriously than other types of troubles, lab workers sought their resolution with fervor. Enigmas not only posed puzzles, but also opportunities for refining knowledge and practice. Thus, when unraveling an enigma, lab personnel sought neither simple recovery nor a fix, but rather discovery.[12] Enigmas most frequently arose when trying new procedures or experiments.

An instructive example of an experimental enigma arose in the FCL. The RSS was pursuing a series of studies for which he was harvesting cells the day before they were needed. After harvesting, the RSS plated the cells onto a slide and washed them in a buffer before examining them under the video microscope. Although cells processed in this manner had responded well during early trials, one evening the RSS noticed trouble: large numbers of cells were dying before his eyes. Cell death continued even after the RSS repeated the procedure to eliminate the possibility of a mistake. The unexpected outcome and the RSS's inability to uncover an error triggered a series of attempts to resolve what had now become an enigma.

The subsequent problem solving was iteratively structured. In each iteration the RSS posed a conjecture for why the cells were dying and then acted in light of the conjecture to determine whether his action eliminated the difficulty. If not, the RSS sought a new hypothesis. Table 2 portrays the sequence of hypotheses, the source of each, the actions the hypotheses triggered, and the results of those actions. As Table 2 indicates, the RSS did not resolve the problem until

Table 2
Sequence of Steps in Resolving an Experimental Enigma in the Flow Cytometry Lab

Hypothesis	Source	Action	Result
1) The washing process is too stressful. Moving the cells from their wells to the slide before washing may cause the cells to dry out.	Based on the RSS's own prior experience in handling cells. In the past, cells have proven fragile and are widely known to require more or less continual exposure to a liquid medium.	Wash the cells in the wells of their culture plate before transferring them to a slide.	No effect. Cells continue to die.
2) The reagent could be causing the problem.	Based on the RSS's own prior experience. Even presumably "safe" reagents have been known sometimes to damage cells. Cells will lyse when improperly buffered.	Experiment. Examine cells exposed and not exposed to reagent. Also examine cells exposed and washed and cells exposed and not washed.	No effect. Cells continue to die.
3) The media are too old and degraded.	Possibility suggested by a specialist st consulted by the RSS.	Prepare and employ fresh media.	No effect. Cells continue to die.
4) A new lamp was recently installed in the video fluoroscope. The new lamp may be killing the cells by raising thier temperatures.	The RSS reasoned that the new lamp represented a change in conditions roughly coinciding with the problem's appearance.	Use a "cold" filter to reduce the heat emitted by the lamp.	No effect. Cells continue to die.
5) The cells have been passaged too many times.	In conversation, a colleague notes that cells are known to change over time as they are passaged.	Revive sample of cells that had been frozen down. Perform procedure on revived cells.	No effect. Cells continue to die.
6) There are at least "two populations" of cell: one "weak" and one "strong." Harvesting is rough on the cells and washing is stressful. Because of this the weak cells die. The strong ones need more time to recover before being studied.	Serendipity. A malfunction in the fluoroscope keeps the RSS from examining a cell sample for 24 hours after it is processed. When the fluoroscope is again operational, the cells appear fine.	Plate the cells out earlier and allow them to incubate for 48 hours before subjecting them to the examination.	Cell death ceases to be a problem.

a malfunctioning instrument serendipitously forced him to wait 36 hours before examining the cells. When the work resumed, the cells appeared healthy. The RSS postulated that the procedure stressed the cells but that it killed only "weaker" cells. Given enough time, "strong" cells revived and multiplied. He therefore decided to allow the "strong" cells 48 hours to reestablish themselves before continuing the procedure. The wait eliminated the trouble. Thus, what was initially a conjecture became a "discovery" about the way cells reacted to the procedure. The discovery, in turn, led the RSS to modify his protocol.

The case of the dying cells illustrates several features of the process by which lab workers tackled enigmas. First, lab workers only gradually concluded that an enigma existed. When events initially went awry, technicians and research support specialists almost always assumed a mistake had been made. Their first act was therefore to review the procedure for errors and repeat steps in hope of recovery.

Resolving enigmas usually required technicians to reframe the situation.[13] Reframings were posited as "hypotheses" or "conjectures" that warranted courses of action designed to test their plausibility. Technicians and research support specialists formulated conjectures from a variety of sources, including published studies, past experience, miscellaneous facts, serendipity, the co-occurrence of events, and superstition.[14] Conjectures served a practical rather than a theoretical agenda: lab workers posed conjectures with an eye to making difficulties disappear rather than elaborating theory. Note, for example, the RSS's notion of "strong" and "weak" cells was simply another way of saying that some cells survived and others died. If there was a difference, it lay in the assumption that not all cells were equally susceptible to death. Although the notion of strength and weakness shed no light on the process that caused death, it did enable the RSS to act in a manner that resolved the problem. The explanation was therefore a discovery, not because it was substantively enlightening but because it was pragmatically useful.

Resolving enigmas often involved pooling competencies. Faced with a recalcitrant problem, lab workers solicited advice from peers who might have encountered a similar situation or who might simply provide a fresh perspective. Lab workers pooled competencies in a variety of ways. On several occasions, staff from different labs joined forces in a concerted effort to unravel a puzzle. More commonly, ideas were solicited casually over lunch or coffee. At other times, technicians and research support staff called or visited their peers with the explicit intention of soliciting advice. Thus, unlike mistakes and malfunctions, enigmas led technicians to utilize the resources of their social network.

Finally, the discoveries that flowed from successful reframings usually remained local. Discoveries expanded the pool of knowledge and skill in a lab, but were rarely disseminated in any systematic way. Word of mouth was the primary path by which others became aware of what technicians and research support specialists had learned. Information was often relayed only when an event, such as an enigma encountered by another lab worker, warranted the telling. Practical knowledge in the laboratory community therefore had a sizable oral component, bits and pieces of which lay scattered among technicians and labs. If for no other reason, then, lab workers were indispensable to the university precisely because they served as repositories for a type of information that fueled empirical work.[15]

VI. The Role and Skills of Technicians in Scientific Work

Commentators have often portrayed technicians as mere hirelings who execute experiments designed by scientists to acquire data that scientists need. Descriptions of this sort are common in publications written by scientists as well as those written by technical educators for would-be technicians. Similar claims can be found in the sociological literature on scientific work (Latour and Woolgar 1979). Although the lab workers we encountered performed experiments and other tasks on behalf of scientists, their work was hardly that of functionaries. Instead, their role centered on managing irregularities, ambivalences, uncertainties, and other forms of trouble that plagued even the most well-practiced procedures.

Troubleshooting was both a discipline and a "way of life" among technicians and research support specialists. A panoply of undocumented practices for increasing the odds of a technique's success enveloped every procedure performed in the two labs and constituted most of the laboratories' routines. Although mentions of documentation, rituals of purity, rules of thumb, and strategies for recovering from mistakes or confronting enigmas were conspicuously absent in published discussions of scientific methods, the fortunes of the labs largely rose and fell by their exercise. Such a state of affairs challenges not only standard common conceptions of the technician's role but prevalent images of the distribution of knowledge in science's division of labor.

As Figure 1 suggests, the technical personnel we observed and interviewed stood between the scientists who nominally ran the labs and the empirical phenomena that the labs were founded to investigate. Lab staff ensured that empirical encounters progressed smoothly and yielded the data and other products that scientists required. To achieve this task, lab personnel employed and elaborated a body of knowledge that most scientists lacked: a *contextual understanding* of materials, instruments, and techniques grounded in hands-on experience. Contextual understanding was an amalgam of formal and informal knowledge whose mix was difficult to untangle. In addition to selected facts and propositions, contextual knowledge involved the ability to interpret situated and subtle signs, sensory-motor skills, heuristics cued to specific activities, personal or vicarious access to an unfolding history of events and fixes, and adherence to a work style marked by a concern for purity, reflexiveness, and constant documentation. Lab staff encoded and preserved their contextual knowledge through standard operating procedures and an oral tradition. In contrast, the scientists' understanding of the same phenomena was more abstract, formal, and distant. Although scientists and the lab staff understood what occurred in the lab, they understood it in different ways.

Because substantive knowledge was differentially distributed, the labs evinced a well-articulated division of labor: technicians and research support specialists were responsible for empiricism, while scientists were responsible for theoretical work. Because theoretical work depended on empirical practice and because empirical practice incorporated theoretical understandings, the two occupations were inextricably linked. Without the lab worker's knowledge, the scientist's activities would have collapsed and vice versa. Yet, unlike scientists, technicians and research support specialists had an ambivalent status in the university. The ambivalence reflected a disjuncture between institutional and everyday evaluations of the relative importance of contextual and formal knowledge.

Commentaries on the shortfall of scientists and technicians routinely conclude that the demands of an economy driven by science and technology can best be met by coaxing a broader segment of the population to pursue a formal scientific education. The rhetoric of employers likewise privileges formal knowledge and educational credentials. For instance, although technicians and research support specialists with vastly different educations were found at every level of employment, the university claimed to hire, compensate, and promote lab workers largely on the basis of credentials. This is not to say that formal scientific training was irrelevant for technicians and research support specialists. All of our informants possessed some form of scientific education, took advanced courses in their spare time, and claimed that competent technicians needed to be versed in one or more of the sciences. Technicians and research support specialists employed scientific theory at critical junctures in their work. The staff of both labs drew on scientific theories to determine what variables they needed to control during a procedure or experiment. Formal knowledge also informed rules of thumb and enabled lab workers to digest the scientific literature when developing protocols and unraveling enigmas. Yet, even the most well-credentialed lab workers viewed their formal education as but a starting point, a necessary but insufficient condition for being an effective practitioner.

Whereas scientists and educators often portray formal scientific training as a platform necessary for understanding the details of practice, technicians and research support specialists subscribed to the opposite point of view. They claimed that practice provided the background necessary for making sense of scientific theory. The MAb lab's RSS explicitly articulated such a philosophy when asked about her approach to training new technicians:

> Sally explained that the first thing she asks is whether the person has any background in tissue culture—whether they have ever done *in vitro* work. If she has to teach someone with no background, they have to read first. But when a person has a general background, her method is as follows: "First I let them observe me do it, then I let them do it, finally I give them materials to read. It's of little use to read about a process before you do it because the papers are too confusing. It works better if you see it first and then read. . . . Reading becomes more helpful once you have an idea of what the words really mean."

The FCL's technician corroborated the research support specialist's opinion of the secondary relevance of formal training:

Tech:	I used a lot more of my expertise from my degree [a master's in microbiology] there [in her old job as a serologist]. Here, I use it hardly at all. When I first came, I knew nothing about photocytology. I had never seen a laser before. I knew very little about computers. So it was really learning from square one, and I don't get to use any of my science here, really.
Bechky:	So how did you learn all this stuff?
Tech:	Just doing it.
Bechky:	Did you read about it?
Tech:	You know Ted [the lab's RSS]. He says, "Just go in there and do that!" "But Ted, I don't know what I'm

doing!" "Well, just try a few things." Occasionally, he'd say "here's some books," but they didn't really apply.

Bechky: They didn't apply?

Tech: Well, in a theoretical kind of a way, but not anything day-to-day.

In short, technicians and research support specialists were acutely aware that contextual knowledge was crucial to effective lab work even though they could not always articulate what constituted such knowledge. When asked what made for a competent technician, informants repeatedly spoke of the importance of "having a knack for the work," "artistry," "non-parallel thinking," "tacit understanding," and "craft work." Lab workers believed that they had more of this type of knowledge than did the scientists for whom they worked and claimed that without such knowledge a lab would flounder.

Many scientists and lab directors concurred. All research support specialists and most of the technicians indicated that professors and postdocs routinely sought their advice on empirical matters. Others, especially the research support specialists, described role complementarity, and even instances of role inversion, between themselves and senior scientists. For instance, an RSS in charge of DNA synthesis remarked:

Tech: From a supervisory standpoint. . . Fred [the senior scientist in charge of the lab]. . .[will] never tell you that you're full of shit. I think that's a general attitude [among most directors]. Let's put it this way. At certain times, he'll realize you know more than he does.

Bechky: Can you give me some examples of things you know more about than he does?

Tech: General theory. Use of DNA. All that kind of stuff. DNA synthesis. Even some aspects of amino acids. But he learns fast. Mainly, it's just specialized. We're all kind of like specialists.

In fact, several scientists who were interviewed readily admitted that they lacked the technicians' knowledge of empirical phenomena and that their lab's work hinged on the staff's know-how. The director of the MAb lab testified:

> I did tissue culture for six years and was pretty good at it. Fifteen years ago, I knew the state of the art. But now, I don't know what they are using to wipe down the incubator. I have no hands-on knowledge of the cells. Sally can tell immediately if the cells are happy, from all the hours she spends looking at them. This is where the art comes in. It isn't mystery or mysticism, just the things that you don't consciously know—they are at the edge of your consciousness. Subtle things. A tech will say, "This doesn't look quite right." No one ever tells you these things, they aren't written down in books. Thinking, aware people develop gut knowledge, a sense of the wellness of the system. I have seen lab directors ruin their lab by giving orders to an RSS or a tech who should be an RSS. A month later, the tech is looking for a new job and the director is left holding the bag.

Such testimonies indicated that lab personnel and scientists both appreciated the fact that scientific activity was variegated and unequally distributed. Both groups recognized that technicians and research support specialists worked at the point of empirical contact where materials, technologies, and natural systems met a symbolic world of theory and representation. In contrast, scientists worked more exclusively within the symbolic domain where they fashioned the products of the technicians' work into findings, theories, papers, and grants. Moreover, within the laboratory community, it was well-understood that the two occupations commanded different knowledge and skills. The technicians possessed most of the contextual knowledge of empirical matters, whereas scientists were masters of formal representations of the empirical. Because scientific productivity required both forms of knowing, scientists and technicians considered themselves to be *mutually interdependent*. Because technicians and research support specialists brokered the scientists' link to the empirical world and because the scientists admittedly lacked the lab staff's contextual knowledge, the lab staff were also understood by both groups to be structurally central to the system of production. Even scientists believed that in the absence of technicians and research support specialists empirical activity would be crippled because few scientists possessed the knowledge necessary to run the labs successfully.

That the lab staff's importance was informally recognized accounts for the discrepancy between policy and practice in the university. As previously mentioned, some technicians and research support specialists possessed no more than a high school degree, although the university claimed that such positions required higher credentials. The departure from university policy apparently occurred because scientists realized that experience was more relevant than credentials when hiring and promoting lab staff. The career of Don, a technician in peptide synthesis, provides a case in point. Don had become a technician after graduating from high school because he was interested in science and because his chemistry teacher knew members of the university's chemistry department. Don eventually left the lab because of low salary to become a carpenter. He was in the process of building a clientele when his current employer (with whom Don had previously worked) asked him to join his lab as the technician in charge of peptide synthesis. The scientist claimed that Don had a better understanding of peptide synthesis than any other technician he knew and arranged for a salary considerably higher than Don would have made on the basis of his degree alone. Don accepted the offer and returned to the university.

If the technician's role was so widely recognized in the scientific community, why did the university continue to privilege credentials and formal education? More generally, why have technicians remained invisible although they command skills and knowledge that scientists know are critical for empirical success? We submit that the answer is ultimately cultural: our system of social stratification has long privileged formal over contextual knowledge. Throughout the history of Western civilization, formal and contextual knowledge have been associated with the distinction between mental and manual work (Joyce 1987; Applebaum 1992). The same conjunction exists in the sociology of occupations where formal knowledge is typically associated with the professions and contextual knowledge with the crafts. In the eighteenth century, most science technicians were indeed craftsmen who built and operated scientific apparati (Shapin 1989). Modern science technicians continue to possess more hands-on knowledge of instruments and materials than the scientists with whom they work. But even though technicians possess considerable contextual knowledge, as we have seen, technicians' work is hardly manual labor in any traditional sense of the term. Nevertheless, the cultural cues associated with the technician's contextual knowledge elicited images of artisanal work and, hence, lower-status labor.

Technicians and research support specialists were well aware that formal knowledge had higher status in the university. As one technician remarked, "People here are infatuated with erudition." Technicians also recognized that scientists were thought to be more "erudite" than technicians and that the respect technicians were accorded informally was inconsistent with their lack of organizational recognition. When asked what they least liked about their jobs, all informants expressed dissatisfaction with pay, promotion, and other university policies, which they interpreted as a lack of appreciation for their contributions. Thus, the existential struggle for lab personnel was how to come to terms with their status as being, as one informant put it, simultaneously "a tech" and "more than a tech."

Among technicians and research support specialists two contrasting patterns of accommodation were common. Several sought to resolve the dilemma by embracing an almost blue-collar identity. These were the technicians who described themselves as "grunts" and who spoke most cynically about the university as an employer. Two had been actively involved in an unsuccessful attempt to unionize the university's technical labor force several years earlier. Others, especially the research support specialists, sought to circumvent status inconsistency by seeking employment in labs where they were treated as "professionals." The career histories of all the research support specialists included a story of how they had moved from lab to lab until they found a scientist willing to grant them the autonomy, flexibility, challenge, and respect they believed they deserved.

Ultimately, neither resolution was satisfactory. Those who embraced a blue-collar definition of self spoke of how much better life would be in industry or of how they hoped eventually to leave lab work altogether. Although in some sense happier, those who settled for local autonomy and recognition feared having only delayed the conundrum. Technicians could become highly specialized and hence indispensable to a lab, but there was always the chance that the research front would move away from their specialty or that technical advances might make their knowledge obsolete. "There is nothing sadder," remarked one technician, "than techs in their fifties whose professors retire. They are totally dependent on the good graces of the department to get a new job and have to start from ground zero with someone new. So a tech in his thirties has to start thinking, 'What is life going to be like if I stay here?'"

The literature on technical work suggests that similar status inconsistencies haunt the work of technicians employed in other contexts. Physicians informally recognize that emergency medical technicians (Nelsen and Barley 1992), medical technologists (Scarselletta 1992) and sonographers (Barley 1990) possess interpretive skills and contextual knowledge that are crucial to the delivery of effective medical care. Yet hospitals rarely compensate or classify members of these occupations at a level commensurate with their informal status. Koch (1977) and Evan (1964) have respectively argued that forestry and engineering technicians also experience status inconsistencies. Although the members of both occupations possess considerable formal as well as practical knowledge, their status is more akin to that of functionaries than that of the professionals alongside whom they work. In short, it appears likely that the privileging of formal over contextual knowledge may be endemic to all technicians' occupations.

If this is the case and if the occupational structure is indeed moving toward an increasingly technical labor force, then the culture of work in the United States may trip over itself as it heads toward the twenty-first century. On one hand, the continued devaluing of contextual knowledge may lead to an unwarranted emphasis on credentials which, in turn, may create unnecessary barriers to entry in precisely those lines of work that are expanding and toward which young people need to be lured. For instance, there is evidence that an overemphasis on credentials and formal knowledge may be partially responsible for the chronic shortages that have plagued medical technology since the early 1960s (Franke and Sobel 1970; Scarselletta 1992). At the same time, employment cultures that devalue technicians by treating them as replacements for the vanishing blue-collar employee are likely to increase turnover among those young people who do select a technical career. Together, these dynamics may virtually guarantee an inadequately trained technical labor force, not because people are educationally "unprepared," but because the economic and cultural rew rds associated with technical training are incommensura.e with its requirements. The transition to a technical workforce may therefore require a cultural as well as an economic journey. Unless conceptions of work rooted in the industrial revolution are revised, any recognition of the sort of horizontal division of labor that characterized actual relations in the science labs is likely to be straightjacketed by a continued replication of an organizational milieu associated with a vertical division of labor (Barley 1991).

Endnotes

1 Professional and technical workers currently account for 16 percent of the workforce.

2 From the beginning, however, an epistemological agenda underwrote the call for lab studies. The primary objective was to show that scientific knowing, like all forms of knowing, is socially constructed and that objectivity, in particular, is a negotiated accomplishment. This agenda led ethnographers to concentrate on the social processes by which theories arise and are subsequently accepted or rejected. Since the production of theories is primarily the scientist's job in the scientific division of labor, most ethnographers have focused on what scientists do rather than on the work of technicians who are perceived to be less involved in the production of "formal" knowledge. For instance, when describing the organization of the Salk Institute, Latour and Woolgar (1979) noted that "for the most part, the technicians were responsible for work which provided data to be used in the arguments of the scientists" (p. 217). They later lamented that technicians' "importance in the production of facts is usually underestimated" (p. 232). However, after acknowledging technicians' significance, Latour and Woolgar went on to say that because they were interested in the social production of facts rather than the social order of the laboratory, they would attend no further to technicians' work.

3 Technicians who repair complex equipment are examples of technical occupations whose work supports an organizational rather than an occupational labor process and hence are not embedded in a professional division of labor. Examples include copier repair technicians (Orr forthcoming) and microcomputer support specialists. Such technicians still manage the complexities of a physical phenomenon (the devices they repair), but other occupations do not treat the products of their work as raw materials for their own activities. Instead, their work is to maintain the infrastructure on which the labor process rests. If sussessful, others may take both the techncians' work and the infrastructure itself for granted, a state which micropcomputer technicians refer to as "transparency."

4 Monoclonal antibodies are to be contrasted with polyclonal antibodies. Antibodies were traditionally produced by injecting an animal with a pathogen and developing a vaccine from the animal's blood after it developed immunity. Because such serums contain many antibodies, including the one of interest, they are called polyclonal. Monoclonal technology produces only the antibody of interest. Monoclonals are used for medical and industrial applications.

5 Although the MAb lab used a variety of instruments (microscopes, hemacytometers, assay readers, cryostats, etc.), the devices were simpler than those found in the FCL and primarily facilitated the lab's main line of action: creating and nurturing cell lines.

6 The former employed a xenon lamp to excite fluorescently labelled cells and enabled researchers to measure emission intensity while varying the wavelength being monitored. The spectrofluorometer was used to optimize wavelengths for particular experiments and to measure such properties and processes as intracellular calcium concentrations, pH, and enzyme activity. The digital fluorescent video microscope also used a xenon lamp to excite cell samples whose images were displayed on a computer monitor. In contrast to the flow cytometers, the video microscope allowed users to view cells over extended periods of time.

7 In keeping with our informants' category system, we shall henceforth use the term technician only to refer to individuals employed in non-exempt positions. When we wish to refer to research support specialists and technicians as a group we shall speak of "lab workers," "lab staff," or "lab personnel."

8 For this reason, minor discoveries are potentially more frequent in the course of routine laboratory work than they are usually thought to be. Although these discoveries are unlikely to be of paradigm-shattering proportions, they grow out of puzzles that initially hamper work and they represent the path by which local bodies of practical knowledge evolve.

9 Similar in function to chromatography, electrophoresis is a technique for separating and identifying proteins. During electrophoresis, proteins propelled by an electrical current migrate across a chemically treated layer of acetate attached to a plastic film. Proteins with different molecular structures cease migrating at different locations, thereby forming "bands" or streaks across the acetate. Stains reveal the bands.

10 Lynch (1985) found that technicians who run electron microscopes deal with mistakes in similar ways. Like the technicians we studied, electron microscopists handled mistakes differently depending upon the lag between the mistake's occurrence and the time at which the technicians noticed the mistake. Lynch describes the

difference between the two approaches as the difference between an "oops!" and determining "what went wrong." We have adopted his vocabulary.

[11] Von Hipple's work on technological innovations (1978) supports the RSS's claims. Von Hipple found that users of equipment were the most frequent sources of ideas for product improvements.

[12] Given the epistemological debate surrounding the term "discovery," it is important to note that by this term we mean nothing more than "becoming aware of something about one's materials or techniques that one did not previously know."

[13] For an extended discussion of reframing in professional practice, see Schon (1983).

[14] For instance, when resolving the dying cell problem, the RSS had asked the person who last handled the cells successfully to do so again in the hope that she had a "magical touch" that would resolve the problem. Of course, she did not.

[15] Although researchers have often associated an oral culture of practice with engineering, commentators have usually assumed that written communication is more important than oral communication in scientific settings (Allen 1977; Zussman 1985). At least with respect to empirical practices, our observations suggest that such an assumption may be wrong.

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National Center on the Educational Quality of the Workforce

University of Pennsylvania
4200 Pine Street, 5A
Philadelphia, PA 19104-4090