DOCUMENT RESUME

ED 351 552 CE 062 417

AUTHOR Martin, Laura M. W.; Beach, King
TITLE Technical and Symbolic Knowledge in CNC Machining: A Study of Technical Workers of Different Backgrounds.
INSTITUTION National Center for Research in Vocational Education, Berkeley, CA.
SPONS AGENCY Office of Vocational and Adult Education (ED), Washington, DC.
PUB DATE Nov 92
CONTRACT V051A80004-90A
NOTE 63p.
AVAILABLE FROM NCRVE Materials Distribution Service, Horrabin Hall 46, Western Illinois University, Macomb, IL 61455 (order no. MDS-146: $5.75).
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Comparative Analysis; *Computer Assisted Manufacturing; *Educational Background; Employee Attitudes; *Employment Experience; Engineering Education; Engineers; *Experiential Learning; *Intellectual Development; Job Performance; Job Skills; Machine Tool Operators; Machine Tools; Machinists; *Numerical Control; On the Job Training; Postsecondary Education; Programing; Secondary Education; Skill Development; Technical Education; Thinking Skills; Trade and Industrial Education

ABSTRACT

Performances of 45 individuals with varying degrees of formal and informal training in machining and programming were compared on tasks designed to tap intellectual changes that may occur with the introduction of computer numerical control (CNC). Participants--30 machinists, 8 machine operators, and 7 engineers--were asked background questions and then presented with a series of paper-and-pencil tasks corresponding to the phases of the machining process. Participants' histories demonstrated many different routes into developing skills at work. Those who began careers by learning on the job were less likely to be involved in programming. Younger workers worked with CNC machines more often. The majority felt that hands-on experience supplemented by class work for certain basic topics was the most efficient way to develop skills in machining. Learning and teaching on the job were commonplace. The experimental tasks revealed distinctions in thinking patterns related to hands-on versus programming experience and to machining versus engineering training. They tapped experiential differences and yielded some evidence of mental restructuring due to learning programming. Participants were convinced of the power of hands-on learning and would not recommend a future work force deprived of traditional practical knowledge. Recommendations for CNC machining training included hands-on experience plus class work in basics and up-to-date techniques and continued training and mentoring among employees. (Contains 25 references.) (YLB)

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TECHNICAL AND SYMBOLIC KNOWLEDGE IN CNC MACHINING: A STUDY OF TECHNICAL WORKERS OF DIFFERENT BACKGROUNDS

Supported by
the Office of Vocational and Adult Education,
U.S. Department of Education

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National Center for Research in Vocational Education
Materials Distribution Service
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Macomb, IL 61455

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Supported by
The Office of Vocational and Adult Education,
U.S. Department of Education

November, 1992

MDS-146

FUNDING INFORMATION

Project Title:	National Center for Research in Vocational Education
Grant Number:	V051A80004-90A
Act under which Funds Administered:	Carl D. Perkins Vocational Education Act P.L. 98-524
Source of Grant:	Office of Vocational and Adult Education U.S. Department of Education Washington, DC 20202
Grantee:	The Regents of the University of California National Center for Research in Vocational Education 1995 University Avenue, Suite 375 Berkeley, CA 94704
Director:	Charles S. Benson
Percent of Total Grant Financed by Federal Money:	100%
Dollar Amount of Federal Funds for Grant:	$5,675,000
Disclaimer:	This publication was prepared pursuant to a grant with the Office of Vocational and Adult Education, U.S. Department of Education. Grantees undertaking such projects under government sponsorship are encouraged to express freely their judgement in professional and technical matters. Points of view or opinions do not, therefore, necessarily represent official U.S. Department of Education position or policy.
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ACKNOWLEDGMENTS

This report was prepared by Laura Martin, Project Coordinator, and King Beach, Research Assistant. Matthew Byrne assisted in the data collection and Roseanne Flores helped with data analysis. The report was completed without the review of the Principal Investigator, Sylvia Scribner.

Professor Scribner's death was a tragic loss to this project and to the other projects she was directing. Her insights will be painfully missed both in her own lab and in our larger professional community.

Sylvia was always careful to enlist the expertise of the people she studied at the workplace to guide her observations. Here, we wish to thank some of the many individuals who educated us and without whom our work could not have been completed. We want to thank John Antignani of Morubeni Citizen-Cincom, Inc.; Sebastian DeGiorgio and his colleagues at Kings Electronics; Steve Kotefsky of the New Jersey Institute of Technology; Andrew J. Rimol and Peter Baumann of the New Jersey Tooling and Manufacturers' Association; and Joseph Washington of Empire State College. We also want to thank the machinists and engineers who gave us so much of their time in allowing us to interview them. Our work has been enriched by our discussions with our colleagues at the Laboratory for Cognitive Studies of Work, as well as with Masato Saseki and Naoki Ueno. Joseph Glick of the City University of New York merits our gratitude for his commitment to and support of the continuing work of the lab.

We have to thank Sue Berryman of Teachers College, whose unflagging support, kindness, and understanding has kept us going through many difficult months. Her respect for Sylvia's intellectual mission is clearly and deeply felt. Sue's confidence that the work Sylvia entrusted to us will make a difference has already made a difference.

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INTRODUCTION

Policymakers and educators agree that there is a pressing need to develop relevant educational programs for workers in this country (Berryman, 1986; Cyert & Mowery, 1987; National Center on Education and the Economy, 1990). Not only do workers need to learn about new production techniques and acquire new, competitive skills, but it is essential that training be based upon scientific principles of learning in order for it to be effective and efficient (Raizen, 1989; Resnick, 1988).

Recent research pertaining to training needs and principles conducted at the Laboratory for Cognitive Studies of Work has examined the nature of different work activities and how they are affected by the introduction of new information technologies (Martin & Scribner, 1991; Scribner & Sachs, 1990, 1991). This research addresses basic questions of how the new work content (e.g., programming electronic technologies) comes to be integrated into existing knowledge systems by people through their activities. It asks how knowledge that comes from the hands is translated into abstract systems of notation such as program code. It also asks whether altogether new systems of thought develop through the savings in physical effort afforded by the new technologies.

For the study reported here, we looked at the domain of skilled machining. We were interested to find out what happens when people introduce a new symbol system such as coded computer programming notation for machine tools into their work routines. We wanted to learn how existing mechanical knowledge is integrated with the machine code in people's activity and thought. This information would give us a basis for making recommendations about training for the new technologies: how might they best be introduced; under what circumstances are they mastered; what kinds of support for learning are useful?

Background research in several disciplinary areas showed that machining activity can be understood as a complexly constituted set of historical practices which continues to be shaped by, as well as impact on, a variety of forces including technological developments, management/labor practices, legislation, and economic exigencies (Martin & Scribner, 1991). The field continues to be in flux; the capabilities and availability of new machines are being regrouped constantly.

The earlier work on machining activity was framed by an approach called activity theory (Leontiev, 1981; Scribner, 1989; Vygotsky, 1988; Wertsch, 1985; Zinchenko, 1985). This theory claims that complex psychological processes such as practical problem solving develop as individuals use specific physical tools (e.g., computers) and symbolic tools (e.g., language) to accomplish various tasks. The purposes of the tasks and the patterns of the tools' use are determined by the social environment which defines work goals and distributes responsibilities.

In the case of machining activity, factory goals, social negotiations among workers, individual work experiences, as well as the local task of getting a piece of work done, are all constituents of a knowledge-building process for machinists. For them, on-the-job thinking and learning can be seen as the outcome of complex and variable practices mentioned above as mediated by traditional tools and tools controlled by new technologies (Martin & Scribner, 1991).

Just as changes at the societal level affect people's activity (e.g., the widespread use of new information-organizing tools), an individual's history and identity as an actor shape how the activities with new technologies are specifically executed. Educational histories, in particular, play a critical role. According to activity theory, concepts that are learned through formal instruction allow different understandings than those learned through informal, everyday interactions (Vygotsky, 1988). Such spontaneous concepts are tied to concrete experiences; formal concepts, learned in school, are said to be more flexible because they are linked to abstractions that can then be applied to many different experiences. Formal concepts are also associated with a reflective awareness of the thinking process by an individual. For example, research that has been conducted among children who are beginning to learn specific scientific concepts shows that subjects' orientations to the experimental problems correlate with their levels of formal thinking such that meta-awareness is associated with formal solution strategies (Rubtsov, 1991).

Clearly, the distinction between spontaneous and formal concepts has important implications for the design of training experiences for workers in hands-on trades. Workers who develop their understandings from their hands may differ in what they can apply and generalize from workers who gain their understandings from blackboards or from working with graphs and code. Formal learning, for example, may not be as easily applied to concrete instances as hands-on knowledge; however, the application of hands-on knowledge may be restricted to familiar situations.

This research attempts to address the question of which kinds of educational experiences provide a better base for functioning in the technological workplace. At this point, researchers can only guess which kinds of training lead to the more flexible, generalizable conceptual development that educators and employers are calling for in the workforce.

The Nature of Machining Activity

In an earlier case study, we attempted to generate a close description of the Computer Numerical Control (CNC) machining job and to examine expert/novice differences in particular aspects of the activity (Martin & Beach, 1990; Martin, Scribner, & Beach, 1990). This investigation allowed us to look at the cognitive demands of the job as well. Our results suggested that, considering the tasks that machinists confronted, the introduction of CNC programming required, not just the simple replacement of thinking patterns, but a certain amount of restructuring of those patterns.

Looking at an expert and a novice machinist/programmer, we found that, with experience on CNC machines, a machinist begins to orient more theoretically to his task, to think in more linear fashion, and to use new means to solve familiar mechanical problems. We also saw some evidence that machinists' concrete visual representations shift to more abbreviated symbolic representational forms with CNC experience. Throughout, the relation between the technical and the symbolic did not appear as disjunctive as we had expected. The two systems interweave, and as the new symbol system is mastered, technical problems remain the focus of the job.

When we first began to study the impact of CNC technology on machinists' thinking, there were few specific guidelines to help us decide what was important to look at in workers' performance. As we collected observations and engaged in conversations with machinists and trainers, and, as we connected these with related work in cognitive studies, we thought we could expect to see the following: changes in programming strategies as machinists got more experienced (moving from program/procedural to job/executive considerations); and changes in verbal or graphic representation of the machining process as a result of visualizing tool movements in a new way (Lebahar, 1987; Lemercier, 1984). In fact, we saw changes in programming style where, after the language was mastered, machining rather than programming considerations predominated for the programmer. Our observations also suggested that, with CNC experience, machinists made different use of written symbols, like those found on the blueprint or layout sheet, as they planned a job.

Distinctions arising from concepts with different origins, namely, practical or theoretical knowledge, were also suggested to be likely among programmers but we were unable to examine it in our observational phase of work. This prediction, generated by an activity theory approach, is particularly important to track since it pertains directly to the following two realities of machining today: (1) the fact that the new technologies can be said to disrupt the sensory-motor information flow on which machinists traditionally have relied, and (2) that programming can be and is carried out by engineers who have been formally trained but who have no hands-on experience. Both of these issues force us to compare concepts whose origins are in classroom (formal) training with concepts derived from shop-floor training, the most prevalent course of learning in the field.

The current study sought to address some of the hypotheses generated by our readings and by our case study observations. Here, we wanted to confirm the evidence of restructuring of thought and to relate this to patterns of experience and training among individuals working in the machining industry. We wanted to see how formal and hands-on learning relate to problem solving and also to orientations to problem solving. We wanted to learn if there were patterns to workers' reflections on their identities as actors in a changing industry that arose from their work and training experiences.

To accomplish these tasks, we collected data according to a methodology pioneered by Scribner (loc. cit. 1984). We compared the performances of individuals with varying degrees of informal and formal training in machining and programming on tasks that were designed to tap intellectual changes that may occur with the introduction of CNC. The tasks were developed out of naturalistic observations of the work activity itself.

We collected three separate kinds of information. First, we collected data on training and work histories of our informants. Then, we presented the informants with a series of cognitive tasks. Specifically, we looked at the abstractness, linearity, representation, and integration of domains in technical descriptions of work generated by our informants. Finally, we asked informants to respond to several questions about the future of the industry and their own plans. Specific hypotheses were not tested. Rather, the interview records were examined for evidence of general qualities of information processing. Specific analytic measures were designed post hoc.

In the following section, we report the results of our interviews with machinists and engineers. We then discuss the implications of the findings for the training and preparation of machinists in adopting technological innovations.

METHOD

Study Participants

Participants were forty-five individuals currently working in the machining industry: thirty machinists, eight machine operators, and seven engineers. Participants had different amounts of hands-on machining experience, amounts of programming experience, and levels of formal education in machining concepts. Nine pilot informants were interviewed as well. Five categories of experience were distinguished as follows:

1. *Operators*—people who operate these machines but do not do the planning involved in setting them up;

2. *Traditional Setup Machinists*—those who are highly skilled at setting up—that is, preparing, adjusting, and planning—a range of traditional (noncomputerized) machine tools;

3. *Low Experience CNC Programmers*—machinists who had written between five and twenty-five programs;

4. *High Experience CNC Programmers*—machinists who had written at least a hundred programs for CNC machines; and

5. *Industrial Engineers*—engineers who may plan jobs and design parts.

A total of thirty machinist participants had experience setting up machines and making parts from a blueprint. Ten had no CNC programming experience, nine had written between five and twenty-five programs, and eleven had written a hundred or more programs. All twenty CNC machinists had setup experience on traditional, non-CNC machines.

Eight of our informants were machine operators. Machine operators follow directions provided by a setup person, or, in some cases, an engineer. They monitor a machine during production. The operators did not have any CNC programming experience at work (two had some classroom training in programming), nor did they have experience planning how to make a part and setting up a machine to run a job. It should be noted that operators often have skills in blueprint reading, micrometry, troubleshooting, and repair.

Seven of our informants were design and manufacturing engineers who had written fifty or more CNC programs; five had never actually made a part on a machine.

Our sample of machinists is representative of workers in smaller, Northeast shops and plants. The engineers cannot be said to be representative of all engineers in the area since most were recruited from a single source.

There were two women among our informants; one is a traditional machine operator and the other is an operator with some setup experience who is taking CNC programming coursework.

Procedure

Interviews with participants lasted approximately two hours. Participants were given a general introduction to our study and told what they would be doing.

Background Questions

Participants were first asked background questions that focused on their educational experiences, their work histories, and their experiences with machining. The interviewer took notes on a structured interview form and an audiotape record was also collected.

Problem Tasks

Participants were then presented with a series of paper-and-pencil tasks corresponding to the phases of the machining process. The method used for developing the problem-solving tasks followed Scribner's model (Scribner, 1984). The tasks were derived from our study of the history of CNC machining (Martin & Scribner, 1991), our case-based study of CNC machinists (Martin, 1988; Martin & Beach, 1990; Martin, Scribner, & Beach, 1990), several previous studies of CNC and machining (Lebahar, 1987; Lemercier, 1978, 1984), and several machining and engineering consultants. The interviewer kept notes of the participants' answers. A videotaped record was collected for four of the tasks (planning, modifying a plan, programming, and program chunking) and an audiotaped record was collected for the other task (problem scenarios).

Planning Phase

The detailed planning process necessitated by having to think through the elements and steps of a machining program differs from traditional setup practices (Hirst, Newman, Reder, personal communications, 1989; Lebahar, 1987; Martin, 1988). Traditionally, a setup person decides the general order of machining for a part but thinks through the details as the parts are manufactured, step-by-step.

Planning a CNC job involves a visualization of the whole process of part making in a more condensed way than previously, so that the image of the whole part-making plan could be said to exist in a more abstract and manipulable form. That is, if the machining process is imagined, considered, and adapted before an actual physical part exists it may be that this mental form of activity results in a more theoretical representation of the part process.

In earlier work, we found that the plan that is conceived for programming purposes seems to be more tightly linear than that prepared in traditional machining, since it has to eventually be recorded in a line-by-line fashion in the program itself. Any iterative or branching forms of thinking machinists do as they plan jobs on conventional equipment could be hypothesized to be smoothed out into a straight-running account in CNC planning.

For this study, the participant was presented with a photocopy of a blueprint of a three-stud electrical connector. This particular part was chosen because its manufacture involves a number of machine operations including turning, drilling, boring, grooving, threading, and milling. The primary operations for this part could most easily be done on a lathe, though they also could be completed on a milling machine. We decided to use a lathed part because machining on a lathe (operating in two or three dimensions) is generally considered less complex to do than on a milling machine (operating from three or more positions). Thus, while the part design and machining sequence were complex, the necessary machine actions were not highly so.

The participants were asked to study the blueprint and name the machine or set of machines they would use to make the part. If a participant had experience with CNC machines, he was asked to choose only among CNC machines. This constraint maintained the comparison we wished to make between traditional and CNC machinists; that is, we wanted them to strongly visualize the process for the different types of machines—mechanically-driven or code-driven:

- *Describing Preparations for Machining*
  The participants were asked to describe what they would have to think about and do before actually machining the part or before writing a program (in the case of CNC machinists and engineers).

- *Layout*
  Participants were asked to then plan out the sequence of operations they would use to produce the part. The blueprint of the electrical connector was available to the participants, as were a pencil and paper, a calculator, and the *Machinery's Handbook* (Oberg, Jones, & Horton, 1975). If participants did not spontaneously provide the sequence of machining operations and the tools they felt were needed to produce the parts, probe questions were used to specifically request the information.

  Preparing to machine a part is a process of mental construction, as is the participant's description of machining sequences. Almost any part can be machined using several different sequences of operations. Participants were asked to explain why a particular machining sequence was selected, whether there was an alternative sequence that could be used to machine the particular part, and what that alternative sequence might be. Whether participants could construct an alternative sequence was taken to be indicative of the flexibility with which they could represent and plan the machining process.

At the end of the description of an alternate machining sequence (if any), we asked the participants to re-state their original sequences of operations to see whether thinking through an alternate sequence had suggested any improvements to the first plan.

- *Modification of an Existing Part*

  Many machinists' parts are modified designs of parts they have produced in the past. However, the process of modifying past machining procedures to produce a new part is potentially quite different for CNC and traditional machinists—the latter may rely on personal memory and possibly on personal written notes that list some operations and tools. The CNC machinist has access to a modifiable program which specifies exact speeds, feeds, and tool paths in addition to operations and tools.

  We presented the study participants with a second blueprint of an electrical connector. This connector differed in several ways from the connector the participants had talked about in the layout tasks, but retained a majority of its features. The participants were asked to describe how they would modify the machine plan for the first connector in order to produce the second.

Programming Phase

The literature on programming suggests cognitive consequences to the activity, for example, improvements in problem-solving ability and planning ability, as well as consequences for programming approaches such as the tendency to consider semantic versus syntactic units (Pennington, 1987).

We were interested to know which aspects of programming were difficult for beginning programmers and how complex considerations of machine constraints, production efficiency, and particular part specifications would come to be integrated in a program. We did not suppose that programming would lead to generalized problem-solving skills, but we did want to see how the constraints of the medium presented obstacles or facilitators to traditional ways of thinking:

- *Programming Two Operations*

  Using the same part blueprint for which they described the sequence of machining operations, tools, speeds, and feeds, the participants were asked to write a section of machine instructions for the threading operation and the operation that occurs immediately before it in their machining sequence. Some of the participants who had more experience programming milling machines were permitted to write code for a milling sequence rather than for the threading. Traditional machinists without programming experience were asked to give machining directions in written English; machinists with programming experience were asked to write program code. As they worked, participants were asked to describe what they were doing while they did it.

  This task was chosen to provide insight into the overall quality of programming displayed by both CNC machinists and engineers at different levels of CNC experience. We were interested in the fluidity of coding or instructions, the detail of the code they chose, and in whether and how non-CNC machinists would attempt to specify tool movements by comparison.

- *Program Code Chunking*

  Chunking is a device often used to get at subjects' psychological categories in text, stories segments, and so forth. We were interested to know if the units of machine action differed for different groups of metal workers. Each participant with CNC experience was presented with several pages of a program for a series of turning operations. The program was an example taken from a CNC manufacturer's guidebook. A glossary of code definitions was provided for those unfamiliar with any of the commands in the sample. Participants were asked to divide the program into sections in a way that was meaningful to them, grouping lines of code together that they felt should "go together." They were also asked to describe why they were grouping the commands together in a particular way. Once they were done grouping the commands, they were asked to group the lines of code to form larger chunks (if the initial groups comprised single commands) or smaller chunks (if the initial groups were underdifferentiated).

Running Phase

Checking the work and interpreting the sources of errors as a job is being run is an essential part of the machinist's job. As we mentioned earlier, feedback on CNC machines is different from traditional feedback, in part because the material being worked on can sometimes be less visible and tangible. Also, mechanical errors are now often corrected via the program. Finally, the computer adds new sources of error, both because the program can be wrong or the system can malfunction. The CNC machinist must be able to sort out these levels of problems and take expedient steps to correct them.

It was observed that a number of problem-solving strategies were employed by machinists as they adjusted their machines, ranging from kicking the machine to reprogramming sections of code. We noted these mixed strategies and wondered whether those individuals with more programming experience would tend to question the program before considering other sources of error.

Problem Scenarios

The participants were presented with two problem scenarios that could occur during the running phase on either a traditional or a CNC machine. Both were problems that could have resulted from either a mechanical or programming error. We wanted to see the tendencies of participants to interpret feedback in specific ways. We also asked participants to develop alternative hypotheses for what went wrong as well as corrective procedures to assess the flexibility of their thinking.

The participants were presented with a simulated blueprint of a simple connector. Participants with CNC experience were asked to assume that the part was being made on a CNC machine while those without CNC experience were asked to assume that it was being made on a traditional machine.

The first scenario involved tool breakage which could have been due to a missing code command or to metal chips building up in a hole. The second scenario presented a problem that could result from incorrectly coded dimensions or incorrect tool fixturing.

Questions about the Future

The last set of questions we presented to study participants asked them about the future of the machining industry and the new technologies. Specifically, participants were asked:

- What do you think is the future of the industry?
- What do you think about the new technologies?
- What do you believe to be the best kind of training and preparation for the field?
- Would you recommend this field to a young person just starting out? Why or why not?
- What do you see yourself doing five years from now?

We wanted to know if people in the same field, who were responsible for different activities, constructed different understandings and expectations about their industry. An audiotaped record of their answers was kept and later transcribed for analysis.

RESULTS

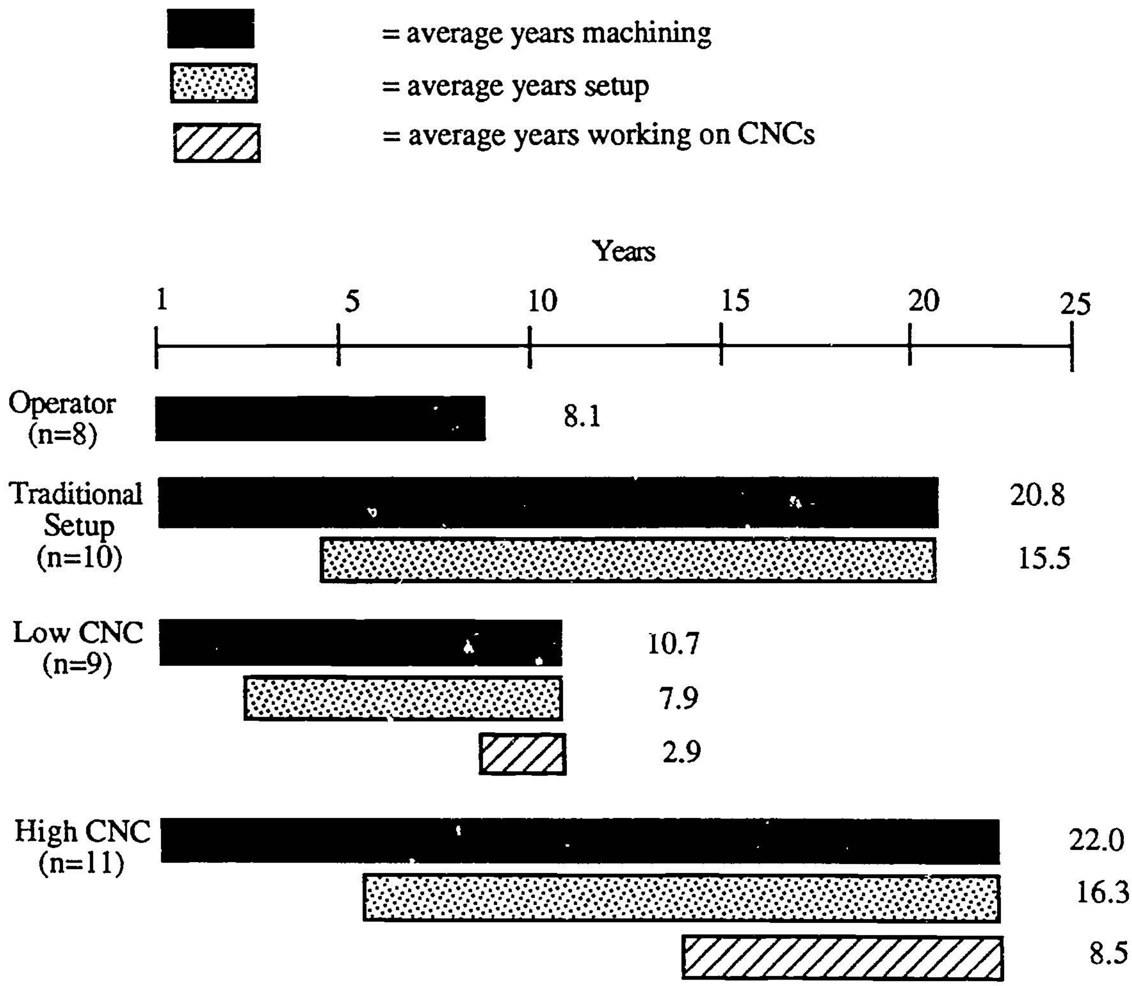
Background Questions

The background questions from our interview protocol yielded a description of the educational and work histories of the machinists and engineers who participated in our study. In this section, we attempt to portray the groups of participants and how they came to be working where they are. The patterns tell us something about the opportunities for professional development that exist as well as something about the role of different training experiences in people's careers.

Work Experience

Our informants consisted of individuals working in supervisory capacities as well as nonsupervisory workers, and one apprentice. Machinists had varying amounts of experience with traditional hands-on machining, both operating and setting up, and CNC work, as Figure 1 indicates.

Figure 1
Average Years of Experience in Machining and Setup



The figure shows, too, that those who entered the field a while ago (Traditional Setup and High CNC) began getting setup experience after about five or six years of operating. Those entering the workforce more recently either do not get into setup work at all (Operators) or get into setup work more quickly (Low CNC), in an average of four years.

The range of tasks required by machinists on the shop floor or in the engineering office is reported as quite varied and involves more than the machinery alone. For example, workers may supervise others, schedule jobs and machine use, make tools, write programs, and revise part plans. Engineers may estimate costs, design parts, oversee production, write reports, and conduct inspections. These responsibilities constitute activities that enter into thinking around new technologies.

Age

We did not explicitly ask the ages of our informants. The distribution of their general age groups (as calculated from their life histories) was tallied, however. Table 1 shows this distribution.

Table 1
Numbers of Participants in Each Age Group

	Low 20s	High 20-Low 30s	High 30-Low 40s	High 40s+
Operator (n=8)	1	2	4	1
Traditional Setup (n=10)	0	4	2	4
Low CNC (n=9)	2	4	3	0
High CNC (n=11)	0	3	5	3
Engineer (n=7)	0	3	4	0
Total	*3*	*16*	*18*	*8*

The ages of the traditional, highly skilled machinists (Traditional Setup) we interviewed fell into a kind of bipolar distribution: several were in their late twenties to early thirties and another group was over fifty. There were fewer traditional machine operators in the youngest and oldest age groups, suggesting that people do not make long careers in this field without becoming more skilled, and, that there are fewer people starting out now.

Setup machinists with low CNC programming experience were younger, the majority falling into the late twenties to early thirties age group. Experienced setup machinists with high CNC programming experience tended to be people in the late twenties to early forties age groups, people who had been working thirteen years at least. We met no new programmers older than their early forties, although a certain proportion of experienced programmers were in their late forties and up. Finally, the engineers with CNC experience that we interviewed were in their twenties to early thirties.

These figures suggest that in the kinds of workplaces we sampled, experienced machinists were the pioneer programmers and that relatively more younger workers are now being introduced to work on computer machinery, soon after they have had some shop floor experience. Overall, the more experienced setup people and operators who have been in plants a while are less likely to be working on computerized machinery. It should be noted that skill at setting up some conventional machines is graded higher than CNC programming according to the National Screw Machine Products Association job classification system so that having the chance to work on CNC may not offer any financial incentive to the most highly skilled.

Thus, from our sample it appears that machinists with a solid traditional background are among those programming the longest. It also appears that younger rather than veteran machinists are now being introduced to programming.

Ethnicity

Another way of understanding who enters CNC programming is to look at ethnicity. In Table 2, we can see that European-American (in this case) men are represented more often in the occupations of Engineer and High CNC. Workers in the other occupational categories come from a range of backgrounds, with relatively few African Americans and relatively more Latin Americans and natives of the Caribbean. The two Asians in our sample (both from India) are traditional setup men.

Among the twenty workers with CNC experience were six individuals with countries of origin other than the United States. These were Argentina, Austria, Columbia, Jamaica, Germany, and Poland; that is, fifty percent European and all those with High CNC experience were of European extraction. In contrast, eight out of ten traditional machine workers from countries of origin other than the United States were non-European. Thus, in our sample, relatively more people of European origin were working with CNC than other ethnic groups.

This trend may reflect patterns of immigration. Newer workers are more often from non-European countries. Perhaps those among them with less advanced language and other skills find work as operators. The fact that they seem to stay in those jobs longer than did immigrants from previous years suggests that training and possibilities for advancement are not the same as they were. It also suggests that non-European immigrants among the Low CNC group advanced because of skills with which they arrived. The lack of African Americans in the field is also striking and probably reflects older patterns of job opportunity in this country.

Table 2
Numbers of Participants in Each Ethnic Group

	European American	African American	Hispanic	Latin American/ Caribbean	European	Asian
Operator (n=8)	2	0	1	4	1	0
Traditional Setup (n=10)	5	0	0	2	1	2
Low CNC (n=9)	3	1	1	3	1	0
High CNC (n=11)	9	0	0	0	2	0
Engineer (n=7)	7	0	0	0	0	0
Total	*26*	*1*	*2*	*9*	*5*	*2*

Career Paths

We were interested to know characteristics of the career paths that led people to this field. About two thirds of all informants had begun their work careers in the field of manufacturing (see Table 3), with relatively more CNC machinists beginning in the field than non-CNC machinists. As we stated earlier, our sample of engineers cannot be said to be representative; however, their experiences illustrate a kind of career path that is not uncommon.

Those who started their careers in fields other than machining began in other industrial or technical jobs about half the time. Again, relatively more CNC machinists had a direct career path in machining.

Table 3
Was Your First Job in Machining/Engineering?
(Numbers of participants)

	Yes	No: Industrial	No: Non-Industrial
Operator (n=8)	3	2	3
Traditional Setup (n=10)	6	1	3
Low CNC (n=9)	7	0	1
High CNC (n=11)	9	2	0
Engineer (n=7)	6*	1	0
Total	*31*	*6*	*7*

*Two engineers began as machinists

The reasons people went into the field varied quite a bit. Some were tinkerers who enjoyed working with their hands and with machinery. A sizable group went into the field through family precedent. Others found jobs by chance and discovered they liked the work, or machining was the only job available. Some became interested in careers after taking machine shop courses, or having the field recommended to them as something they might like to do. Table 4 shows the different kinds of reasons cited by informants in each job category.

It is quite striking that those working with CNC show a more clearly chosen career path than others; that is, they most often entered the field by choice or family precedent.

Table 4
Numbers Choosing Different Reasons for Going into Machining/Engineering

	Choice	Family Precedent	Chance	Recommendation	No Choice
Operator (n=8)	6	1	0	0	1
Traditional Setup (n=10)	3	1	3	1	2
Low CNC (n=9)	5	2	0	2	0
High CNC (n=11)	4	4	2	0	1
Engineer (n=7)	6	1	0	0	0
Total	*24*	*9*	*5*	*3*	*4*

Formal Education

In the sample we interviewed, CNC machinists (who also had traditional setup skills) tended to have more formal education than non-CNC traditional setup workers. Only two CNC machinists, for instance, had not completed high school. Again, this suggests there is a more committed career path among those who are learning new technologies.

At the point that they began working in the field, the majority of our informants had at least a high school degree (see Table 5).

A small group of machinists undertook degree work after becoming machinists. In all, ten individuals (including five engineers) among our informants finished formal degrees after starting their careers. Table 6 shows the last grades ultimately completed.

In total, about half the non-CNC machinists (n=18) completed high school or higher grades. Individuals who did not complete high school all grew up outside the United States.

Table 5

Highest Degree Before Beginning Work

(Numbers of participants)

	None	High School	A.A.	B.S.	M.S.+
Operator (n=8)	4	3	1	0	0
Traditional Setup (n=10)	8	2	0	0	0
Low CNC (n=9)	2	6	1	0	0
High CNC (n=11)	3	8	0	0	0
Engineer (n=7)	2	2	1	2	0
Total	*19*	*21*	*3*	*2*	*0*

Table 6

Numbers of Participants Completing Each Grade Level

	Below High School	High School	Some College	Four-Year College	Postgraduate
Operator (n=8)	4	3	1*	0	0
Traditional Setup (n=10)	6	3	1*	0	0
Low CNC (n=9)	2	5	2	0	0
High CNC (n=11)	2	4	4	1	0
Engineer (n=7)	0	0	0	5	2
Total	*14*	*15*	*8*	*6*	*2*

*Schooling in Latin America/Caribbean

Of those informants who had attended high school, sixteen had studied machining in vocational programs. While members of every group had taken vocational classes in high school, relatively more workers involved with CNC had this type of training (except among engineers). In addition, twelve informants had participated in formal apprenticeship programs (several more had served informal apprenticeships in family businesses). Two traditional setup men had participated in formal apprenticeship programs (both in England) and two in our sample of seven engineers also had apprenticeship experience in machining. In addition, three non-CNC machinists in all had received training in some technical field in the military.

Training on the Shop Floor

From our discussions with numerous machinists over the years, we can say with certainty that their most meaningful learning takes place on the shop floor. Three short cases provide illustrations of the importance of hands-on learning:

Case 1 John M. had attended shop classes in high school and began working as a machine operator in a senior year work-study program. After high school, he served a four-year apprenticeship and worked his way up the ranks. He then attended a manufacturer's course in CNC programming as part of his job and took a CAD/CAM course at a local community college. For the past seven years, he has been programming. John feels that classes are good for covering some of the machining basics. He also feels that the real lessons occur with trial and error on the job.

Case 2 Edward S. is a machinist who can set up and operate lathes, mills, and screw machines, although now he works exclusively on Brown and Sharpes, a type of cam-driven screw machine, whose setup requires highly-rated skills. Edward got into machining by chance and got into an apprenticeship program through a local college. He believes working with an experienced person on the job is the best way to learn machining.

Case 3 A student engineer we talked with (but whose data is not included in our analysis) came up through the ranks of machining. Steve began his career in a two-year vocational technical high school program. He entered a four-year state apprenticeship and worked four years before doing setup. After about seven years, he began doing engineering work on the job. He subsequently went back to school and got an Associate's degree in engineering and is now finishing his Bachelor's degree. Steve feels his machining background is essential for his work. He talks about a colleague with no hands-on experience as working with a great disadvantage.

On the job, people receive training that ranges from opportunities for close observing, to being verbally instructed, to trial and error.

Most of our informants reported experiencing a variety of training situations. As Table 7 shows, most did receive specific verbal or nonverbal instruction. Everyone had to make their own mistakes, though a few were entirely left to their own devices.

Table 7 also shows that CNC machinists are more likely to receive on-the-job instruction that comes before being required to carry out an action (Observing, Formal Apprenticeship), while non-CNC machinists are more likely to be told what to do and then corrected after their actions (Being Told, Trial and Error).

Table 7

Numbers of Participants Experiencing Each Type of Training on the Job

	Observing	Formal Apprenticeship	Being Told	Trial and Error	Other	None
Traditional Setup (n=10)	1	2	8	6	1	0
Low CNC (n=9)	4	2	3	4	3	0
High CNC (n=11)	2	7	5	2	0	0
Total	*7*	*11*	*16*	*12*	*4*	*0*

Training is part of workplace activity. When we asked people whether they had ever taught anyone as part of their work, the overwhelming majority (89) of our informants answered affirmatively. In fact, informants reported that they teach "everything," including basics of machining, programming, blueprint reading, setup, and specific machine features.

Our informants also provide help to a variety of coworkers and management, as Table 8 indicates. This kind of assistance may not be counted as training activity, but reveals the cooperative, problem-solving nature of the machining environment in which workers regularly learn from each other's experience.[2] When they need help on the job, our informants consult with others, too (see Table 9).

Table 8
Who Comes to You for Help*
(Numbers of participants)

	Peers	More Skilled	Less Skilled	Supervisees	CNC	Engineers	Setup	Other
Operator (n=8)	6	1	4	0	-	1	-	0
Traditional Setup (n=10)	5	0	6	4	-	0	-	2
Low CNC (n=9)	2	1	3	2	-	0	-	0
High CNC (n=11)	6	0	5	8	-	2	-	2
Engineer (n=7)	3	2	6	3	2	-	2	0
Total	*21*	*4*	*24*	*17*	*2*	*3*	*2*	*4*

*Responses in more than one category are possible

What is striking about Tables 8 and 9 is that they suggest that CNC may be breaking up traditional hierarchies of expertise. CNC programmers are consulted by engineers and CNC programmers do not consult with their supervisors, but, rather, with management, among others. This finding is consistent with reports in the manufacturing literature which describe increased collaboration between engineers and office workers with CNC machinists because efficient programming demands knowledge of machining.

[2]Other machining professionals discussed a traditional lack of communication between engineers and machinists, with engineers being described as less than willing to share information and to learn from machinists.

Table 9
Whom Do You Go To for Help*
(Numbers of participants)

	Peers	More Skilled	Super-visors	CNC	Engineers	Setups	Managers	Manu-facturer
Operator (n=8)	1	6	5	0	2	1	0	0
Traditional Setup (n=10)	3	1	7	0	2	-	1	1
Low CNC (n=9)	0	2	4	-	2	0	3	0
High CNC (n=11)	4	3	0	-	4	0	6	2
Engineer (n=7)	2	2	1	0	-	1	1	1
Total	*10*	*14*	*17*	*0*	*10*	*2*	*11*	*4*

*Responses in more than one category are possible

Formal Training in Conjunction with Work

The problem-rich environment of the shop floor fosters training, collaborative work, and assistance across many job categories. The shop experience stimulates many workers to pursue formal instruction in their field outside their workplaces, most often in community college technical programs.

In fact, the great majority of our informants reported having taken additional professional classes or professional classes for the first time once they had been employed as machinists and engineers. In a machinist's or engineer's career, technical courses may or may not have been part of formal degree programs. Table 10 shows the distribution of technical courses taken by our informants in relation to degree programs (completed and not completed). The classes reported included a range of technical topics, for example, algebra, CAD/CAM, and blueprint reading.

Relatively fewer of the traditional setup machinists were involved in continuing education. Among all machinists taking technical courses, however, only one had taken

CNC programming exclusively, while three out of the five engineers taking classes had taken programming exclusively.

Table 10

Number of Individuals Taking Technical Courses and Program Types

	None	Non-Degree Program Only	Part of Degree Program Only: High School	Part of Degree Program Only: Post High School	Combined Degree and Non-Degree Program
Operator (n=8)	1	4	0	0	3
Traditional Setup (n=10)	2	5[3*]	0	1	2[1]
Low CNC (n=9)	1	0	2	1	5[1]
High CNC (n=11)	0	1[1]	1	0	9[2]
Total	*4*	*10*	*3*	*2*	*19*

[*] Number of informants in the group having participated in certificate (non-degree) technical programs: military, apprenticeship, specialty certification

One informant was counted twice; his coursework was part of secondary and postsecondary degrees only.

Patterns of Training

We conclude from these patterns of formal and informal training that education in this profession is not a straightforward matter. While those involved with CNC seem to have more direct educational trajectories overall, members of all categories of workers are involved in on-the-job training, classwork, degree work, and practical and basic courses. Formal class topics included general math and machining, engineering, specific machining techniques, CNC, and blueprint reading. Whereas engineers often took additional courses in programming alone, CNC machinists took a variety of courses. Traditional machinists were somewhat less likely to take classes while working.

About half of those extending their technical education probably had some support to do so. Of the total group of study participants, only twenty-four percent noted that their employers paid for coursework; another twenty-two percent stated that coursework was definitely not paid for by their employers. Among the remaining, we infer from the type of classes they took (e.g., training on a specific machine at a manufacturer's premises) that about half were likely to have had employer sponsorship for training in some way.

Summary

There were many different routes into developing skills at work, as our study participants' histories demonstrated. Those who began their careers by learning on the job, however, were less likely to be involved in programming than those who had had vocational training or formal apprenticeships. Younger machinists worked with CNC machines more often than older machinists. Younger workers with high school vocational experience were also more likely to have opportunities to learn CNC. People of color were less likely to be involved in CNC programming.

The majority of informants felt that hands-on experience supplemented by classwork for certain basic topics is the most efficient way to develop skills in machining. Most machinists (and engineers) combined on-the-job learning with formal classwork of some kind in technical subjects after they were employed, with many beginning classwork only after starting their careers. Support for continuing training falls short of what workers would like. Most workers would avail themselves of training if it were paid for by their employers.

Learning and teaching on the job are commonplace, and in this period of rapidly changing technology, workplace training is likely to be the most efficient route to diffusing skills, both traditional and new.

Interestingly, CNC machining may be disrupting some of the traditional social patterns of sharing expertise on the shop floor. These patterns seem to have arisen out of necessity in that engineers who are formally trained in programming need to access traditional knowledge to be efficient and machinists learning programming can get conceptual assistance for programming from engineers.

Experimental Tasks

In the previous section, we described the participants in our study and the routes they took to arrive at their current work situations. This section describes something about the ways that members of groups we interviewed think as they work.

Recall that we were interested to see (1) if working with CNC machines created any changes in thinking patterns; (2) how technical knowledge about machining becomes integrated with the symbolic ways of describing work, that is, through code; and (3) whether having a formal technical education made a difference in how someone solved everyday problems.

For this project, we developed and piloted a number of tasks designed to examine differences in thought and problem solving associated with traditional hands-on mechanical machining on the one hand and machining as mediated through the symbol system of a computer program on the other. The tasks we developed for each phase reflect what, from our previous research, we inductively reasoned to be critical areas of cognitive change as CNC technology was mastered.

We decided at the outset that the task battery should reflect the three phases of the machining process: (1) planning or layout of the job, (2) programming of the CNC machine, and (3) running the job on the machine. Our reason for addressing each of the phases goes beyond coverage of the process simply for the sake of completeness. Each phase involves actions that are influenced by the new technology.

The programming phase, during which the program is actually written, is unique to CNC machining. It provides an indirect, symbolic link between the machinist's knowledge and skills and the machine's mechanical actions because the programmer uses code to describe, in advance and in sequence, what the machine and tools will do. The programmer also takes into account what he knows to be the constraints of the metal, the size, characteristics, and nature of the part.

Unlike the programming phase, the planning and running phases are not unique to CNC machining. However, they may function differently for traditional and CNC machinists. The increased flexibility and accuracy afforded by CNC machines and the fact that programming is an intermediary step between planning (or layout) and running, restructures the planning phase. With CNC, it becomes preparation for programming. With CNC, too, the running phase becomes restructured as an exercise in program debugging in addition to one of mechanical fine tuning.

For the layout or planning phase, the participants were asked to describe their preparations for machining a part presented to them in blueprint form. The programming phase asked participants to write a section of machine instructions, in code if they were programmers or in English if they were not. Coders were also asked to read a section of code and to "chunk" it into sections that "belong together." Finally, the running phase was addressed through questions based on two scenarios of what might occur during the actual cutting of a part.

A special coding sheet was prepared for the interviewer to record the informants' responses. Interviews were audio- and videotaped as well, to permit analysis of verbal and nonverbal behaviors.

Planning

Our previous work (Martin & Scribner, 1991; Martin, Scribner, & Beach, 1990) suggested that the planning of how to make a part is an intellectual domain that might be affected by the introduction of computerized technology into machining (see Introduction). In order to study the approaches to the process of part planning taken by people with varying backgrounds, we presented machinists and engineers with a blueprint for a 1.034-inch cylindrical connector and asked them to develop a machining plan.

Among the features of this part were holes, flats (planes cut perpendicular to the arc of the cylinder), studs, a thread, grooves, and shaped inner and outer contours. Machining this part requires milling, turning, and screw machine action.

We asked our informants to study the blueprint to imagine the machine or machines they would make the part on and then to tell us what they would have to think about before they began. Participants were also asked to either write code or write step-by-step machine instructions for carrying out two sequential operations for machining the part. Our analyses were based on the actual plans they produced as well as on their verbal descriptions.

Initial Orientation

We were interested to see how people oriented to the planning task because orientation has been suggested to be related to the level of a person's abstract thinking about a problem (Rubtsov, 1991). Our own piloting suggested that there may be some interesting differences in how people with different levels of experience framed the planning activity. We wanted to know both how participants interpreted our request to them and how the complex elements of machining are integrated for them at that point. To assess orientation, we analyzed the content of the informants' responses to our probe ("What would you have to think about before you actually began making the part?").

In orienting to the planning process, participants showed a fair amount of variation in the elements they thought about before they began to make a part. In all, individual participants from each professional category reported between eleven and fifteen different elements taken into consideration as they prepared to run a job. Table 11 shows the array of nominal topics our informants mentioned as elements they considered as they began setting up a job and the percentage of responses in each category by group. The percentage represents the number of times a topic was mentioned by a participant in a category compared to the total number of considerations mentioned by the group members. Some topics listed actually encompass several subtopics. For instance, the category "Economy" glosses Cost of the Job, Time Efficiency, the Size of the Job, and Whether Materials have to be Ordered. The category "Social Relations" encompasses responses such as "First, I wait for the engineer to tell me what to do."

There are several trends in the data. First, operators' initial considerations were fairly evenly distributed among categories and showed an unsystematic set of planning concerns in orientation. There is a slightly stronger orientation toward the blueprint specifications, which tells them what part they are working on.

Traditional machinists who are used to planning either one step at a time or to setting up a multipurpose machine thought primarily about practical procedural steps at the outset of planning, for example, which cams they would select (e.g., "Put your cams on, check your slides, clean them, check the tool rollers"). They mention objects that mediate action less often, like the blueprint, the materials, and the machine. Furthermore, the part specifications dictated by the blueprint are implicit in their choice of cams, and in the machine adjustments which come after tools are put in order and mounted.

Table 11
Topic Considerations During Initial Planning by Group
(Percent of total responses per group)

Topic	Operator	Traditional Setup	Low CNC	High CNC	Engineers
Blueprint	21	12	5	24	16
Materials	5	0	19	30	30
Tools	11	8	10	6	8
Machines	5	12	0	18	8
Program	11	—	10	3	0
Procedures, Specifically	16	32	24	9	4
Procedures, Generally	16	24	29	9	16
Economy	11	8	5	3	19
Social Relations	5	4	0	0	0

Less experienced CNC programmers expressed a hybrid pattern of orientation between the High CNC and traditional setup orientations, showing concern with material specifications like the High CNC group as well as to procedure like the traditional setup group.

Experienced CNC machinists tended to mention thinking about the blueprint (i.e., part specifications and dimensions) and the materials with which they have to work. The materials in part drive the fixturing, the operation order, and the choice of tools, which some also mention. Experienced CNC machinists were less immediately focused on practical operations.

Engineers oriented to the materials and economy issues more strongly than to other elements. This orientation is understandable since, in their work, they are responsible for designing the most efficient manufacturing sequence for a part given available materials. Engineers also express a fair amount of concern for low cost, high efficiency, and availability of materials in their planning (setting factors).

When we group the topics that participants oriented to into functional categories and calculate percentages, we see that a number of participants oriented to planning by describing a contingent or relational consideration, for example, the type of machine to be used given the specific metal stock (material) or the type of tools needed given the operations required for the part. Table 12 shows the functional categories of participants' orientation.

Table 12

Types of Considerations in Planning Orientation for Each Group (Percent of total responses per group)

Type of Consideration	Operator	Traditional Setup	Low CNC	High CNC	Engineer
Relations between Objects and Actions	21	28	20	57	39
Non-Relational Topics:					
Objects	26	4	24	24	23
Specific Actions	16	32	24	9	4
Action Principles	5	16	14	0	12
Setting Factors	16	12	5	3	19
Other	16	8	13	7	3

The High CNC experience and Engineer groups show more consistent expression of relational statements (e.g., "The material will give you an idea of what my cutting tools are going to look like."). Table 12 suggests that, with CNC programming experience, knowledge domains become more integrated. Furthermore, while some people experienced in CNC programming do talk about objects, they drop their discussion of actions. Low experienced CNC programmers show as yet unintegrated thinking, much like operators.

In all, there were a total of ten types of relations mentioned (see Table 13).

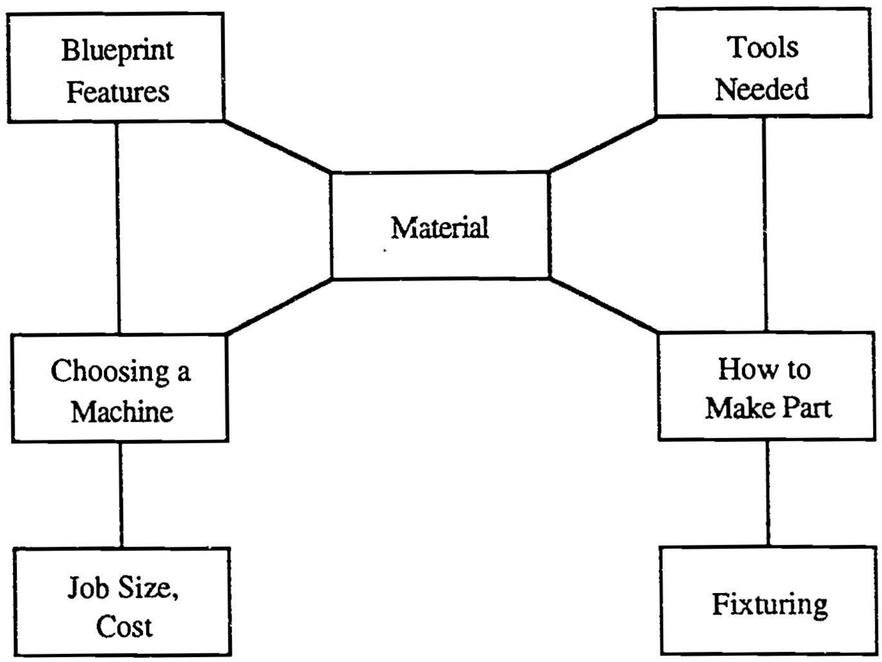
Table 13
Types of Relations Mentioned in Planning Orientation

Blueprint, Part Features: Choosing a Machine
Blueprint, Part Features: Material
Tools Needed, Assembling Tools: How to Make the Part
Tools Needed, Assembling Tools: Material
Choosing a Machine: Job Size, Cost
Choosing a Machine: Material
How to Make the Part: Fixturing
How to Make the Part: Material
Cost: Material
Program: Production Needs

Interestingly, if we map the elements of the relations expressed by participants, we see that materials form a core concept (see Figure 2). We see that a (literally) material consideration is often the basis for relational thinking. We also see that considerations of action *per se* do not drop out but are integrated into a multifaceted concept. This suggests there is an integration of concrete aspects of machining into abstract, contingent relations.

The relations that CNC programmers articulated are not ones unknown to any of the other groups of study participants. In fact, many times these relations seemed to be implicit or assumed in what people said. We hypothesize that experience in writing programs leads to a tendency to be verbally explicit about the conditional relations that exist between all aspects of machining and to assuming this orientation of thought in the planning process. Programming consists of expressing relationships between objects and actions.

Figure 2
Relations Between Elements Mentioned in Orientation



Elements of Planning

In an effort to further understand the integration of elements in planning, we can compare which elements participants of each background included in their complete planning descriptions. Specific aspects of the participants' planning reveal their experiential differences. Table 14 shows the activities displayed by the participants as they planned the assigned job.

As Table 14 shows, operators focused on how to make the part, and also on discussing general machining issues and aspects of making this particular piece. Both operators and traditional setup men listed practical steps more often than CNC machinists and engineers, with traditional machinists most consistently describing the tools they needed and the nature of the part they were making. Traditional machinists did not tend to list the sequence of operations, as did CNC machinists.

Table 14
Planning Activities
(Percent of total responses per group)

Activity	Operator	Traditional Setup	Low CNC	High CNC	Engineers
Lists Practical Steps	60	60	43	36	0
Lists Machining Order	0	20	57	45	20
Discusses General Issues	60	30	57	55	80
Discusses Nature of the Part	40	70	0	64	20
Discusses Metal	20	20	29	91	60
Describes Tools Needed	40	90	57	45	20
Assigns Operations to Spindles	20	40	29	36	40
Other	40	70	43	45	20

Low CNC machinists engaged in various planning activities but, again, in a pattern midway between traditional machinists and experienced programmers.

For High CNC machinists, and to an extent for engineers, the metal again became an integrating theme for the other activities. Consistent with their initial orientations, most individuals in these groups discussed the effect of choices of material stock. In the case of CNC programmers, concern with the metal stock may occur because CNC machines can handle more types of metal than can any single conventional machine. Whatever metal is called for determines how you program the CNC machine. Since we had asked participants to think about a machine to make the assigned part, the consideration of the material may have occurred before planning for the traditional setup men who work on more "dedicated" machines.

The High CNC machinists also discussed the nature of the part and how it influenced their choices with general principles of planning, elaborated by people in each group, most often discussed by engineers.

Of all the groups, engineers talked most in general. They discussed the materials and the operations to a certain extent, but they mainly interpreted the planning task as one that demanded explaining the principles that come into play in preparing work; they did not actually do the planning. We would argue that this is consistent with their more formal training in approaches to planning and their lack of hands-on experience.

Overall, CNC machinists showed unique planning activities, showing some commonalities with experienced hands-on setup people and some with engineers. The commonalities in their planning with engineers related to the use of CNC machines. CNC machinists seemed to think about the nature of the part, what the material was like that they needed to work with, and the practical sequence of how to make the part.

Those with Low CNC experience showed concern with general and practical machining issues, tools, and the order of operations, but did not think about the metal or the nature of the part as often as more experienced programmers did.

Where the High CNC group thought about general issues of making the part, the traditional setup group thought about practical issues of machining. Other details of how to make the particular part, however, were offered by everyone with hands-on experience, for example, considering tolerances and how the tool paths would have to be designed.

Again, we see evidence of traditional and CNC machine-mediated activity entering into the activity of planning. CNC machinists consider practical issues as well as computer-related issues. Engineers, who do not consider practical elements, cannot really be said to be planning.

To look at an example of changes in specific thought patterns, we looked at the sequential nature of planning talk.

Linearity

Our observational study had shown that, compared to the expert, the novice programmer referred to events out of sequence a lot more as he talked. That is, the novice foreshadowed operations and referred back to others as he planned, while the experienced programmer described completely linear sequences, rather like a program. We suspected that as machinists gained experience in programming they would express the planning process in an increasingly linear way; that is, the sequential reasoning about operations would become more abstracted on a mental level. Here, we looked at how our informants described the sequence of operations needed to machine the part.

We took a sample of the planning talk of five randomly selected participants from both the High CNC and traditional setup groups and analyzed the planning patterns. The traditional machinists all worked on multipurpose cam-driven machines. All of the machinists, including those in the High CNC group, were experienced setup people.

There were a couple of differences in the material we analyzed from the observational study of the expert and novice. For one, the level of detail in the planning talk in the current study was not as detailed since the planning task was relatively truncated, and so there are fewer mentions of operations and machining actions altogether. Secondly, the fact that the planning was being done for the purposes of a hypothetical job could have affected the nature of the talk we analyzed.

Keeping that in mind, we analyzed participants' talk for references to what we call operations of focus (the operation that is part of the machining plan, which falls in a sequence) and to operations or machining issues that came before or could arise following the focus operation. Table 15 shows the frequency and percent of forward and backward referencing by machinists in the two categories that emerged from the analysis.

Table 15
Forward and Backward References

Machinist Group	Number of Instances	Percent of Total
Traditional Setup (n=5)	13	68
High CNC (n=5)	6	32

The analysis of the linearity of planning talk shows restructuring of thought as a result of CNC programming experience. Compared with traditional machinists, experienced CNC machinists do indeed express the planning process in a more linear fashion, showing a mean number of 1.2 forward or backward references, while traditional machinists average 2.6. Furthermore, two-thirds of the references by CNC machinists were produced by one individual so, in fact, the difference is probably greater than it appears.

Programming

Several researchers and informants have claimed that programming machine tools to move in space is accomplished by adopting a new point of view in visualizing and expressing the tool's movement in space. We were interested to see if machinists who worked on traditional machines could adopt that point of view and express directions to the machine in English that are comparable to code, telling the machines how to run.

Each participant in the study was asked to write instructions to a machine of their choice, either in code or in English, telling the machine how to move to complete two specific operations.

In writing their programs, approximately two-thirds of the CNC programmers used code, while all of the engineers used code. Ten of the participants, including five operators, were unable or unwilling to do the task.

To evaluate the programs, an expert programmer/machinist read each one without knowing the background of the programmer and completed an evaluation of the program with a researcher.

Elements Included in Programs

As they interpreted the task, all the engineers and eighty-four percent of the CNC machinists created sequences with program-like specifications. About two-thirds of the conventional setup people, all of whom used English or abbreviated English, were able to as well. Those who did not use specifics described the operations in general terms, for example, "do turning" instead of "turn this [specific] length." A majority of all machinists with hands-on setup experience included the names of operations (engineers did not), but most engineers and CNC machinists included specifications about the machinery, whereas conventional machinists did not. The High CNC group included mention of specific tools more often than did other groups. A majority of all the groups used exact values for dimensions in their programs. Table 16 shows the percent of individuals in each group including different elements in their code.

Table 16
Elements Included in Programs
(Percent responses in each group*)

Element	Traditional Setup	Low CNC	High CNC	Engineers
General descriptors	33	13	11	0
Specific descriptors	67	75	89	100
General values	50	0	11	0
Exact values	83	88	78	83
Estimated values	0	11	0	14
Names of operations	50	75	44	17
Names of tools	0	13	33	17
Machinery indicators	17	50	44	50
Other	43	14	12	0

*Responses in more than one category are possible

This data suggests that, under these simulation conditions, experienced CNC machinists produce more complete descriptions of programs than engineers and that traditional machinists could create instructions comparable to code fairly well. The details the CNC machinists include derive from the setup aspects of the work (i.e., thinking through operations), programming experience (i.e., using specific terms, naming tools, giving machinery specifications), and the exigencies of machining in general (i.e., considering exact values taken from the blueprint). Traditional machinists show similar considerations, except when they omit machinery indicators, which are necessary for instructions to CNC machines but not to non-CNC machines.

Program Voice

The relation between point of view and problem solving is one that has also been discussed in the cognitive literature (Hutchins & Levin, 1981; Miyake, 1986). These studies find subjects shifting their points of view as they try to work out a difficult visualization problem.

A study of student programmers (Lebahar, 1987) found that more experienced programmers talked as if they were on the tool point as they described tool movement and then shifted to an abstract viewpoint. Novices went from the tool point perspective to assuming the point of view of someone standing beside the machine.

We were interested to see if programmers kept a consistent point of view of directing the tools or if they shifted viewpoint to solve problems; also, we wanted to validate the task demands of writing a program. Among the CNC programmers (high, low, and engineers), then, we analyzed where their program commands were directed. That is, we looked to see if the programmers were truly giving tool or machine directions, or whether they took on other points of view and let other kinds of commands intrude such as commands to a human operator.

We found that the majority of each group consistently maintained a tool command voice although some high experience CNC machinists also delivered instructions to the person running the job. Some low experienced CNC machinists diverged from programming and wrote commands for the interviewer to understand. Engineers wrote consistently abstract code.

We conclude, first, that individuals with more programming experience can produce code in a relatively uncontexted manner while less experienced programmers may need more of the whole programming environment in order to carry out a codewriting task. We also conclude that codewriting and the relations it evokes symbolically causes programmers who know these relationships to think about shop floor realities.

We should note that the programs produced in these experimental conditions, though rarely running more than ten lines, were unusually imperfect compared to what we had observed in real work circumstances. According to our expert rater, only between twenty-five and thirty-six percent of the programs were judged to be runnable, with high experience CNC machinists making fewer syntax errors in programming (m=1.5) compared to engineers (m=2.5) and low experience CNC machinists (m=2.75).

Program Chunking

CNC programmers were asked to group the code they wrote into "chunks" that went together to see if the "grammar" they saw in the code was more related to the abstraction of the programming language or to the actions to which it refers. Several data points are missing because participants either did not complete the programming task itself, or wrote short programs—often in English—that did not allow grouping of lines. In addition, many people did not understand the instructions although instructions were reworded in several ways. The very pronounced nonunderstanding we encountered could mean that, for some people, the point of view assumed in programming was part of a very different organization of thought, one which we did not identify.

The patterns created by the participants who were able to complete the task were described and tabulated. Table 17 shows the types of groupings identified by programmers.

Table 17
Types of Code "Chunks" by Group
(Percent of responses*)

Chunk Type	Low CNC (n=4)	High CNC (n=9)	Engineers (n=7)
By Function	100	78	86
By Machining Operation	25	33	0
By Syntax	25	33	14
Other	25	0	0

*Responses in more than one category are possible

In all, the data shows no important differences between groups on the nature of their chunks, with most dividing the lines of code by function. Engineers show a slightly more consistently abstract pattern of chunking.

The overall pattern of the group is fairly sophisticated. It relates to the command structure of the code as well as to its meaning: the operations being programmed. Engineers, not surprisingly, are less likely to read machining operations into the code. A few individuals in each group chunked their lines of code by syntax (commands that can legally be written on the same line). Mixed strategies were in evidence among some experienced CNC machinists.

Running the Part

The final set of tasks presented to participants in the study asked them to analyze elements in two problem scenarios and tell us how they would go about solving the problems embedded in them. Here, computer control means that a new source of potential error—the program—is introduced as a part is machined. Each problem we presented to participants was one that could have resulted from either a mechanical or a programming problem. We were interested to see the kind of priority CNC programmers would give to computer error in their thinking about practical problem solving. We also wanted to know if experience in manipulating code gives programmers a more abstracted sense of problems—that is, whether they mentally manipulated possibilities more often than machinists who worked with problem representations that were concrete.

For this task, the interviewer read the scenarios one at a time to the participants, who were given a mocked-up blueprint of the part referred to in the scenario. As mentioned earlier, each problem could have been interpreted as a mechanical or programming error. The problems were taken from real incidents we had heard about during our field work. For both scenarios, participants were told "a colleague comes to you with the following problem. What do you think caused the problem? What could you tell him to correct the problem?"

Tool Breakage

Scenario One asked participants to solve the mystery of a broken drill. The problem was selected because we witnessed an experienced programmer admonishing a novice for leaving out a crucial command (failing to cancel a tool offset value) as the latter wrote a drilling sequence, which would have resulted in the drill breaking.

Among the variety of explanations for the breakage given by our informants, all groups except the operators gave mechanical reasons for the drill break. Furthermore, the majority of answers referred to a secondary result of a mechanical problem: chips clogging the drill. Why the chips would clog the drill was not seen as a primary issue, although participants could easily generate a long list of possibilities when prompted. Operators, on the other hand, mentioned chip clogging *per se* relatively less often. They gave a wide variety of guesses for the source of error. The two operators who had taken a class in programming, however, were the only ones to suggest that the problem could have been due to a programming error.

Interestingly, low experience CNC programmers and operators showed consistent flexibility in thinking about alternative problem solutions. Here, flexibility may indicate uncertainty. Somewhat less than one-hundred percent of the experienced programmers (.89), conventional machinists (.89), and still fewer engineers (.57) saw multiple possibilities for solutions to the problem.

Ultimately, in terms of error attributions, the majority of participants located the primary problem in the tool itself (e.g., "wrong drill"), while some people in the High CNC and Conventional Machinist groups also attributed the error to instructions given to the machine, but not the program (e.g., "insufficient lubricant").

Out-of-True Dimensions

The second problem scenario involved a part that ends up being completed with incorrect dimensions. Here, all groups with CNC experience primarily cited programming errors as a source of the problem. Operators gave a wide variety of reasons, while the conventional setup group had a tendency to cite tool positioning as well as other reasons for the problem. For this problem, operators and low experience CNC programmers (who are also somewhat less experienced machinists) were less able to envision multiple possibilities for the problem source.

One explanation for the contradictory findings on flexibility in problem solving by experts and nonexperts on the two problems may be that tool breakage represents a very open situation while dimension problems are more constrained ones. Here, we might look at the origin of the knowledge base where expert setup people have a lot of experience to draw upon. To a slightly greater extent, they tended to advise one most likely troubleshooting procedure for the tool breakage scenario. For the more constrained case of the wrong dimensions, they drew upon their experience to propose a set of equally complex explanations for the problem. Less experienced setup people might have done a lot of guessing for the more common occurrence (tool breakage) but could only reason out a limited set of possibilities for the more unusual scenario. Engineers' flexibility may reflect their lack of hands-on experience and their experience with CNC.

Summary

Our experimental tasks revealed distinctions in thinking patterns related to hands-on versus programming experience and to machining versus engineering training. Most notably, we saw that in orientation to planning participants expressed trends consistent with what their jobs ask them to consider in planning, so that engineers thought about economic matters while experienced CNC machinists thought contingently and setup people thought about practicalities. It was suggested that contingent thinking about machining elements represents a more explicit view of their relations that programming forces you to clarify.

In the planning itself, all the groups discussed machining issues, but CNC machinists talked about the nature of the part and engineers talked about principles of machining as opposed to the immediate issues involved in machining the particular part. Overall, CNC machinists combined systems of technical and symbolic knowledge, planning like other machinists but also somewhat like engineers. Machinists with low amounts of CNC programming experience appeared to show patterns of responding that were transitional between the setup and high CNC machinist groups. These patterns suggest evidence of a transformation of practical experience with learning CNC, but also of continuity and discontinuity as well with traditional practices.

Our results on the planning task lead us to think that verbal representations, at least of the machining process, do in fact differ with CNC experience and that working in programming leads to more conditional thinking, with secondary emphasis on concrete practical steps at that point. While relational thinking about factors involved in machining increases, programming simultaneously seems to lead to more linear thinking about the sequence of operations needed to machine a part (i.e., abstracted relations between operations). This implies there is a transformation in the expression of the relational nature of the operations into a program-like format.

In programming, however, the programs of CNC machinists showed differences from those of engineers, including the practical elements that would make a program work; hands-on machining experience was related to inclusion of practical program details. Engineers produced programs fluently though with fewer elements to make the programs operational, so we question the sense in which they were planning. We had some evidence that low experience CNC programmers were doing some of their planning as they programmed.

In troubleshooting problems that may occur on the job, we found differences in where groups attributed error and in flexibility of offering alternative hypotheses. These differences were related to machining experience rather than programming experience *per se*.

Overall, our tasks did tap experiential differences and yielded some evidence of mental restructuring due to learning programming. They also showed that, for experienced machinists who program, machining considerations remain in the foreground of their thoughts. Complete discontinuities from traditional thinking also were seen, having to do with experience with the workings of CNC machines and the activity of mentally planning and writing out action steps before their execution.

Thus, we have evidence of traditional skills being maintained, traditional skills being transformed, and new skills being incorporated simultaneously.

Views of the Future

One of the most important sections of our protocol involved asking our participants to talk about their feelings about their work, their aspirations and thoughts on the future of the industry and the new technologies, and what they would recommend to young people entering the field. Many of our informants have seen small shops close, large factories lay off workers, and a general migration of jobs away from the Northeast. They have seen exciting new technologies arrive only to displace workers and increase the need for training. The contracts for parts that their companies undertake, the flow of work to the shop floor, the amount of overtime available, all have an immediate impact on these individuals who discuss the economy on the shop floor.

Machining and engineering are said to be the kind of skills that "travel." In fact, one of the instructors we interviewed reported he tells his vocational students that with this training they can get on a plane, go anywhere in the world, and have a job in a few days. But not everyone is prepared to relocate and, in this uncertain economy, few experts can predict either the future of the machining industry or what will happen to individual businesses. Thus, even highly skilled workers live with uncertainty at this point in time.

In an effort to examine the link between broad changes in the workplace and patterns of thinking, questions were included in our interviews to see if we could identify a relationship between activity with the new technology and workers' attitudes and sense of themselves at this moment. Although respondents interpreted some questions in different ways, their responses can be compared.

Overall, we found striking differences between groups of participants in their feelings about the field and striking consistency between members of each group. The only question on which there was consensus, and this was universal, was on the question of what kind of training would be best.

The Industry

Operators

Operators see computerized machinery taking over, but they are respectful of the higher quality and quantity of parts that can be achieved with the new technology. They see the economy as sluggish, but feel that education can help a lot with job security. Operators claim little knowledge of the new technologies, but, again, they see it will benefit the industry while creating hardships for individuals.

As far as recommending the field to young people, operators were divided. Some felt the future is uncertain, the jobs are only good if you are an engineer, and the new technologies create boring jobs ("feeding information into machines"). Others felt there is a demand for workers, you can make decent money depending on what you do, and that the work will be getting more interesting in the future.

When asked what they saw as the future of the industry, the sense from skilled traditional machinists was that shortcuts are happening—people will be coming out of school and going directly onto CNCs (partly because younger people do not want to "get their hands dirty" anymore); more complicated machines will be replaced by CNCs because "there are too many operations to go through" on older machines. With these shortcuts, they say, the precision of tool-making may decline. Yet, they see that people will still be needed to run machines and skills will continue to be in demand.

As professionals, traditional machinists appreciate the new technology because "you can produce more work at a faster rate." They are skeptical about its value, however, because CNCs, for one, are only good for certain types of jobs so they will never compete with some machines. Furthermore, they feel CNCs will never replace traditional machining because even to run CNC you will be required to have an understanding of "the general layout of a part," which only comes with hands-on experience. The same level of training and skills will continue to be needed.

All but one traditional machinist felt that machining is an "excellent" or "good" career for young people. They feel it is challenging, "there's always something new to learn," and it "doesn't get boring." To them, it is important to "get into the right company," that is, one that would train a person in everything she or he needed to know.

CNC Machinists

CNC machinists express a much more pessimistic view of the future. They talk about the fact that the trade is "dying," that the industry offers poor pay for hard work that requires learning a lot of information, and that machines are taking over, both because of robotics and because machines can run twenty-four hours a day. CNC machinists also feel the industry is not reaching out to young people and it is "not educating them as to what machining is actually about."

They feel new technologies cannot replace individuals with knowledge, yet at the same time they fear that ultimately there will be a loss of knowledge because you will only have to push buttons ("that's the wave of the future"). They recognize that the technology is helpful to the industry but that it creates a disadvantage to workers because you need fewer people to make the parts.

Like several traditional machinists, some CNC machinists would tell young people entering the field that how good your situation is will depend on the company and your chances for growth. They say you have to like to work hard and, if so, machining can be a challenging career. They emphasize that the demands of the job don't compare well with the size of the paychecks.

Engineers

Engineers view the future as continuing to demand technical skills, but at a lower level—that is, computer literacy and some operating skills. Above all, they see the industry as becoming more competitive in ways that both foster growth but also make things harder for individual firms. The new technologies are good because they require less training time, but they are not always efficient. As a word of encouragement, engineers say there will always be a need for people to operate machines. They agree with CNC machinists that workers are underpaid.

Training

Our informants uniformly believe that a combination of in-shop and in-class learning plus mentorship is the optimal way to learn what they need to know because each setting provides unique educational experiences that contribute to understanding and internalizing the details of the work. For example, traditional machinists, who seem to regard school as the best place to learn CNC, felt on-the-job training may not always be sufficient because coworkers may not always be the most expert. Still, they point out, hands-on learning is more apt to stay with you.

Interestingly, engineers felt you needed to learn manual machines first, through experience, and then the CNC machine. In fact, as we will point out, engineers are needing and getting more hands-on experience than in previous years because of the advent of CNC.

The Future

We asked the study participants what they saw themselves doing in five years. In general, operators saw themselves as stagnant, remaining in their same positions. From our analysis of their backgrounds, we can say that that is a realistic assessment. Some felt they would learn CNC or otherwise continue with schooling, but they know that advancing through education is a long, slow process because the classes are not subsidized. Our data also suggests there is a "glass ceiling" operating for workers in this category.

Several traditional machinists saw themselves going into new technical fields, like refrigeration and air conditioning, perhaps because they feel they might lose their jobs in the next five years. Others saw themselves continuing with their current work or retiring.

Although CNC machinists were quite gloomy about the industry as a whole, the general attitude of the group towards their personal futures was one of moving ahead, going on to new positions, and/or going into teaching, engineering, or full-time programming.

Finally, engineers see themselves working their way up to supervisory roles, getting more involved in computer technology, and, winning the lottery!

Summary

The machinists and engineers we met are learners, creators, and problemsolvers. They are fascinated by technical things and admire efficient machinery. In describing their views of the present and hopes for the future, our informants were, for the most part, respectful about the importance of new technologies for the industry. At the same time, they were convinced of the power of hands-on learning and knowledge and would not recommend a future workforce deprived of traditional practical knowledge.

Obstacles to learning had to do with social, not mental factors—the cost and time required for training, the shrinking industry and the difficulty of keeping plants up to date, the limited opportunities for some job categories.

Worker experiences shaped their views of the industry and of themselves. Traditional machinists seem to have a strong sense of their skills and a positive view of their trade. They see a declining commitment of the industry to continuing these traditions. CNC machinists are frustrated about the lack of recognition of their skills and hard work and are pessimistic about the future of the industry. At the same time, they see themselves as having many options. Operators like to believe they can progress, but are also resigned to unchanging hard work with little possibility of betterment. Engineers, at the other end of the educational spectrum, see themselves as progressing—not so much in their technical skills as in their managerial skills.

Looking at the background information we compiled, we see that the CNC machinists in our sample are people who have a sense of a career commitment. They enrolled in vocational programs, they chose their profession more often than non-CNC machinists and operators, and, when CNCs became available, they learned to program them. Looking at educational patterns, we could also say the traditional machinists and operators, in contrast to CNC programmers, may be just doing a job. They had less choice, they had less training, and they often fell into their work by chance. However, when we talk more in depth with these individuals, we learn that there is pride, aspiration, and commitment among them as well.

A good deal of the difference between people's views of themselves, their views of how they fit into the changing industry, and their levels of commitment seems to hinge on opportunities for learning, both for those already in the field and for those who would enter. Therefore, it is important to summarize the implications for training of what we learned about worker backgrounds, thinking patterns, and identities.

IMPLICATIONS AND RECOMMENDATIONS FOR TRAINING

In this section, we discuss the implications of our findings about how people in CNC machining come to learn their jobs and how their thinking is affected by working with computer-based technology. We discuss how training might best be introduced and what kinds of support for learning would be useful.

Technical and Symbolic Knowledge

Our study showed that the knowledge and skills associated with CNC machining (e.g., the use of a specialized code, the specification of coordinates in space) do not exist independently of mechanical machining knowledge and skills for any machinist learning CNC. In fact, we distinguish *programming* from the activity of *CNC machining*, which better describes what our informants do.

When an experienced machinist learns programming and the use of CNC machines, some of what occurs mentally is *transformational* such as thinking more linearly about the machining process; some of it is *discontinuous* with mechanical machining such as in learning the programming syntax; and some of it is *continuous* such as in knowing the speed you need to turn a particular type of stock or the conditions under which tools are likely to break.

Much of the information used in the process of traditional machining is accessed directly through the sensory aspects of hands-on activity, for example, the sound produced by the cutter on the metal, that serve no symbolic representational function (the use of the blueprint being an important exception). For the machinist, knowledge of these primary feedback systems assists in learning secondary systems, or those which represent primary systems and the actions behind them (i.e., program code). Another way of looking at the information used in traditional machining is that it derives from concrete experiences with metal, tools, and machines. Learning code without these experiences to refer to as content may be a less useful or even counterproductive approach.

A pattern of having skilled machinists learn CNC is the most common one we see right now. In the future, though, the novice machinist may learn machining for the first time through CNC machining. Some of the knowledge and skills that would otherwise be derived from more mechanical experience would then be derived from CNC, that is, more through secondary than primary representational systems.

Engineers trained in CNC programming are also part of the future of machining. They participate in activities encompassing part design and programming, in which the economic parameters are more explicit than they are for machinists. When CNCs were first introduced to manufacturing on a large scale, mechanical engineers were thought to be able to program CNC machines without having had actual machining experience; however, the background of engineers learning CNC programming has shifted out of necessity. Most engineers now working in the field seem to have some hands-on experience through CNC machining (as we found out when we tried to recruit a sample of CNC engineers without any such experience). On the job, too, engineers interact more on the shop floor with machinists than in the past. Because CNC machining evolved from traditional activities, programming is introducing some breakdowns between domains of knowledge that have been socially and functionally distinct in the past.

Informal Training On The Job

Our work showed that new knowledge and skills associated with CNC machining do not generally replace or conflict with those gained through traditional practices. Rather, symbol-based systems build on traditional skills. Whether equivalent machining skills can be learned by novice machinists through CNC is a question that needs to be examined. For now, it seems critical that traditional skills not be lost or removed from the shop floor where the most important learning seems to take place, albeit unrecognized in job descriptions for either the novices or the experts. This means continuing to provide workers access to a variety of machines and to allow more skilled machinists opportunities to become CNC instructors.

It should be noted that most of the problems encountered in learning CNC machining are not specific to CNC, but, rather, involve general machining issues. This suggests that CNC machining needs to be regarded as a powerful new means of machining rather than as a formal system that is an end in itself. In fact, for the most part, participants in our study learned programming on the job.

Knowledge of and skill at mechanical machining in no way interferes with learning CNC machining and, in fact, provides a supportive context for learning programming. While it may not be desirable or efficient for someone who wants to learn CNC programming to first become a skilled machinist, aspects of the traditional hands-on activity can be used to facilitate learning CNC programming and machining, both for engineers and machinists.

School-Based Programs

Insofar as there are skills basic to all forms of machining, school-based training programs can offer preparation in some of these skills, for example, basic math. However, the basics become usable in the context of real work. Thus, school-based training programs should adapt to the various possible paths towards acquiring basic knowledge and skills, for example, the engineer learning CNC programming, the experienced machinist learning CNC machining, or the novice learning machining through programming.

School-based knowledge and skills (e.g., Cartesian geometry and programming syntax) seem related to CNC work to a greater extent than to traditional machining. This is reflected in the greater degree of formal education obtained by CNC machinists among our informants than by the traditional machinists. The relationship should not be construed, however, as suggesting that those who wish to become CNC machinists require a higher level of formal schooling than others. It does suggest that certain forms of knowledge acquired from general schooling are important in learning CNC machining. They may be relatively more important for those learning machining the first time through CNC to compensate for a lack of a mechanical context for structuring learning.

Becoming a CNC machinist is not a matter of simply learning a static body of knowledge and skills. Over time, CNC machinists come to plan the machining of a part as a more efficient linear sequence. They also utilize the concise symbols and records made possible by the programming language, both in their communications with other machinists (through the semantic use of code) and in the creation of a record of action—the program, which can be used by others or modified. The process of becoming a CNC machinist may be facilitated by including preplanning orientation, linearity, program voice, and debugging as explicit parts of the training curriculum.

Opportunities for Formal Training On The Job

For many reasons, it may not be possible to rely on formal school-based training programs to keep pace with the rapid technological changes taking place in the field of machining. Training provided by companies who make various machines and on-the-job training generally respond more rapidly to technological changes in the field because they are part of the change. They, too, need to be able to respond to changing educational needs, a policy matter.

The current work strongly shows important trends in who gets trained, when, and how. Few individuals in the field pursue linear careers of high school, followed by formal or informal apprenticeship, followed by career advancement on the job. While many have formal training, in most cases significant training is obtained after an individual's career has begun.

Individuals working in less skilled positions have less opportunity to take coursework, essentially because of the expense. Where employers offer to support training, all levels of workers seek it out. Note that in our sample, only twenty-four percent had received some employer-supported training. Those with less technical backgrounds choose to take a variety of general technical courses, and those with more technical background take more specialized classes. All levels of workers take programming courses when they can, although engineers do not tend to take machining courses.

Some groups have more opportunity than others to pursue career advancement with new technologies. European-American men, for instance, are more often represented among engineers and skilled workers, who are most likely to be sent for CNC training. They also happen to be more likely to have high school and college-level degrees, which allows them to apply for "cleaner" work.

Skilled workers in older age groups, however, are less likely to become involved in programming, probably because their jobs are more highly rated and therefore more highly paid than CNC work. A couple of skilled setup men told us, too, that they preferred to work with their hands, not to "sit in an office" programming (though others told us they liked the idea of staying clean on the job).

Workplaces must be structured to support learning on the job with the introduction of new computer-based technologies. This not only means providing space, time, and support for acquiring new knowledge and skills, but seeing this as a worthwhile investment for a company. This may require changes in the contractual relations of machinists with their employers as well as cooperation rather than competition in training between manufacturers.

Recommendations

In summary, we recommend that the following be considered as training for the new technology is designed:

- Training should ideally include hands-on experiences under the guidance of knowledgeable practitioners, plus classwork in basics and up-to-date techniques.

- Keep traditionally skilled machinists training incoming workers; offer opportunities for skilled workers to learn CNC.

- Employers should allow time and resources for continued training and mentoring among employees of all levels.

- Increase employer sponsorship and other kinds of sponsorship for continuing education.

- Training programs should be adapted to the needs of traditional machinists, novice machinists, and engineers for learning basic skills, so that technical and symbolic knowledge is fully integrated.

- CNC classes could develop curriculum concerned with cognitive aspects of information processing through programming.

- Improve recruitment among minorities, women, and immigrants into high vocational and apprenticeship programs.

REFERENCES

Berryman, S. (1986, April). *Shadows in the wings: The next educational reform.* Paper presented at the Annual Meeting of the Council of Chief State School Officers, Louisville, KY.

Cyert, R. M., & Mowery, D. C. (Eds.). (1987). *Technology and employment: Innovation and growth in the U.S. economy.* Washington, DC: National Academy Press.

Hutchins, E. L., & Levin, J. A. (1981). *Point of view in problem solving.* Unpublished manuscript, Laboratory for Comparative Human Cognition, University of California at San Diego, La Jolla.

Lebahar, J.-C. (1987). L'influence de l'apprentissage des machines-outils a commandes numeriques sure la representation de l'usinage et ses niveaux de formalization. *Le Travail Humain, 50*(8), 237-249.

Lemercier, D. (1978). La pensee naturelle: Dans l'apprentissage technologique. *Le Travail Humain, 41*(1), 153-167.

Lemercier, D. (1984). Etude differentielle d'un apprentissage technologique: La conduite de la machine-outil en Lycee d'Enseignement Professinel et en Lycee Technique. *Le Travail Humain, 47*(1), 31-49.

Leontiev, A. N. (1981). *Problems in the development of mind.* Moscow: Progress Publishers.

Martin, L. M. W. (1988). Unpublished field notes.

Martin, L. M. W., & Beach, K. (1990, April). Learning to use computer machinery on the job. In S. Scribner (Chair), *Work and learning.* Symposium conducted at the American Educational Research Association Annual Meetings, Boston, MA.

Martin, L. M. W., & Scribner, S. (1991). Laboratory for Cognitive Studies of Work: A case study of the intellectual implications of a new technology. *Teachers College Record, 92*(4), 582-602.

Martin, L. M. W., Scribner, S., & Beach, K. (1990, May). *Hand to symbol: Studying the transformation of machining activity in the introduction of computer control.* Paper presented at the Second International Conference on Research in Activity Theory, Lahti, Finland.

Miyake, N. (1986). Constructive interaction and the iterative process of understanding. *Cognitive Science, 10,* 151-177.

National Center on Education and the Economy. (1990). *America's choice: High skills or low wages!* Rochester, NY: Author.

Oberg, E., Jones, F. D., & Horton, H. L. (1975). *Machinery's handbook.* New York, NY: Industrial Press.

Pennington, N. (1987). Stimulus structures and mental representations in expert comprehension of computer programs. *Cognitive Psychology, 19,* 295-391.

Raizen, S. A. (1989). *Reforming education of work: A cognitive perspective.* Berkeley: National Center for Research on Vocational Education, University of California at Berkeley.

Resnick, L. B. (1988). Learning in school and out. *Educational Researcher, 16*(9), 13-20.

Rubtsov, V. V. (1991). *Learning in children: The development of cooperative actions.* Commack, NY: Nova Science Publishers.

Scribner, S. (Ed.). (1984). Cognitive studies of work. [Special Issue]. *Quarterly Newsletter of the Laboratory of Comparative Human Cognition, 6*(1&2). La Jolla: University of California at San Diego.

Scribner, S. (1989, April). Learning and working in an activity theory perspective. In R. D. Pea (Chair), *Learning at work: An interdisciplinary perspective.* Symposium conducted at the American Educational Research Association Annual Meeting, San Francisco, CA.

Scribner, S., & Sachs, P. (1990). *A study of on-the-job learning* (Technical Paper No. 13). New York, NY: National Center on Education and Employment, Teachers College.

Scribner, S., & Sachs, P., with DiBello, L., & Kindred, J. (1991). *Knowledge acquisition at work* (Technical Paper No. 22). New York, NY: National Center on Education and Employment, Teachers College.

Vygotsky, L. S. (1988). *Problems of general psychology, Volume I: Thinking and speech.* New York, NY: Plenum Press.

Wertsch, J. V. (1985). *Vygotsky and the social formation of mind.* New York, NY: Cambridge University Press.

Zinchenko, V. P. (1985). Vygotsky's ideas about units for the analysis of mind. In J. V. Wertsch (Ed.), *Culture, communication, and cognition.* (pp. 94-118). New York, NY: Cambridge University Press.