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BECOMING A MACHINIST IN A CHANGING INDUSTRY

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# BECOMING A MACHINIST IN A CHANGING INDUSTRY

By

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ABSTRACT

BECOMING A MACHINIST IN A CHANGING INDUSTRY

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The study examines the development of the knowledge, skills and identities of machinists in relation to changes in the work activity of machining. It addresses three inter-related problems. The first is to formulate a model of worker development in the context of changes in machining. The effects of technological change have been characterized as an upgrading and downgrading of skill (Spenner, 1988). This is a form of technological determinism which is not based on an adequate empirical understanding of what happens to workers' learning and development in the process of technological change.

The second problem is to provide a satisfactory conceptualization of how knowledge and skill carry over from one situation to another. The relation between changing contexts and learning has been considered in terms of transfer. The construct of transfer does not adequately deal with how individuals learn and develop in an activity such as machining that is transformed through the introduction of new technology.

The third problem is to consider the development of identity in relation to the development of knowledge and skill. Research in educational psychology has

tended to disassociate the development of knowledge and skill from considerations of who one is or is becoming.

The study was conducted in a machine shop where 13 machinists were observed and interviewed over a period of 12 weeks. Changes in knowledge and skill were described in terms of changes in *artifactual relations* as a unit of analysis. An artifactual relation is a semiotic unit of analysis that defines knowledge and skill in terms of the relation between the artifacts used (e.g. CNC program code), the referents they are tied to (e.g. machining processes), and the meaning of the artifact-referent relation to individual machinists in given work roles (interpretant).

The findings indicate *continuities, transformations,* and *discontinuities* of knowledge and skill tied to changes in artifactual relations over time. There were changes in the identities of machinists tied to changes in knowledge and skill. The findings indicate a tension between a *traditional craftsmanship identity* defined in terms of individual autonomy and all-round skill, and an *emergent craftsmanship identity* defined in terms of differentiated and complementary skills exercised by a technically sophisticated team.

DEDICATION

To my parents, Baba na Mai Hungwe

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I am primarily indebted to Dr. King Beach. He suggested the line of inquiry that I followed and guided me through a long journey. It was a privilege to work with Drs. John Smith, Mun Tsang and Anna Neumann whose criticism, advice and encouragement were invaluable.

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Conventions of anonymity prevent me from naming the individuals at the machine shop where the study was conducted. They were a remarkable team of dedicated and caring professionals. It was a wonderful experience to be a part of their team, albeit for a brief period of time.

Negotiating a suitable site was difficult and there were several disappointments. I am deeply indebted to Jim Lynch and other friends at East Lansing Trinity Church for their assistance.

Finally, I wish to express my appreciation to Chipo Hungwe who has maintained a keen interest in this work.

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| | |
|---|---|
| APT | Automatically Programmed Tools. |
| CNC | Computer Numerical Control |
| NC | Numerical Control |

# CHAPTER 1

# INTRODUCTION

The purpose of this study was to examine the development of the knowledge, skills and identities of individuals engaged in the work activity of machining and its relation to changes in that activity. The effects of technological change have been characterized as an upgrading and downgrading of skill, or in terms of upskilling and downskilling (Shaiken, 1984; Spenner, 1988; Ehn, 1988). This is a form of technological determinism which is not based on an adequate empirical understanding of what happens to workers' learning and development in the process of technological change (Martin and Scribner, 1991; Martin & Beach, 1992). Machining is an economically critical activity undergoing rapid technological change. It was used as a site for formulating a model of worker development in relation to technological change. A second and more general problem is that we do not have a good understanding of how individuals learn and develop in relation to changing contexts. While we have models of how contexts influence individual learning and development, these models assume that the contexts are static. In reality contexts are rarely if ever static.

The mechanism generally invoked to account for learning across contexts is called *transfer* (LCHC, 1983). Transfer has been considered from several theoretical positions. For example, Piagetian theory has encouraged research into mental structures that "manifest themselves in uniform performance across a broad spectrum of tasks regardless of task content, social context, or subjects' prior experience" (Guberman & Greenfield, 1991, p. 235). It is assumed that reasoning is an individual property that is independent of context as well as content. This approach has been challenged by findings from cross-cultural research that have shown that many inter-individual and intra-individual differences are better explained in terms of prior experience and context, "especially the tasks used and how they are presented" rather than in terms of differences in general cognitive abilities (Guberman & Greenfield, 1991, p. 236)

Another important approach to the study of cognitive functions is cognitivism. Cognitivism assumes a general cognitive mechanism.

> The central intuition behind cognitivism is that intelligence--human intelligence included--so resembles computation in its essential characteristics that cognition can actually be defined as computations of symbolic representations (Varela, Thompson, and Rosch, 1993, p. 40).

Cognitivism has come to be defined as a research program[1] in its own right. As Gardner (1987) has noted, "while not all cognitive scientists make the computer

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1 . Lakatos (1970) distinguishes between 'mature science' consisting of research programs, and 'immature science' consisting of " a mere patched up pattern of trial and error." The history of science is a history of competing research programs. Varela, Thompson, and Rosch (1993) describe cognitivism as a "well-defined research program, complete with prestigious institutions, journals, applied technology, and international commercial concerns." (p. 8)

central to their daily work, nearly all have been strongly influenced by it" (p. 40). Computers and computational theory have become a powerful or 'root' metaphor in cognitive science and psychology. It is assumed that problem solving can be characterized in terms of a task environment, and a mental 'representation' or cognitive structure that corresponds, in a systematic way, to the task environment.

Cognitivism has been criticized for the tendency to ascribe to the mind "structural descriptions that essentially represent the very property that is sensed" (Gardner, 1987, p. 315). The problem is that for a person to see, detect, register a property of the environment he or she must have that very property *a priori.* Cognitivism does not therefore help us to understand the mechanism of learning and development in changing contexts. As a matter of tradition, the cognitivist research program has marginalized the role of contexts. Gardner (1987) summarizes this perspective as follows:

> Though mainstream cognitive scientists do not necessarily bear any animus...against the context that surrounds any action or thought, or against historical or cultural analyses, in practice they attempt to factor these elements to the maximum extent possible (p. 41).

The study of meaning in relation to cultural contexts is central to "context-specific" approaches, or "situationism." What is useful in context-specific approaches is the *a priori* assumption of some relation between reasoning and the context in which it occurs (Guberman & Greenfield, 1991; LCHC, 1993; Saxe, 1982). This is in contrast to cognitivism where experience is treated as epiphenomenal and meanings are taken to be properties of representations that can be fixed "without reference to the context in which they appear" (Winograd & Flores, 1986, p. 19).

The case for studying meaning in relation to contexts has been made elsewhere, for example in speech act theory (Searle, 1969). Consider, for example, the distinction between *waiting* and *loitering.* The distinction is constructed through descriptions, and an appeal to norms and rules. To describe an individual as *waiting*, as opposed to *loitering* means that there are norms in the social order which define what it means to *wait* and how it differs from *loitering.* Action concepts therefore make sense in the "context of social rules which provide the criteria in terms of which an actor can be said to be performing that action" (Fay, 1975, p. 75). Meaning is therefore social and is to be understood "in relation to a significant context" where it is "oriented, structured to achieve certain effects" (Eagleton, 1983, p. 114). In other words:

> mental activity is not essentially a Cartesian or inner set of processes but a range of moves or techniques defined against a background of human activity and governed by informal rules (Harré & Gillet, 1994, p. 19).

We understand meanings when we "get inside the forms of life and the norms, conventions, rules, and so on in which...activities have taken shape" (Harré & Gillet, 1994, p. 20). This kind of understanding has been called *verstehen* or *reason explanation* (Fay, 1975; Harré & Gillet, 1994). "It is based on empathic identification with the other that helps the observer make sense of what the other is doing" (Harré & Gillet, 1994, p. 20).

In other words:

> ...understanding human activity requires us to interpret the behavior of another according to some appreciation of the self-positioning of the subject within the complex structure of rules and practices within which that individual moves (Harré & Gillet, 1994, p. 20).

There is an important limitation to situationism's contribution to our understanding of learning and development. What is missing is an explicit statement of how a context-specific theory accounts for the ways in which past experience carries over from one context to the next (LCHC, 1983). Guberman & Greenfield (1991) summarize the limiting assumptions as follows:

> Thinking consists of a variety of cognitive skills, each independently acquired in socially organized activities, forever tied to the contexts in which they develop (p. 240).

Context-specific approaches do not therefore resolve the problem of how to study development in dynamic cultural settings.

My goal is to outline an alternative theoretical framework that can be used to address the problem of learning in dynamic cultural settings. The framework is more fully developed in chapter 2, but the preliminary outline of the argument is as follows. The point is not to reject or marginalize the role of the environmental or individual factors, for their influence appears incontrovertible. Rather, the challenge is to pose the question differently, as a problem of *how* environmental and individual psychological factors jointly account for development, taking their joint contribution as a given.

## Re-examining the Assumptions

The theoretical framework that I used to address the re-formulated question is derived from the work of Vygotsky (1981). A core assumption of Vygotsky's cultural-historical psychology is that cognitive functions have social origins. In other words, cognitive functions are accounted for in terms of culture where culture is taken to be historically emergent, rather than a completed object (Luria, 1976). In other words, culture is a "human artifact, something that people have made" in the course of historical activity and through which they act and interpret the world (Gose, 1989, p. 103).

The development of the individual psyche is derived from the appropriation and internalization of cultural signs, of which language is the most typical. Vygotsky called semiotically mediated psychological functions 'higher' functions "having in mind above all the social nature of their inception" (Vygotsky and Luria, 1994, p. 132.). These functions are not products of the biological evolution of behavior but of its historical development and arise as a new structural entity tied to new functional relations.

The development of higher psychological functions is the history of the transformation of the means of social behavior into means of individual psychological organization (Vygotsky and Luria, 1994, p. 138). In describing how behavior is transformed, Vygotsky considered the use of external signs, for example in writing, reading, drawing, and counting. He referred to the use of such signs as "external symbolic forms of activity." External symbolic forms of activity have usually been regarded as additional or irrelevant in relation to thought. Vygotsky argued that they should be included into "the system of higher psychological functions on an equal footing with all other higher psychological processes " because they are products of the historical development of behavior (Vygotsky and Luria, 1994, p. 136).

Vygotsky's assumptions about the relation between individual development and the environment are reflected in the tradition of research established by Wallon (see for example, Voyat, 1984). Wallon argued that the contexts in which individuals act are not autonomous but are created through human activity and that "different environments, according to their differences...evoke or bring to the fore different capacities, already potentially present, in a species or in individuals" (Wallon, 1984b, p. 245). The relation between the environment and the organism is reciprocal. In other words:

> nature and environment do not simply make separate contributions which are then combined; more likely, each one serves to bring out the other's potentialities." (Wallon, 1984a, p. 217)

Wallon concluded that "in transforming the conditions of his life, man transforms himself" (Wallon, 1984b, p. 245).

In this study I examine the development of the knowledge, skills and identities of individuals engaged in the work activity of machining and its relation to changes in that activity. I have used the term activity in a technical sense to mean "molar historical phenomena that possess their own developmental courses, and principles of explanation" (Beach, 1995). In other words, machining has its own history of development, structure, and transformations over time (Leont'ev, 1981).

There is one more assumption that is central to this study. It is that human action is *historical* (Fay, 1975). By historical I mean that human beings are self-conscious actors who have the capacity to reflect on, and change their actions. As self-conscious actors they can

> reflect on their experiences and actions and on the arrangements by which they order their lives, and...can, on the basis of their self-reflection, change the way they live (Fay, 1975, p. 54).

They can "change themselves by internalizing new conceptions of self and society, new possibilities of action, and by incorporating these into social practices and relations" (Fay, 1987, p. 52). The capacity to reflect on one's experiences and to change one's life (in terms of knowledge, skills, beliefs, desires, etc.) defines an active, rather than passive human nature. In this study I investigated the development of the identities of skilled machinists in terms of changes in self-conception over time in a changing machining activity. I assume the disposition of machinists to self-consciously reflect on their knowledge and skills and to evaluate these on the basis of some such criterion as whether they are in accord with some ideal. In summary, changes in the self-conception of skilled machinists over time define the changes in identity that are the focus of the study.

As indicated earlier, machining was used as a site for the study. I now describe the historical changes in machining on which the study was based.

## History of Changes in Machining

Machining is at the core of the manufacturing-based US economy. In the machine shop, metal in the form of rods and blocks is transformed into gears, cams, crankshafts, and other precision parts that are vital for industrial production. Machinists convert engineering conceptions in the form of drawings or verbal descriptions into finished parts. They use power driven machine tools, for example the lathe and the mill, to cut, shear, or press metal into desired forms to produce precision parts.

The earliest machine tools were small and hand held. With time, they evolved into bigger and more precise mechanical power tools capable of making heavy cuts with greater speed and accuracy. These machines were manually controlled. By 1900, the development of machine tools had stabilized. That was to last until the post Second World War era when the first automated machine tools, controlled through computer programs, appeared. The technology was called Numerical Control (NC) because it was controlled by central computers using punch tape and sets of numbers. Since then, automation of machining processes has progressed at a rapid rate. NC was followed by a Computer Numerical Control (CNC) which is based on a system of programming code and a decentralized control system. CNC machine tools can be programmed on or off the shop floor by individual machinists rather than through a central computer. In the 1990s, graphic-based programming systems, rather than code-based systems, have set a new standard in programming. Programmers on graphic-based systems generate machining instruction by manipulating graphical computer images that represent the part. The rate of change in machining is unprecedented in the industry. As Shaiken (1984) has noted:

> In the past, the design of automation evolved slowly over years if not decades. For example, an engine line brought into an auto plant in 1964 would probably only be marginally different from one introduced in 1954. The development of computer technology however, has been proceeding at an exponential rate. New levels of capability are often achieved in a matter of months rather than years (p. 7)

These changes have laid the basis for an unprecedented restructuring of production, with consequences for the skills of workers and the meaning of work (Shaiken, 1984).

In many ways, Numerical Control technologies[2] form a continuum with previous (conventional) machining technologies (Shaiken, 1984). Manual controls such as levers and dials were replaced by computer program code. The code represents machine operations, dimensions (such as size, depth, length), materials (tools, stock and accessories), and relations between materials. Where a conventional machinist turns a wheel to regulate a metal cutting process, a CNC machinist inputs a code equivalent which drives computer controlled tools to achieve the same result. CNC also affords machinists capabilities to machine complex curved surfaces that can not be machined conventionally.

Machine tools operate through combinations of sliding linear and rotating motions. The detailed machine operations that are available will vary from machine to machine. The motions have traditionally been defined in terms of three planes, designated longitudinal, transverse, and vertical. With the advent of CNC it became necessary to adhere to standardized symbolic representations of the planes. The Electronic Industries association lists 14 different designations of motion. The standard adopted is derived from three-dimensional Cartesian geometry which defines points in space in terms of mutually perpendicular coordinates X, Y, and Z (see Figure 1).

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2 . I will use the term Numerical Control technologies to refer to both NC and CNC.

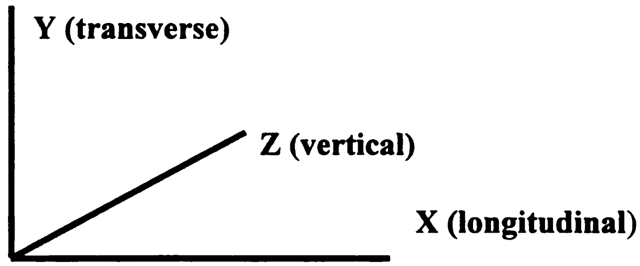


Figure 1: Three dimensional coordinate space

The difference between conventional and Numerical Control technologies is summarized by Shaiken (1984) in these terms: "an NC machine is controlled by pre-coded information while a conventional machine is guided by the machinist" (p. 67). The part program defines the part and the procedures needed to make it. It is a codified statement of the machining operations, detailing the sequence of cuts, the cutting tools needed, the rate at which cuts are to be made, the path of the cutting tool, and all the processes that are needed to make the part. Figure 2 illustrates a small portion of a program.

Numerical Control technologies afforded management new options for re-organizing production. It became possible to divide machining work into a programming and machine operation aspect, carried out by different individuals in a different space and time. Programming is the creation of computer programs that are used to machine parts. Machine operation work is the use of programs, created at a different point in time, in some cases by a different individual, to machine parts. The impact of these changes has been greatest on highly skilled all-round machinists and tool and die makers who make up about half of all machinists in the USA (Shaiken, 1984). For some of these machinists, numerical control technologies are "breaking down the trade" (Shaiken, 1984, p. 132). They resent the changes in the job content and what they see as the devaluing of the skills that machinists have historically exercised (Shaiken, 1984).

**AN EXAMPLE OF CNC PROGRAM CODE[3]**

CNC code is organized as a computer program. Simple examples of the code and their meanings are:
*N10: Program line number 10*
*G71: work in inch mode (as opposed to millimeters); T2: select cutting tool number 2; GO: move rapidly to the coordinate position indicated; G1: cut along a linear path, etc.*

```
% { identifies first line of program}
N10 {PGM, I46732405) {program identifier}
N20 (MSG, KEDMON HUNGWE, ORIGIN AT CENTER OF
PART)
N30 G90
N40 G71
N50 (MSG, FACE MILL)
O60 T2 M6
N70 G0 X-98000 Y17000 Z3000 S418 M3
N80 G1 Z0 F251
N90   X98000 Y17000
N100 X98000 Y-17000
N110 X-98000 Y-17000
N120 G0 Z3000
N130 (MSG, 20MM ROUGH END MILL)
O140 T20 M6
N150 G0 X-60000 Y-45000  Z3000 S1590 M3
ETC.
```

Figure 2 : CNC program

3. This is part of a longer program that I created and used as part of the research process, Fall 1994. There are variations in CNC code across machine types.

## Changes in Machining and the Skilled Machinist

Manufacturing has been moving towards the concept of what has been termed the 'automated factory' (Shaiken, 1984, p. 56). There is a long-held assumption that the skills of machinists can and should be transferred to machines through programming. Shaiken (1984, p. 54) has noted that skilled machinists keep a "legendary" notebook, often referred to as a 'black book'. The book contains a record of problems that have been encountered in the course of work and the techniques used to solve them. The book is an embodiment of the machinist's expertise. Automation with numerical control technologies has been described as a process of capturing such experience and codifying it in the form of computer programs:

> That old-time machinist might be a vanishing breed, but the wealth of experience contained in that black book is today being captured and stored, allowing shops to improve their productivity by gaining control of their processes (*American Machinist*, cited in Shaiken, 1984, p. 54)

Changes in knowledge and skill associated with the introduction of Numerical Control technologies have brought to the fore political issues of power and control of work and the workplace. At General Electric, where NC was pioneered, workers referred to NC as a "management system, not as a technology of cutting metals" (Noble, 1979, p. 118). Management did in fact have a tendency to view Numerical Control technology as a means of wresting control of the manufacturing processes out of the hands of craft labor and the unions. Pioneer programmers were engineers, rather than machinists. When the management at a large domestic airline withheld training in Numerical Control programming from machinists, they secretly obtained copies of the programming and operating instructions for the machines and

> for several weeks they pored over those manuals at home during the evening since they had no time for study on the job. After this they began producing parts with their own manually developed programs (Shaiken, 1984, p. 116).

They were able to produce parts more efficiently than when they received programs from non-machinist programmers. They were also able to spot errors in the manufacturers' manuals. Management did not, however, welcome these initiatives, and switches were installed on the machines to lock the programming features that were available on the shop floor. In this and other cases, management was motivated by the desire to "to preserve its authority on the shop floor, realizing that the ability of machinists to produce more might also mean the ability to produce less", when labor disputes arose (Shaiken, 1984, p. 119).

The views of skilled machinists on technological change have tended to differ from those of management. Their collective view, stated in the 'Bill of Rights' as proposed by the International Association of Machinists and Aerospace Workers, is that technology must be used to create and maintain jobs (Shaiken, 1984, p. 272) and to "expand the responsibilities workers have on the job" (p. 273). Skilled machinists have a strong desire to retain control over how work is carried out. Their views are informed by a strong sense of shared values and concerns. They believe that technological change should not erode the ability to exercise skill and autonomy on the shop floor (Noble, 1979; Shaiken, 1984). The exercise of autonomy and skill has been referred to as "craftsmanship" (Shaiken, 1984).

I assume that changes in machining work are not solely determined by the technology (Noble, 1979). Workplaces are social settings with histories embodied in the individual and collective experiences of workers and management. The upshot of this argument is that we can not fully understand the development of knowledge and skill without addressing the broader question of the nature of the setting where they are developed and the individuals who participate, in terms of their history and the goals they seek to attain. The role of new technologies in a given workplace will depend on localized understandings and broader economic trends (Shaiken 1984; Applebaum, 1992; Noble 1979).

## Site of Study

The study was conducted in a unionized machine shop, at Makro Corporation, which is a pseudonym for a major automobile manufacturer in the United States. The shop was part of the engineering division of the company and specialized in the machining of prototype parts, mostly engines. It had been in operation for over fifty years, and for about twenty of those years, machining work was performed conventionally. The first Numerical Control machine tool was acquired in the early 1960s. Workers, as individuals, and collectively through the United Auto Workers union (UAW), have been negotiating the use of Numerical Control technologies for decades, beginning in the early 1960s, when these technologies were first introduced. The UAW has a long-standing concern that the use of Numerical Control technologies has undermined the collective ability of the skilled machinists to negotiate their conditions of work. In one dispute at a UAW controlled site, the workers filed a grievance that management was limiting access to programming facilities (Shaiken, 1984). A union representative summed up the frustrations of skilled machinists as follows:

> The job has been specialized, trivialized, and downgraded. Merely pushing buttons and watching warning lights is unlikely to hold intrinsic interest and challenge for very long. Initiative is no longer required and the work is boring. Pride of craftsmanship has been destroyed for the man who operates a Numerical Control machine tool. The machinist can no longer identify with the product. He used to make the part from start to finish and received a lot of satisfaction from it. The job has been routinized and bureaucratized and has become less and less interesting (Shaiken, 1984, p. 129-130)

These remarks were made in the 1970s. Since then use of Numerical control technologies has intensified at all automobile manufacturing sites including Makro.

A skilled machinist, interviewed by Shaiken (1984) in England, described his transition from conventional machining to machine operation on Numerical Control technologies as follows:

> I've worked in this trade for seventeen years. The knowledge is still in my head, the skill is still in my hands, but there is no use for either one now. I go home and I feel frustrated, like I haven't done anything. As a result, I find myself wanting to make things around the house. I feel something has been taken away from me that I could put into the job (Shaiken, 1984, p. 128-29).

Another skilled machinist who was working as a machine operator --running programs generated by others--put it this way:

> The work gets on your nerves. You become apathetic after a while so you don't want to do anything even when something goes wrong. Since you have no direct involvement with the workpiece, you don't take any personal pride in what happens to it. It's even unloaded in a separate area by somebody else. So guys stop caring if the part is good or bad or whatever (Shaiken, 1984, p. 152).

The preceding discussion suggests that changes from conventional machining to Numerical Control machining may have profound consequences on skilled machinists in terms of their knowledge and skills, as well as their self-concept as skilled machinists.

## Summary

The purpose of the study was to examine the development of the knowledge, skills, and identities of individuals engaged in the work activity of machining and its relation to changes in that activity. Previous studies have highlighted the importance of machining as an economically critical activity undergoing rapid technological change (Shaiken, 1984; Adler & Borys, 1989; Noble, 1979). Others have highlighted the importance of machining as a site for developing new conceptual models of worker learning (Martin and Scribner, 1991; Martin & Beach, 1992; Hungwe & Beach, 1995).

This chapter has provided a broad overview of the issues of interest, and the direction the rest of the inquiry will take. The theoretical framework that guided the study is further developed in Chapter 2. That chapter concludes with a statement of research questions. In Chapter 3, I describe the research site and discuss the research design and the methods using during field work. Chapter 4 is the first stage of analysis of the data. In that chapter I discuss changes in machining activity and their relationship to institutional changes as well as changes in the automobile manufacturing industry as a whole. I describe the changes in machining that have occurred at Makro and argue that the changes need to be understood in the context of broader societal and institutional changes. In Chapter 5, I discuss changes in knowledge and skill, tied to the historical changes in machine tools that have occurred at Makro. The changes described in the study have occurred within the working history of the informants who were interviewed, with consequent changes in their individual work and knowledge and skill. In Chapter 6, I consider the significance of these changes for the development of the professional identities of machinists. The dissertation concludes with Chapter 7 which is a summary and synthesis of the findings. I also consider the implications of the study for research on learning and development.

# CHAPTER 2

# METHODOLOGICAL FRAMEWORK

## Introduction

In this chapter, I outline the methodological framework on which the study was based. As part of that process, I review studies on changes in knowledge, skills, and identity, in relation to changing contexts. By methodology I mean the relationship between the theoretical framework that I used and the research questions. I conclude the chapter with a statement of two research questions, one on the development of knowledge and skill, and the other on the development of identity. I begin with a brief review of how changes in knowledge and skills in changing contexts have been investigated in other studies.

## Studies Relating Changes in Knowledge and Skills to Changing Contexts

The problem of changing knowledge in changing work contexts has been explicitly or implicitly characterized as a problem of the transfer (Beach, 1995). One strand of research has been generated by researchers whose primary interest is in cognitive development. The second strand is from researchers whose primary interest is in the labor process. I begin with studies whose primary interest is cognitive development.

Studies Whose Primary Interest Is Cognitive Development

The relationship between changing situations and learning and development has been characterized in psychological literature as a problem of the transfer (Reed, 1993; Sternberg and Frensch, 1993; Fleishman, 1987; Palinscar & Brown, 1984). The transfer construct describes "whether and how knowledge, strategies, and representations learned through one task are applied to a new task" (Beach, 1995, p. 285 ). Transfer has been examined in terms of task representations, and relations between target and transfer tasks (Reed, 1993; Detterman, 1993). Some studies have focused on the development of both tasks and instructional environments, incorporating the teaching of strategies to foster transfer (Palinscar & Brown, 1984; Schoenfeld, 1982; Marini & Genereux, 1995). These studies have

> fairly consistently indicated that transfer is obtained when reasoning principles are taught in conjunction with self-monitoring practices, potential applications to a variety of contexts are discussed and resemblances between problems are pointed out. (Beach, 1995, p, 285).

These studies implicitly or explicitly assume that knowledge is defined through representations. Meanings are therefore fixed, independently of individuals in activities and the object of learning is to discover those meanings, rather than to construct them. Knowledge is therefore context independent and absolute. This is in contrast to the key assumption of this study that meanings are socially and historically contingent.

The findings from studies on transfer have been mixed, with some studies showing transfer and others not (Detterman, 1993). Beyond that, studies have not provided a satisfactory account of how individuals learn and develop in changing contexts. As Beach (1995) has argued:

> current conceptualizations of transfer, successful or otherwise, are inadequate for explaining how people gain knowledge and skill across situations, particularly those embedded in changing societal institutions such as school and work (p. 286).

In 1983, the LCHC concluded that the construct of transfer "as a central mechanism" may be an inadequate basis on which to build a theory of culture and cognitive development (LCHC, 1983).

## Studies Whose Primary Interest Is the Labor Process

In labor process type studies, the effects of technological change on skill have been characterized as upgrading and downgrading of skills, or as deskilling and upskilling (Black, 1983; Shaiken, 1984; Helfgott, 1988; Noble 1979; McLoughlin & Clark, 1994; Ehn, 1988). Changes have been analyzed quantitatively. For example, upgrading means that changes in technology have resulted in an increase in the range of skill requirements, and a higher average of skills that are needed from the labor force. Skill in a given category has been measured directly, or quantitative measures have been inferred using indirect methods (Spenner, 1988). An example of a direct measurement of skill is the US Department of Labor's Dictionary of Occupational Titles (DOT) that uses a range of measures and aggregates the data to determine skill requirements. The measurements are (a) general educational development required for a job category (mathematical, language and reasoning development), (b) vocational preparation (total training time for an average performance at the job), (c) eleven aptitudes (e.g. verbal, numerical, spatial, motor coordination, etc.) and (d) twelve work conditions (e.g. variation, repetitiveness, discretion).

The findings from studies based on quantitative measures have been mixed (Spenner, 1988). In summary, despite the wide range of studies on the effects of technological change on skill requirements, there is uncertainty about the relation between them (Spenner, 1988).

## Alternative Conceptualizations

Alternative conceptualizations of the relationship between contexts and knowledge have come from two related strands of research. One strand examines knowledge within given settings, and social practices. Examples are studies of the practice of arithmetic among Weight Watchers (de la Rocha, 1985) and in grocery shopping (Lave, Murtaugh, de la Rocha, 1984). The findings indicate that problem solving practices are situationally specific. Other studies have examined the same issues from historical perspectives, taking the starting point as culturally organized human activities (Scribner, 1985; Beach, 1995; Scribner & Cole, 1981). These studies have demonstrated the reciprocal relation between the development of individual psychological processes and changes in social and historical contexts in which they occur.

In this study, I examined the development of individuals within the context of the culturally organized human activities in which they occur. The unit of analysis was not tasks separate from individuals who perform them, or individuals cognitions separate from tasks, but it included both elements, within the context of the societal changes and institutional settings. I assumed that knowledge and skills were historically and socially contingent (Winograd & Flores, 1986; Bruner, 1990; Collins, 1990). This is an interpretive view of knowledge where the focus was on actions and contexts of action, rather than representations. As Winograd and Flores (1986, p. 74-75) put it:

> Knowledge is always the result of interpretation, which depends on the entire previous experience of the interpreter and on the situatedness in a tradition. It is neither 'subjective' (particular to the individual) nor 'objective' (independent of the individual).

This is in contrast to the representational view of where:

> Knowledge is a storehouse of representations, which can be called upon for use in reasoning and which can be translated into language. Thinking is a process of manipulating representations (Winograd & Flores, 1986, p. 73).

I therefore defined knowledge and skills in terms of meaning, that is how individuals engaged in acts of meaning in contexts of practice (Bruner, 1990).

I investigated the relationship between knowledge and identity. The development of knowledge and identity have tended to be examined separately in other studies. I examined them in relation to each other. As Packer (1993) has observed:

> There is a temptation to view learning as mental change, mental re-organization--as change in the individuals' internal capacity or competence....This dominant concern with epistemological issues precludes any reference to changes in practice or changes in being (including self-understanding and identity) to which learning might equally, or more closely, be seen as applicable (p. 264).

In a related argument, Litowitz (1993) argues that

> mastering activities and establishing a sense of oneself are not two distinct lines of development but are, rather, entwined in complex ways--that one can not 'study' one without the other. (p. 184).

The idea of relating the development of knowledge to that of identity finds support in neo-Vygotskyian theory and most clearly in Penuel & Wertsch (1995) and to a lesser extent in Litowitz (1993) and Packer (1993). In the next two sections, I outline the assumptions of Vygotskyian psychological theory and indicate how it can be extended to enhance our understanding of human development, in terms of knowledge and skills, as well as identity.

## Assumptions on the Development of Knowledge and Skills

The theoretical framework that I used to analyze changes in knowledge and skills is derived from the work of Vygotsky (1981) and Wartofsky (1979). Wartofsky and Vygotsky's work assumed a distinction between natural (biological), and cultural development of mental functions. Cultural development is mediated by what Vygotsky termed psychological tools or signs, and Wartofsky called artifacts. I will discuss each of these in turn.

Vygotsky made the decisive step of studying human cognition in terms of its cultural, rather than biological basis. His work was premised on the assumption that human action is mediated by psychological tools or signs (e.g. language) whose origin is cultural. Writing from this perspective, Bozhovich (1977) discussed the emergence of culturally based cognitive functions in these terms:

> When the child learns to master tools such as language, mathematical symbols, letters, etc., the structure of his mental processes undergoes a change (these processes become mediated) and becomes more perfected and productive. (p. 8)

In other words, the use of psychological tools (or signs) makes it possible to transcend "the limits of the psychological functions given...by nature, and proceeded to...new, cultural organization of...behavior" (Vygotsky & Luria 1994, p. 143).

Vygotsky took culture to be a human invention brought about by purposeful action, for example labor. In other words, the signs that mediate thought do not pre-exist practice, rather, they are generated in activity. The meaning of a sign is not fixed and given once and for all, but rather grows organically in the process of interaction (Auerbach, 1991). For Vygotsky, meaning is therefore not separated from practical activity. Meaning cannot be located in the person or the social environment but rather in their combination (Auerbach, 1991). It is constituted through purposeful human action and is therefore something that cannot be analytically separated from the transformation of the world through human activity, for example labor (Gose, 1989).

Vygotskyian psychological tools or signs are *material*, by which I mean that the meanings they embody are not simply mental states, but have evolved historically in human activities. Meaning is neither inside the head nor outside it (Auerbach, 1991). As Gose (1989) puts it, "the materiality of the sign, the fact that is it not simply a mental state, is what underwrites the social nature of meaning" (p. 105). The cultural approach to psychology therefore assumes that meanings have cultural origins, they are produced in activity, and are shared.

There are parallels between Vygotsky's uses of the terms tools and sign and Wartofsky's uses of the term artifact. Both tools and artifacts are products of cultural, rather than biological evolution; both derive their meanings from purposive use in human activity; and both are produced, and transmitted culturally through learning. As Wartofsky (1979) put it:

the crucial character of a human artifact is that its production, its use, and the attainment of skill in these, can be transmitted, and thus preserved within a social group, and through time, from one generation to the next (p. 201).

In a related argument Weber (1976) argues that an artifact:

> can be understood only in terms of the meaning which its production and use have had or will have for human action...Without reference to this meaning such an object remains wholly unintelligible (p. 212).

Artifacts and signs function in a similar way in the sense that the meanings they embody are not simply mental states, but are historically tied to referents in the sphere of activity. It is instructive to turn to semiotic theory, and in particular to the work of Pierce, to understand how artifacts function (Silverman, 1983; Gose, 1989). Pierce argued that the meaning of a sign is grounded in practical activity through a historical relationship to a *referent* that exists in the sphere of activity. He referred to the mental effect or meaning generated for someone by the relationship between a sign and its referent as an *interpretant*. As an example, consider the use of traffic signals to regulate traffic. Traffic signals do not have independent meanings, but are only meaningful in relation to safety and the flows of traffic that they are used to regulate. Traffic lights are a part of other devices that have been historically created to facilitate the flow of traffic and to induce safe operations. They are a cultural invention and have meaning in relation to modern transportation, and in particular the use of the automobile.

The meaning of traffic lights occurs in relation to a larger set of artifacts that are used in transportation. The larger set of artifacts (or system) is made up of regulatory signs (e.g. speed-zone signs and stop signs), warning signs that call attention to hazards, and information signs (e.g. route markers). These are all examples of artifacts. Their production, use, and the attainment of skill in using them is transmitted through time, from one generation to the next. Their meaning occurs in relation to other artifacts that are used in the same activity. In other words, particular artifacts are parts of systems of artifacts used in the activity at specific historical points.

An artifact such as a traffic light, exists in relation to some referent (e.g. traffic flow) and that relation has a meaning to someone in some historical situation. It is a triadic relation, that was first proposed by Pierce with respect to sign systems (see for example, Silverman, 1983). I have adapted Pierce's semiotic triad as a tool for understanding the meaning of technology. Figure 3 illustrates the structural relation that I used in the study. The relation between the artifact and the referent is historical. I will call the structural relation between an artifact, its referent and interpretant an *artifactual relation*. Alternatively, it can be referred to as a *semiotic triad* or a *mediating relation.* An artifactual relation defines meaning in terms of a triadic relation between an artifact, its referent, and an interpretant.

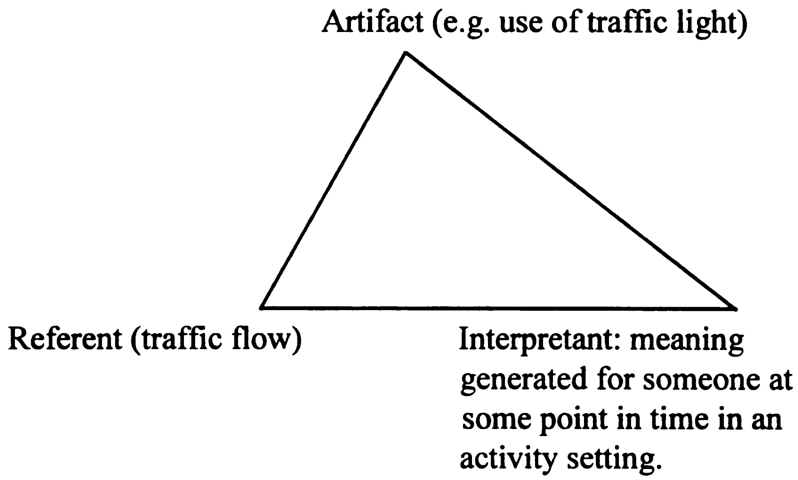


Figure 3: Artifactual relation

An artifactual relation changes when one or more of its elements changes. For example, the artifacts used in machining can change. In this study, there were changes in artifactual relations tied to the transitions of machinists from one machining role to another. I assumed that changes in artifactual relations constituted changes in knowledge and skill. I therefore described changes in knowledge and skill qualitatively in terms of changes in artifactual relations. The artifactual relation locates knowledge neither in the individual, the referent, nor the artifact, but rather in their relations.

By using an artifactual relation as a unit of analysis, I departed from mentalistic approaches to the study of knowledge and skill (see for example, Anderson, 1980; Schank and Abelson, 1977). These approaches conceive of knowledge and behavior as two different modes of life . Scribner (1985) summarizes this position well:

> ...the dominant image they present of the human knower closely resembles that of a computer: The knower is an intelligent system with a storehouse of knowledge and a set of programs, performing tasks in isolation. The knower neither interacts with other people nor engages in transactions with the environment (p. 199).

I took the alternative view that knowledge and skills are embodied in relations between individuals and their contexts of action (Varela, Thompson & Rosch, 1993). The artifactual relation is an example of a unit of analysis that is intended to define such a relation.

## Distinctions Between Artifacts

Wartofsky defined three categories of artifacts, primary, secondary and tertiary. Primary artifacts are materially non-arbitrary with respect to their referents. They may resemble the referent in certain ways, share certain properties that the referent possesses, or they may duplicate the principles according to which the referent is organized or operated. In machining, examples of such artifacts are dials, knobs, and levers that are used to control machining processes. Primary artifacts may also have an 'existential' connection to the referent. In machining, examples are the sounds and smells connected to metal cutting processes. Machinists use such artifacts to interpret and control machining processes.

Secondary artifacts, on the other hand, are materially arbitrary with respect to their referent. Their relationship with the referent is based on convention, and is unmotivated by any other association. Examples of secondary artifacts are natural language, and notational systems. In this work, I took CNC program code to be a secondary artifact because of its arbitrary relation to machining processes.

Finally, tertiary artifacts are "abstracted from their direct representational function" (Wartofsky, 1979, p. 209). I took this to mean that tertiary artifacts are derived from the organization of other artifacts, and only indirectly reference phenomena from which they derive their meaning. For example, tertiary artifacts have secondary artifacts as their referents.

This study used changes in machining, from conventional machining, to Computer Numerical Control machining (CNC) as a site for the study of the development of knowledge and skill. In conventional machining, metal cutting processes were controlled manually through devices such as levers, knobs and dials. Operating such machines is rather like handling a car with a manual interface. It involves knowledge of the process as well as manual dexterity. Levers, knobs, and dials, are examples of primary artifacts because they have a non-arbitrary relationship to the machining processes that are their referents.

Computer Numerical Control (CNC) is an alternative and historically more recent method of controlling the cutting of metals using computer program code. Computer program code has a purely arbitrary relationship to the machining processes which are its referent. It is therefore a secondary artifact (Hungwe & Beach, 1995). I will describe the use of such artifacts in chapter 5.

Artifactual relations are embedded in historical and institutional settings on which their meaning depends. As an example, Scribner and Cole (1981) demonstrated that the meaning of literacy was socially and historically contingent, depending on the activity setting in which is was practiced. In a study on changes in CNC, Martin and Scribner (1991) argued that the unit of analysis for cognitive studies of new technologies can not be limited to the technology itself, or to isolated tasks removed from the context of their performance. Such analyses would only provide partial and possibly misleading information for policy makers and practitioners who are concerned with defining educational goals for the future. Rather, research needs to begin with a broader view--an analysis of the societal conditions, institutional settings, and activity structures into which new tools and symbolic systems are being introduced.

## The Development of Identity

Vygotsky's work does not provide specific guidelines for understanding the problem of identity formation (Penuel & Wertsch, 1995). However, the basic assumptions of his psychological theory provide a framework for a cultural-historical theory of identity formation. A useful starting point is to assume, as

Penuel and Wertsch have done, that the development of identity is a cultural-historical process. By that I mean that identity develops over time in relation to cultural experiences.

## Conceptualizing Identity

Much of the literature on identity is based on inter-group comparisons and social roles (Jenkins, 1996; Tajfel, 1981; Netting & Williams, 1996; Aryee & Luk, 1996; Truss, Goffee and Jones, 1995). Netting & Williams (1996) examined the identity of social workers within a health care delivery system; Aryee & Luk (1996) compared work and family identities between males and females workers; and Truss, Coffee and Jones (1995) compared identities of secretaries across different countries. Studies based on inter-group comparisons and social roles are useful provided it is recognized that group categories and their meanings are historically contingent (see for example Hannaford, 1996). Other studies have made a distinction between personal identity and social identity. The distinction is problematic because identity is generated in social contexts (Breakwell, 1992; Deaux, 1992; Abrams, 1992; Hermans, Kempen & van Loon, 1992).

In this study I give analytic primacy to changes in identity in relation to changes in work activity, rather than to groups, inter-group comparisons or social roles. I will use the term identity to refer to self-concept in an activity setting or specific historical contexts. The development of identity is therefore a process of transformation of the self-conception as an actor in an activity setting. Labor, as a purposive human behavior is an important site for the generation of identity. The development of identity involves "self-reflection, self-observation and self-judgment", in other words self-conscious action in an activity setting (Penuel and Wertsch, 1995, p. 87).

In this study, there were changes in machining work tied to work roles (e.g. from conventional machinist to CNC machine operator). The detailed historical development of the role-structure at the site of the study will be described in chapter 3. I have used changing work roles to understand the development of machining activity over time, and the transitions in work experiences that the site afforded machinists. In other studies, particularly in sociological literature, role has been defined in terms of structurally given demands associated with a social position (Levinson, 1976; Henslin & Nelson, 1996). In other words, it defines the context-bound nature of human action. My use of the concept of role is consistent with Levinson (1976), who has criticized the tendency to assume that behavior is entirely defined by the social structure. He has argued that individuals interpret and evaluate structurally given roles and act on the basis of interpretations.

This brings to a conclusion the discussion on methodological issues. I will now turn to the research questions that guided the study.

## Research Questions

The study examined the development of individuals engaged in the work activity of machining and its relationship to changes in that activity. Machining is a relevant area of study because it is an area of practice that is experiencing re-organization of work. The re-organization is tied to changes in machine tool technologies, from manually controlled conventional systems, to automated computer controlled systems (CNC). I have characterized the changes that have occurred in machining work as a shift from machine control mediated by *primary artifacts* to that mediated *secondary artifacts* and *tertiary artifacts* (Wartofsky, 1979). These changes have been described by the United States National Commission on Technology, Automation and Economic Progress as "probably the most significant development since the introduction of the moving assembly line" (cited in Shaiken, 1984, p. 66).·

There have been a number of studies on the subject of changes in machining technology (see for example Shaiken, 1986, Adler and Borys, 1989; Noble, 1979). Other researchers have focused on learning to become a machinist (Martin and Beach 1992; Martin and Scribner 1991, Hungwe & Beach 1995). This study examined the changes in machining activity and its relationship to the changes in knowledge and skills, and the professional identities, of machinists. In addition, we have little understanding of how changes in knowledge and skill of machinists are related to changes in professional identity. This study advances our understanding of that relationship as well. Two questions, one on the development of knowledge and skills and the other on the development of identity guided the inquiry at the research site.

1. *Are there changes in the knowledge and skills of skilled machinists related to the change from machine control mediated by primary artifacts to that mediated by secondary and tertiary artifacts? If so, what are they, and how are they related to the change in the mediation of machine control?*

2. *Are there changes in the identity of skilled machinists related to the change from machine control mediated by primary artifacts to that mediated by secondary and tertiary artifacts? If so, what are they, and how are they related to the changes in machining work?*

## Summary

I have outlined the theoretical framework that guided the study. I used artifactual relations as a unit of analysis. An artifactual relation defines meaning in terms of a triadic relation between an artifact, its referent, and an interpretant. By using artifactual relations, changes in knowledge and skill could be described qualitatively in terms of changes in meaning. The artifactual relation locates knowledge and skills neither in the individual, the referent, nor the artifact, but rather in their relations. I was critical of other approaches that conceive of knowledge and behavior as two different modes of life (e.g. Schank and Abelson, 1977) I took the alternative view that knowledge is embodied in action (Varela, Thompson & Rosch, 1993).

I have argued that the basic assumptions of Vygotsky's work provide a framework for a cultural-historical theory of identity formation (Penuel & Wertsch, 1995). I take the development of identity to be the process of transformation of self-conception as an actor in an activity setting. Identity is a cultural-historical construction and labor is an important site for the generation of identity.

The discussion now turns to chapter 3, where I describe the research design and the methods that were used in field work.

# CHAPTER 3

# RESEARCH DESIGN AND METHODS

The research site was a machine shop at Makro Corporation. The research design and procedures were informed by the research questions, as well as the structure of the site. I will begin by describing the site, how it was identified, and access negotiated. That will be followed by a discussion of the research design and the methods used in field work.

## Identifying the Site and Negotiating Access

This line of inquiry was initiated in the fall of 1992 by reviewing a study of machinists in New Jersey carried out by Martin and Beach (1992). Machining work has been changing rapidly as new technologies are introduced. It therefore affords the opportunity to study the development of individuals in relation to societal change.

I made preliminary explorations of this area of study through visits to various machining sites in Michigan, and through discussions with several machinists, engineers, and college instructors in machining technologies. Machining is a technical area where expertise develops over years of study and practice. It became necessary for me to undergo a period of training in order to understand the changes that were going on in the industry and their significance for individual development. I enrolled in machining related classes at a community college beginning Summer 1993. The courses were on conventional machining, CNC machining, drafting and blueprint reading. These experiences were helpful in clarifying the research questions, identifying a suitable research site, and developing research methods and instruments.

The goal was to identity a site where machinists were undergoing the transition from conventional to CNC machining and to track the development of individuals over time. There were difficulties in finding a site that matched those criteria precisely. Some potential sites were closed to researchers. The eventual research site was a machine shop located at Makro Corporation, a major automobile manufacturer in the United States. The shop was part of the engineering division of the corporation and specialized in the machining of prototype parts. Machining work was organized around sub-sites and work roles (e.g. Conventional machining & CNC programming), each of which represented different historical points of development of machining activity. The development of machinists over time could therefore be studied through a comparative analysis of the work activities of individuals in distinct machining roles that represented different historical points of  machining work, rather than tracking the same individuals over time as their machining roles changed.

Access was negotiated through a family friend who had the confidence of both management and union representatives within Makro Corporation. The shop had been in operation for over fifty years, and for about twenty of those years, machining work was performed conventionally. In 1962, the first Numerical Control machine was acquired. This and subsequent changes in machining technology were designed to improve productivity and efficiency. When Numerical Control technologies were first introduced, the programs that were used to run machines were developed on a mainframe computer. White-collar employees were employed as programmers. At that time, programs were written out with pencil and paper and then transferred onto a punch tape. The tape was brought to the machine shop and inserted in the machine to machine the part. The machines on the shop floor were operated by blue-collar machinists. Machine operation and programming were therefore distinct work roles performed by different categories of workers.

The early technology based on punch tape was called NC (Numerical Control). This is in contrast to CNC which was introduced in the 1970s at Makro. CNC can be operated as a decentralized system because programs can be inputted by machinists using microcomputers attached to the machine tools that they operate. The interface between the machinist and the computer consists of a visual display unit and a terminal which is used to enter and edit programs. The machinist has total control over the process, in contrast to the arrangement with NC where programming and machine operation are distinct work roles. The switch from NC to CNC was in many ways compelled by problems in program preparation and verification on NC systems. As Fleck, Webster, and Williams (1990) have observed:

> It is easy to program a tool to move through space to the dimensions of the workpiece. It is difficult to get it to cut metal to these dimensions. A great deal of metal cutting skills, theoretical knowledge and experience are required to deal with the complex behavior of machine tools--tool wear, temperature expansion, judder [vibration], variability in materials--to ensure that the product is cut to the right dimensions and to devise a tooling and cutting strategy that will maximize output (p. 621)

There was therefore some efficiency to be gained by combining programming and machine operation functions.

In the 1990s the management at Makro made a decision to re-introduce specialist programmers at some of the work sub-sites, using a graphics-based programming system. The system is called Unigraphics. Unigraphics programming improved the shop's capacity to design and machine complex parts needed to sustain Makro's competitiveness in the industry. The introduction of Unigraphics at some sub-sites effectively removed the programming aspect of machining from some metal cutting sub-sites. Programs created by specialist programmers were routed to the floor where they were tested, edited, and run by specialist machine operators. In some ways, this was a return to the policy of separating the programming and machine operation functions that had characterized the shop in the early days of NC. There were two main differences in the new arrangement:

first both the programmers and the machine operators were skilled and unionized machinists. Under the previous arrangement, programmers had been white collar workers. Second, this time round, the more experienced machine operators had input into the programming aspect. They were required to test new programs and authorized to make or recommend changes to the program code, depending on the complexity of the changes. These distinctions will be clarified shortly when the site is described in more detail.

All the machinists at the site were at the same grade, that is toolmaker, except for three apprentice toolmakers. According to an agreement between the United Autoworkers union (UAW) and Makro Corporation, all toolmakers were on the same rate of pay, regardless of years of service to the company, or type of work. In addition, all the machinists were male, which is reflected in the pronouns used in the text.

Figure 4 is a summary of the changes in machining work over time. Conventional machining was the first to be introduced in the early 1940s. There were machinists who specialized in conventional machining at the time of the study. However, the main development work was now carried out on CNC, conventional machining being mostly used as a suppoortive base. Figure 4 shows the introduction of NC programming in the early 1960s. Programming and machine operation on NC were separate work roles as described earlier. NC programming was phased out and replaced by Unigraphics programming. Under the Unigraphics system, programming and machine operation continued to be separate specialized work roles, tied to two distinct sub-sites, those of programmer and machine operator.

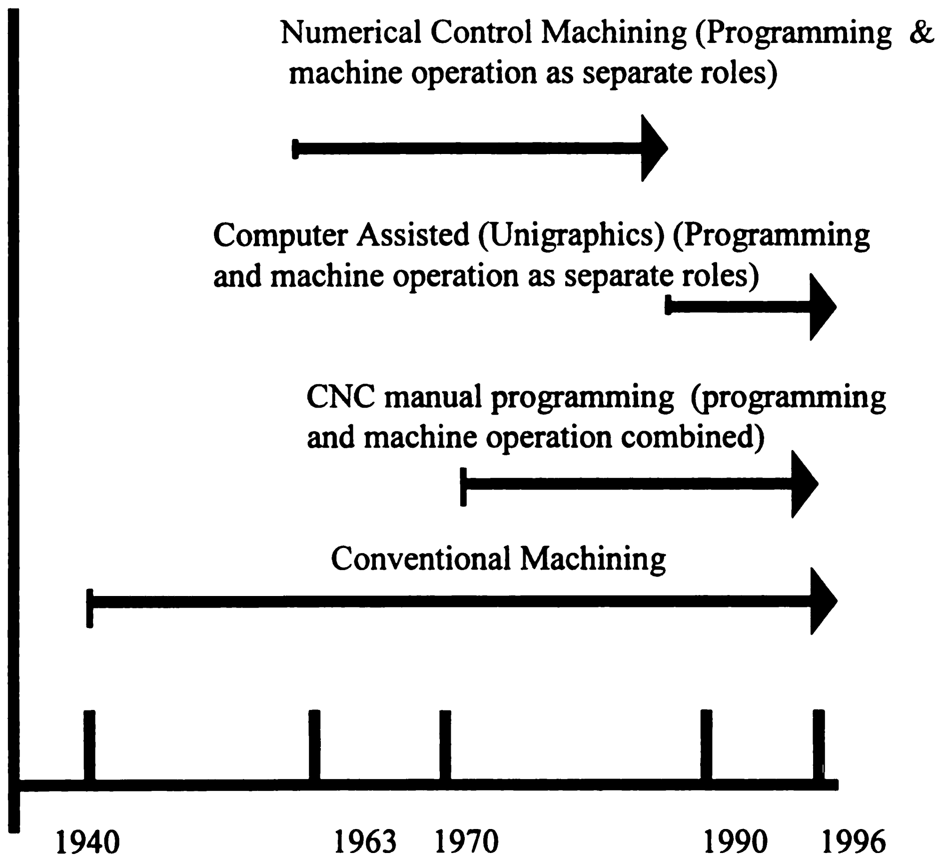


Figure 4: Historical changes in machining activity at Makro

Finally, figure 4 indicates the introduction of relatively small CNC machines around 1970. Machinists working on these machines wrote CNC programs and also machined parts using those programs. The introduction of these machines defined a new work role, that of a machinist whose work combined programming and machine operation.

In summary, there were ongoing changes in machining work at Makro since the 1990s. NC had been phased out and replaced with Unigraphics programming. The other technologies had continued over the years. The existing sub-sites and work roles at Makro were therefore a mirror image of the changes that had occurred in machining over a period of about fifty years at Makro. Beyond that, these changes mirrored changes that were going on in the industry as a whole.

## Research Design

The study was based on a cross-historical design (see for example Luria, 1976). This means that changes in knowledge and skills, as well as identity, were studied by examining the work activities of individuals in distinct machining roles that represented different historical points of development of machining activity at Makro, rather than tracking the same individuals over time as their machining roles changed. The sub-sites and roles tied to them mirrored the historical changes that had occurred in machining work at Makro.

Four machining roles were identified. They were Conventional machining, CNC manual programming, Unigraphics programming, and CNC machine operation. Workers were assigned to sub-sites by management. Assignment to a sub-site was on a long term basis, and an individual's work was defined by that assignment. The sub-sites represented changes in machining roles over time. Figure 5 summarizes the data on the four sub-sites. Figure 5 is a description of the work at each of the sub-sites.

| Work Sub-Sites and Average Number of Workers | | | |
|---|---|---|---|
| Conventional machining | CNC Machining | | |
| | Manual programming | Unigraphics programming | Machine operation |
| 8 | 3 | 5 | 10 |

Figure 5: Work sub-sites and number of workers

## Conventional Machining

Machining at this sub-site machining work was performed manually. Manual operation means physically turning dials, knobs, wheels, and so on, to operate the machine and cut the part. Conventional machining was the oldest type of work in the shop, dating back to the establishment of the machine shop in the 1940s. Most of the machine tools were lathes and milling machines. There were some grinders as well.[1] On average, there were about eight persons per shift working at this sub-site.

## CNC Manual Programming

In CNC manual programming work, the machinist wrote CNC programs based on the specifications of the features and dimensions of the part. Programs were written using paper, pencil and calculator, and then typed into a computer. Programming was manual, in contrast to computer assisted Unigraphics programming, where CNC programs were generated by computer using an image of the part (Repp & McCarthy, 1984). Machinists at the manual programming site machined parts, using the programs they had created. The machines used were lathes, mills. The number of workers averaged three per shift.

[1]. Lathes, milling machines, and grinders are machine tools classified according to the method of material cutting that they are designed for. A milling machine is a machine tool on which material (usually metal) is secured to a carriage and is shaped by rotating milling cutters. A lathe is a machine tool on which material is rotated about a horizontal axis and shaped by a fixed tool. A grinder is machine for polishing machined parts.

## Unigraphics Programming

Unigraphics programming work involved the use of computer tools to generate CNC programs. A computer system was used to capture the descriptions of the part in terms of features and dimensions, and to generate the CNC program needed to machine the part. Unigraphics programming was mostly used for creating CNC programs for the more complex parts, such as engine blocks. The programs were written for lathes and mills.

There were an average of five machinists per shift working as programmers. This sub-site was different from the other three in that it was located in an air conditioned office space, separated from the shop floor.

## CNC Machine Operation

The work at the CNC machine operation sub-site involved running CNC programs created by Unigraphics programmers in order to machine parts. The work also involved testing and editing newly created programs, routed to the floor by Unigraphics programmers. The number of individuals working at this sub-site averaged ten per shift.

## Sampling and Recruitment

Recruitment was arranged through the machine shop supervisor. The supervisor notified the workers of the proposed study at a regularly held meeting, and asked for volunteers interested to meet with me to discuss possibility of participation. Work at Makro was organized around three shifts, twenty-four hours a day, and seven days a week. The research was confined the morning shift which was from 7:30 am to 3:30 p.m. Initially, four machinists volunteered. They were a programmer (Dan), two conventional machinists (John and Peter) and one machine operator (Warren). The initial group did not include workers from the manual programming sub-site. With time, I was able to recruit an additional eight informants. The additional informants were recruited by approaching them, explaining the purpose of the study, and requesting their participation. One criteria for recruitment was to, where possible, include at least one worker who was training within a sub-site. The second criteria for recruitment was to include machinists of different generations, in terms of machining experience. Some had been machinists for over thirty years, while others were relatively new to the trade. The third criteria were to ensure that machinists from each of the sub-sites were adequately represented.

## Phases of the Study

The initial visit to the site was on in the second week of June, 1996. Four additional visits were made to the site as part of the process of writing the research proposal. The initial visits involved discussions with supervisors, tours around the shop, and informal discussions with machinists. Data collection commenced in the first week of September 1996.

My preparations for the study included training on both conventional and CNC machine tools at a community college. Nevertheless, the research site had a wide variety of machine tools that needed to be understood before meaningful observation could begin. The initial stages of observations entailed learning about the machine tools from the informants. The informants were very helpful. Indeed, one informant offered me the opportunity to do some work on his machine, which I declined!

Having achieved some understanding of the machines and machining processes at the site, I began to address my research questions. I made an average of two visits per week for a total of twelve weeks until the first week of December, 1996. The duration of the visits averaged three hours. I spaced out the visits to enable me to transcribe data between visits. By working with the data on an ongoing basis, I was able to identify emerging patterns and themes and to do follow-up observations and discussions in cases where they appeared warranted. There were indeed several follow-up discussions with individual machinists, over and beyond the interviews that had been initially scheduled.

## Observations

My observations focused on the machinists' actions and their use of artifacts. Verbal exchanges between machinists and myself were audio taped using a cassette recorder and microphone that I wore.

A proposal to use video tape was not acceptable to the company in order to protect trade secrets. In addition, the company did not allow documents (e.g. hard copies of computer programs, blueprints) to be taken out of the building. I therefore used detailed field notes to describe machining actions and the use of artifacts. The field notes consisted of summaries of talk, and detailed descriptions of the role of artifacts. The observation form is indicated in the appendices. After each field visit, field notes were used together with transcripts of the audio to develop a full description of the observations.

## Interviews

Each of the informants was interviewed. Two interviews were initially scheduled. The goal of the first interview was introduce informants to the study, to go through the consent procedures, to learn about the kind of work that they did, their education, and their training.

The second interview focused on their work experiences as machinists. A set of questions was developed to establish how informants had responded to the changes in the trade, and why they had responded that way. The interview questions are in the appendices. Interviews were tape recorded and later transcribed. While the prepared questions guided the discussion, interviews were not restricted to them. The goal was to set the discussion as a dialogue and to ensure that the informants were comfortable to tell personal stories of their work in the changing trade. In most cases, discussions went beyond the initially scheduled interviews, and included some hours of informal chats.

## Summary

The research was organized around four distinct work roles tied to four work sub-sites. The sub-sites mirrored the historical changes that had occurred in machining at Makro. The changes in machining had occurred within the lifetime of the informants. The four sub-sites defined different aspects of machining work and changes in the work experiences of machinists at Makro over time. A cross-historical design was used, with the different sub-sites representing changes in the work experiences of machinists over time.

In the next chapter I begin the analysis of the data focusing on changes in machining activity in relation to broader societal changes.

# CHAPTER 4

# HISTORICAL OVERVIEW OF CHANGES IN MACHINING AT MAKRO CORPORATION

## Introduction

This chapter focuses on changes in machining activity at Makro in relation to broader societal changes. In chapters 5 and 6, the focus shifts to the development of knowledge, skills and identity. The discussions are based on interviews and observations of machinists at Makro. Thirteen machinists and one machine shop supervisor participated in the study. Of the 13, one was an apprentice machinist and the others were *toolmakers*. Toolmaker was a designation for skilled machinists who had completed the program of apprenticeship training at Makro.

The group of informants was highly skilled with an average of 20.8 years of work experience in the trade. Their work experience ranged from 10 to 37 years, if the one apprentice is excluded. The informants were drawn from the four sub-sites of conventional machining, CNC machine operation, Unigraphics programming, and CNC manual programming. They were representative of the generational differences in the machine shop. Figure 6 is a summary of the informants' backgrounds. Pseudonyms have been used for all informants.

| NAME | Highest academic qualification | Grade | Years in the trade | Years at sub-site | Sub-site at time of study |
|---|---|---|---|---|---|
| Al | High school diploma | Toolmaker | 27 | 27 | Conventional machining |
| Peter | High school diploma | Toolmaker | 34 | 30 | |
| John | High school diploma | Toolmaker | 12 | 12 | |
| Jonathan | High school diploma | Toolmaker | 35 | 15 | |
| Matt | High school diploma | Toolmaker | 10 | 4 | CNC Machine operation |
| Mark | High school diploma | Toolmaker | 16 | 10 | |
| Warren | High school diploma | Toolmaker | 16 | 13 | |
| Bernard | High school diploma | Toolmaker | 15 | 1 | Unigraphics programming |
| Dan | High school diploma | Toolmaker | 24 | 14 | |
| Ed | High school diploma | Toolmaker | 37 | 25 | |
| Mike | Associate degree in mechanical engineering | Toolmaker | 22 | 4 | CNC Manual programming |
| Bill | High school diploma | Toolmaker | 19 | 5 | |
| Tom | High school diploma | Apprentice machinist | 4 | 1 | |

Figure 6: Background of informants

Changes at Makro Corporation have occurred in a context of global changes in automobile manufacturing. Makro is a major player in an automotive industry that has become intensely competitive over the years. Automobile imports, mostly from Japan, have taken a significant share of the US domestic market. The trend began with the oil crisis of 1973 when American consumers began to demand smaller, more reliable, and higher quality products (Shaiken, 1984; Monden, 1994).

In order to enhance competitiveness, corporations such as Makro have re-organized their systems of production. Some Japanese approaches to manufacturing have been studied and adopted. In particular, US auto makers have taken note of the system of production used by Toyota, described as having the most efficient production system in the world (Monden, 1994). These changes are based on greater coordination of production across different divisions of corporations, and the standardization of products. Some corporations have adopted the concept of the "world car" which is "a standardized vehicle marketed throughout the world and built using global design and manufacturing facilities" (Shaiken, 1984, p. 236). These trends have been aided by the development of computer technology and telecommunication systems. The introduction of CNC at Makro was part of the process of re-organizing production to maintain competitiveness.

SOCIETAL CHANGE-Mass production of automobiles; Global competition and demand for new and better products.

LOCAL INSTITUTIONAL CHANGE-- development of prototypes; product development and testing; production; and organizational change.

ACTIVITY DEVELOPMENT-- Changes in work practices related to the introduction of new machine tools and processes (e.g. CNC). New training programs tied to emergent corporate goals.

INDIVIDUAL DEVELOPMENT-- workers re-evaluate their knowledge and skills, as well as goals. Changes in knowledge and skills, and goals. Development of identities of machinists.

Figure 7: Relation between societal and individual change

Figure 7 is a heuristic model that I used to conceptualize the different levels of change that had some bearing on the work experiences of machinists. The model incorporates societal, institutional, and machining activity changes. Changes in machining at Makro were broadly tied to changes in manufacturing industry as a whole, and in particular to competition within the domestic US market and the international automobile industry. Global changes (e.g. automation, competition, and higher quality demands), were paralleled by local institutional changes that included new corporate goals and organizational change. At the machine shop level, there were changes in machining technology, a re-organization of machining work, and the introduction of training programs tied to changing corporate strategies and goals. The precise relation between the different parts of the model is an empirical question. It may very well be that there are tensions between the different levels. For example, changes in technology may meet worker resistance (Noble 1979; Shaiken, 1984).

The discussion now turns to specific changes that occurred at Makro.

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## Changes in Machining at Makro

The machine shop was located in a division of Makro Corporation which began automobile production in the 1940s. At that time, the division specialized in the manufacture of one line of cars and was wholly responsible for their design and manufacture, from start to finish. Over time, the activities of different divisions became more integrated and work came to be shared across different plants, located in different parts of the country. Rather than specializing in a particular car model or models, divisions now specialized in components. For example, a division might specialize in one type of engine. Other parts of the car would be designed and manufactured elsewhere. Design and production was therefore distributed, mostly within national borders, and in some instances, across different countries. This was a significant shift from the time when the whole car was designed and manufactured at one site. Ed, who had been with Makro for over thirty-five years recounted the changes:

> We used to do one specialized line of cars. So any engineering thing that involved our specialized line--transmissions, engines, manifolds, or rear end parts, or the frame or body, or anything--this engineering unit did that. Now we are responsible for whatever they assign to this site...Now we are responsible primarily for engines. Engines have always been a big part of this. But now we are just engines. (Ed, 12/3/96. p. 29)

The distribution of manufacturing across different divisions was accompanied by the standardization of parts. Makro Corporation manufactured a range of automobile models, many of them with common design features, and parts. Standardization of design and development was cost-effective. Chuck, a supervisor in the machine shop, described the changes in the following terms:

> We used to have a lot of specialized work, it was actually development type work where some engineer would scratch on a napkin a design...and our guys would work on it. It was a lot of specialty work...Now we are doing less specialty work. (Chuck, 12/6/96, p. 11)

The re-organization of manufacturing had consequences for the work of the machinists involved in design and development. In the following exchange, Ed describes the significance of the changes for machinists working in the prototype shop.

| | |
|---|---|
| Ed: | The engines aren't assigned to any of the cars. So they take the same engine and put it on different models now. It didn't use to be that way. And they put them in whatever car they want. |
| Interviewer: | Why do they do that? |
| Ed: | To save money. There is a commonality of parts. So that one starter can work in different cars. Same way with engines. One engine will work in different cars. |
| Interviewer: | So that changes the work you do? |
| Ed: | Quite different from what it used to be. |
| Interviewer: | If the engine is the same then the work is less varied. You do more of the same. |
| Ed: | We have to compete with other auto-makers. And we have to compete with the Japanese and the Europeans. And this is spreading to Asia. They are making cars all over now. And this market is getting so competitive we've got to hold down costs to be competitive with all those people. |

(Ed, 12/3/96. p. 31-32)

Over time, the machining of prototype parts involved a narrower range of products. Another important change was the volume of parts machined. In the 1990s, the industry was facing unprecedented demands for quality products. The pressure came from other corporations. It also came from the Federal and State governments who were passing more stringent safety and environmental regulations. The higher quality demands necessitated the machining of larger quantities of prototype parts for use in product testing. Chuck, a supervisor in the machine shop, described these change in the following terms:

> In our particular shop here, years back when you would do a prototype engine or whatever, you made a half dozen to a dozen engine blocks. And they used those to validate their parts. Now they have gone from using a few parts to two, three, four hundred of them. So you are doing a lot more volume. (Chuck, 12/6/96, p. 10)

Chuck saw the change in volume and the reduction in the range of products machined in the shop as the most significant changes over the last 30 years.

> That's the big change. We went from one and twos to three, four hundred of each part. So its kind of like from specialty to almost like, [chuckle], a production environment. (Chuck, 12/6/96, p. 12)

These changes have occurred within the working life of individual machinists and have significantly altered machining work. For example, individuals who were used to working on small batches of a part now had to work on large batches for weeks, and sometimes months.

Changes in machining work were intimately related to the introduction of Numerical Control technologies at Makro in 1962. The technology has grown in importance over time. Similar trends have been reported elsewhere (Martin & Scribner, 1991; Martin & Beach, 1992; Shaiken, 1984; Noble, 1979). In the 1960s and early 1970s, Numerical Control technologies played a peripheral role in the design and production of automobile parts at Makro. It was viewed with some skepticism by skilled machinists. Dan came to the shop in the early 1970s and recalled the first NC[1] machine:

> It didn't work very well by the time I hired in here. I never worked on that one too much. It had weird controls. Everything was old fashioned. It was terrible compared to what we have now, anyway. (Dan, 11/7/96, p. 8)

In the early days of Numerical Control machining, programs were written for the machine by white-collar workers and run on the machines by blue-collar machinists. In conversations, informants referred to the white-collar workers as 'salaried people,' and to machinists as 'hourly people'. Blue-collar workers were opposed to the arrangement. They felt that programming was part of their work. As Peter, put it, "We thought all along it should be hourly people who should be doing the programming." (Peter, 10/8/97, p. 7). Eventually the machinists won the right to program through union negotiations. Since then, Numerical Control technologies have become more central to the operations of the company. It affords repeatability of precision machining processes, in a shopwhich has shifted from small batch, to large batch production of prototype parts. Beyond that, more powerful computers and new software packages have been acquired over time, increasing the shop's capacity to machine complex parts.

CNC machining has not been merely a substitute for conventional machining. The use of Unigraphics programming has enhanced the shop's

[1] NC programs were controlled through a central computer and were written by specialist programmer working off the shop floor.

capability to machine complex surfaces. Previously, some complex surfaces were designed using wood models, and then manufactured through a molding process. The use of CNC has therefore expanded the range of machinable tasks, leading to the closure of the wood modeling shop, and the disappearance of the wood modeling trade from the plant. Ed described wood modeling as a high skilled trade.

At the time of the study, machining work was carried out at four different sub-sites. As indicated in the previous chapter, these were conventional machining, CNC Unigraphics programming, CNC manual programming, and CNC machine operation. The distinctions represented the re-organization of the workplace, by work roles. They were also representative of changes in machining over time as new technologies were introduced to enhance productivity and competitiveness. Unigraphics programming was the latest addition to the shop.

The increased use of CNC in machining work was related to broader societal changes. It was a response to competitive pressures. Beyond that, the use of CNC generated competitive pressures by making higher standards of quality control affordable for competing corporations. There were therefore no simple cause and effect relationship between societal changes and the of CNC. The complexities of the relationship have been highlighted elsewhere (Martin & Scribner, 1991; Noble, 1979).

## Summary

I have provided an overview of the changes in machining work at Makro over the years and its relation to societal changes in manufacturing. There were changes in the work of skilled machinists tied to institutional and societal changes. The changes in machining were tied to increased global competition, and a trend towards standardization of products as exemplified by the concept of the 'world car'. The variety of machining work narrowed over time, while the volume of production grew to meet more stringent quality demands. There were changes in technology, from conventional, to CNC machining, and the re-organization of work into new work roles (e.g. CNC programmer and CNC machine operator). The development of individual machinists therefore occurred in a social and historical context of changes.

The discussion now turns to Chapter 5 which focuses on the development of machining knowledge and skills.

# CHAPTER 5

# THE DEVELOPMENT OF KNOWLEDGE AND SKILLS

## Introduction

The focus in this chapter is on the development of knowledge and skills in the transition from conventional to CNC machining. The research question has been stated as follows:

*Are there changes in the knowledge and skills of skilled machinists related to the change from machine control mediated by primary artifacts to that mediated by secondary and tertiary artifacts? If so, what are they, and how are they related to the change in the mediation of machine control?*

The data was derived from the machine shop at Makro Corporation through interviews and observations of skilled machinists. The site was divided into four work sub-sites which defined distinct work roles. They were a conventional machining sub-site and three sub-sites involving CNC work. The three CNC machining sub-sites were (1) manual programming, (2) machine operation, and (3) Unigraphics programming.

The shop started in the 1940s as a conventional machining shop. Numerical Control technologies were introduced in the early 1960s. Initially, program code was created manually, and later computer assisted programming was introduced. At the time of the study, conventional and CNC technologies existed side by side. Changes in knowledge and skills were studied by examining the work activities of individuals in distinct machining roles tied to work sub-sites that represented different historical points of development of machining activity at Makro. The sub-sites and the roles tied to them also reflected the historic changes that were occurring in the industry as a whole as CNC technologies increased in importance (Shaiken, 1984). In this sense, the site was a microcosm of changes in American manufacturing.

## Overview of the Sub-sites and the Informants

The following is a description of each of the four sub-sites and the informants drawn from each of the sub-sites. The discussion begins with the conventional machining sub-site.

### (a) Conventional Machining

Prior to 1962, all the machining work in the shop was performed conventionally. By conventional machining I mean the use of manually controlled machine tools. Conventional machining continued to be important in the shop in the 1990s. All apprentice machinists at Makro received the bulk of their training on conventional machines. They had to complete 8,000 hours of work on the shop floor and over 80 percent of that time was on conventional machines. Machinists recruited by Makro from other shops completed a similar apprenticeship program. Conventional machining was therefore a base from which machinists made transitions to other sub-sites. Conventional machinists generally worked on one-of-kind, or small-batch parts. CNC was considered more efficient for large batches. Once a CNC program was created and tested, the technology afforded mechanical repeatability of machining processes for large numbers of parts.

Four machinists were observed in detail at the sub-site (Al, Jonathan, Mark and John). The analysis in this chapter focuses on observations with Mark and John. Observations with the other two informants were consistent with Mark and John. In the first part of this chapter, I discuss observations with John, and in the second, observations with Mark.

(b) CNC Manual Programming

The work at the CNC manual programming sub-site involved writing CNC programs and using them to machine parts. The programming was termed 'manual' in contrast to computer assisted programming (to be discussed later) where a computer generated program code using geometric descriptions of the part. In manual programming, the calculations needed to describe the path of cutting tools were computed using paper, pencil and calculator. The program was initially handwritten using program code and the program code was manually entered into the computer through a computer keyboard. In most cases, the same individual was involved in programming and machining parts using the programs created at this sub-site. The CNC code used in manual programming was also used by CNC machine operators.

Three machinists working at the manual programming site were observed in detail. They were Mike, Tom, and Bill. Bill was training Tom at the time of the study, Tom being an apprentice machinist. The discussion in this chapter is primarily based on observations with Bill in the first part of the chapter and Bill and Tom in the second part. The training sessions involving Bill and Tom provided important insights because of the interaction between the two informants. Observations with Mike were consistent with Bill and Tom. Some limited data from observation with Mike is included in the second part of the chapter.

(c) CNC Unigraphics

Unigraphics programming was phased in around 1990. Unigraphics is a computer technology for generating program code using geometric descriptions of the part. The process of programming involved creating descriptions of the features and dimensions of the part using computer graphics, and defining the machining processes needed to machine those features. The Unigraphics programmer generated the control codes for the machine. One programmer (Dan) described the process of programming as follows:

> What it gets down to is drawing a picture or describing the features that you want to machine in some way to the computer, and the computer takes that and translates it into something that the machine will understand (11/7/96, p. 48)

The Unigraphics programming system was used to generate programs for machining complex parts on large CNC machines. The size of machine was defined in terms of dimensions, but more importantly in terms of the number of axis of motion it was capable of executing. The most basic machines had three axiis, that is longitudinal, transverse, and vertical motions. The available CNC machines ranged from 3- to 6-axis. The 3-axis machines were programmed manually and were used to machine relatively simple parts. The more complex parts (e.g. engines, and exhaust manifolds) were machined on machines with four or more axis. Dan explained why Unigraphics was used on machines with four or more axis.

> With a 3-axis machine, myself or somebody else that knows about it can sit down and write out on a paper, long hand, exactly where each axis on the machine is, where you want to go, and what you want to do after it gets there. You can write all that out. When you get to a 4-axis machine, you can do that. It's barely possible...When you get to a 5-axis machine there is no way a person can sit down and write it out long hand. It will take years. You need a computer to figure out the angles and so on. It takes a computer to know what to do. (11/7/96, p. 49)

There were three people who participated in the study from the Unigraphics programming site. They were Dan, Bernard, and Ed. Of the three, only Dan was involved in writing a new program at the time of the study. The other programmers were refining existing programs. Observations at this site were based on the work of Dan. Ed and Bernard participated through interviews.

(d) CNC Machine Operation

The role of Unigraphics programmers was associated with another role: that of the machine operator. Programs from the Unigraphics sub-site were routed to a CNC machine on the shop floor. That machine was operated by a CNC machine operator. With newly created programs, the work also involved testing and editing them to ensure that they machined parts to specifications.

Three machinists participated in the study from this site. They were Matt, Mark, and Warren. During part of the study, Warren was running an existing program that had been developed by Bernard (a Unigraphics programmer). The program had been running for several months and the basic problems had been resolved. There was not much to learn from observing him in terms of knowledge and skill. The data that in this chapter is therefore derived from the work of Matt and Mark.

In summary, the analysis is based on detailed descriptions of the work of seven main informants, two from each of three sub-sites, and one from the Unigraphics programming sub-site. Figure 8 is a summary of the main informants.

## Analysis of Historical Changes in Knowledge and Skill

As indicated in chapter 2, I used artifactual relations as a unit of analysis. An artifactual relation defines meaning in terms of a triadic relation between an artifact, its referent, and an interpretant. By using artifactual relations, changes in knowledge and skill can be described qualitatively in terms of changes in meaning. The artifactual relation locates knowledge and skill neither in the individual, the referent, nor the artifact, but rather in their relations as organized by a particular activity.

| SUB-SITE | Main Informant | Grade | Experience |
|---|---|---|---|
| Conventional machining | John | Toolmaker | John had only worked as a conventional machinist. |
| | Mark | Toolmaker | Mark was observed at both the conventional and CNC machine operations sub-sites. He primarily worked as a CNC machine operator. |
| CNC manual machining | Bill | Toolmaker | Bill primarily worked as a CNC machine operator. At the time of the study, he was training Tom at the manual programming sub-site. |
| | Tom | Apprentice | Tom was in the fourth and final year of apprenticeship program. |
| CNC machine operation | Mark | Toolmaker | Mark was a trainee CNC machine operator. |
| | Matt | Toolmaker | One of Matt's roles was to train other machinists on machine operation. |
| Unigraphics programming | Dan | Toolmaker | Dan was the only Unigraphics programmer working on a new program at the time of the study. |

Figure 8: List of main informants by sub-site

The analysis focuses on three specific transitions, tied to the four sub-sites of conventional machining, CNC manual programming, CNC machine operation, and Unigraphics programming. The transitions were:

1. Conventional to CNC manual programming;
2. CNC manual programming to Unigraphics programming;
3. CNC machine operation to Unigraphics programming.

The transitions were selected to reflect the historical transitions that had occurred, or had the potential to occur for individual machinists at Makro, given the structure of the workplace. The analysis is intended to be illustrative rather than exhaustive. It is not therefore my intention to discuss all the possible transitions. In particular I do not analyze the transition from CNC manual programming to CNC machine operation. There was some overlap in the type of work at these two sub-sites. Both sub-sites were involved with machine operation, using CNC program code. In some ways, the work at the CNC machine operation site was a sub-set of that at the CNC manual programming sub-site, where machinists wrote programs and, in addition to that, operated their machines.

## Aspects of Knowledge and Skill Examined

There are a number of skills that are important in machining work. They include blueprint reading, determining the rate at which metal is cut, communication (with engineers and designers and other machinists), computer skills and so on. The study focused on two aspects of skill directly related to machine control in metal cutting processes. These are *translation of control* and *control of speeds and feeds*. The term *speeds and feeds* is commonly used by machinists. I have created the term *translation of control* based on observations of the work of machinists.

The control of speeds and feeds entails the use of artifacts to regulate the rate at which materials are cut in order to maximize the rate of production, as well as the quality of the product. The quality of the final product depends on the use of appropriate speeds of cutting and feed rates for materials to be cut. This is a critical aspect of machining because metal cutting conditions tend to be unpredictable (Shaiken, 1984). There is a tension between high rates of production, and quality of final product. High quality tends to be associated with slower rates of production.

*Translation of control* means the use of artifacts (primary, secondary or tertiary) to generate the machine control procedures and processes needed to machine a part to specification. The machinist has to interpret blue print specifications and make decisions about the appropriate machining processes, their sequence, and how they can be effected using a given set of artifacts.

The discussion of changes in knowledge and skill is organized around translation of control and the regulation of speeds and feeds. I begin with the translation of control.

## Changes in Knowledge and Skill in Translation of Control

My analysis begins with the conventional machining sub-site which was the career starting point for all Makro machinists. In this and other cases, an observation is described in some detail, followed by a discussion of its significance for changes in knowledge and skill.

### Translation of Control: Conventional Machining

In the following example, I illustrate how John carried out the operation of drilling holes and milling a block of steel. Milling involved cutting excess metal to shape the block of steel. The part was requested by the engineering section and was needed to hook up two components together in an experimental set up. The design was submitted to John as a sketch. The drilling and milling operations required were basic and were used frequently by machinists on both CNC and conventional machines.

The first stage of the operation was to drill holes. The sketch below illustrates the pipe holes that had to be drilled.

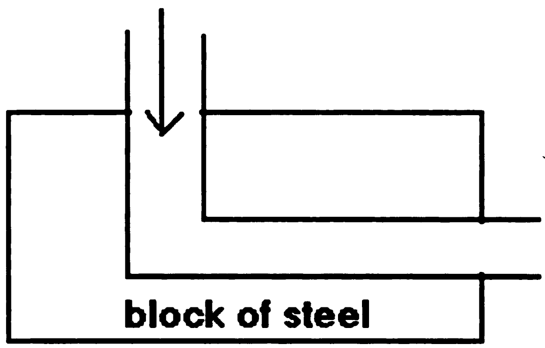



Figure 9: Pipe holes

According to John's sketch, the location of the holes was not critical.

John: This is not a precision part. All I want to do is to hook those two ends.

He measured the position of the hole on the block of steel and then marked that position on the stock. The mark was to be used to guide his tool operations. He could use the mark because in conventional machining tools can guided to machining positions by sight.

He picked up a drilling tool (called a *center drill)* and inserted it into the machine. The center drill is used in pre-drilling operations to prepare the location of a hole. John turned the machine on and the center drill began to rotate rapidly.

He lowered the tool towards the upper surface of the secured steel block by turning a lever. John paused to satisfy himself that the tool was properly aligned. He then pushed the center drill downwards, punching a small hole in the block of steel.

John turned off the machine. He was now ready to drill the hole proper. He picked up a drill, and inserted it into the machine. He set the depth of the hole on a digital scale. (The use of digital scales on conventional machines was a recent innovation. The same type of scales are used on CNC). He turned the machine on and lowered the drill using a lever, cutting into the steel block (stock) to a short depth. He pulled out and poured some oil and drilled again, watching the depth of the hole on the digital scale and then pulled out. He measured the radius of the hole. He drilled again. He stopped the machine, and took a larger drill. He was going to enlarge the hole to the final size. He inserted the drill into the machine, turned the machine on, and drilled again. Throughout the drilling process, he regulated the depth of the hole using a digital scale.

John: One drawback of this machine is that it takes so much time to change things.

Observer: It belongs to a different era.

John: People had more time back then. Now we are all in a hurry.

John was referring to the fact that it took longer to change tools on that machine, than on the other conventional machines. The machine was about thirty years old.

The second hole was drilled using the same procedure, beginning with a center drill. Having finished the two holes, John had to cut another feature into the square block of steel (see sketch below). He moved to another machine.

At the second machine, he picked up a cutting tool (endmill). He had a lot of material to cut, and he could not cut it all at the same time.

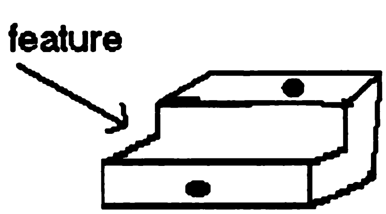



Figure 10: Location of pipe holes

Observer: How much are you going to cut? [ at a time]

John: It depends on how it feels. I will start and see how it goes.

He set the depth of cut a at half an inch using a digital scale. He then manually moved the cutter along the stock by turning a *wheel* with his hands. A wheel generates linear tool motion when it is rotated. John was guided by feel for the process, but he was also looking at the tool to guide him in the control process.

John: That's a deep cut, but the speed is slow, So it's OK. Watch the band [on the cutting tool]. Watch the level. If the cut is too heavy, the cutter will drop. It's doing OK.

In machining the part, John had to initially study his drawing and determine the required machining processes and the tools needed to achieve his goal. He used different types of drills and drill sizes in sequence to get to the final result. He manually picked up the drills, inserted them into a tool holder, and guided them into the part with his hand. The control of the tool was based on sight and feel.

John manually changed the tools. We will see that for machinists on CNC, the change in tools was controlled by program code. John's planning included marking the location of the holes on the block of steel. Those markings visually guided the drilling tool. In CNC programming, the machinist operates on a mathematical representation of the part, using numerical coordinates in space.

John's control of the process was in real time. This is in contrast to CNC where machine control processes are programmed and then executed at a different point in time. Because his work was mediated by primary artifacts (e.g. turning a lever), he could use *feel* to control the process. Figure 11 summarizes the artifactual relationship in the case just described. It highlights the use of primary artifacts, whose referents are machining processes. The artifacts have a materially non-arbitrary relation to their referent, the machining processes. The machinist interpreted the process within his role as a conventional machinist. Hence the interpretant (or meaning) of the action was tied to that role.

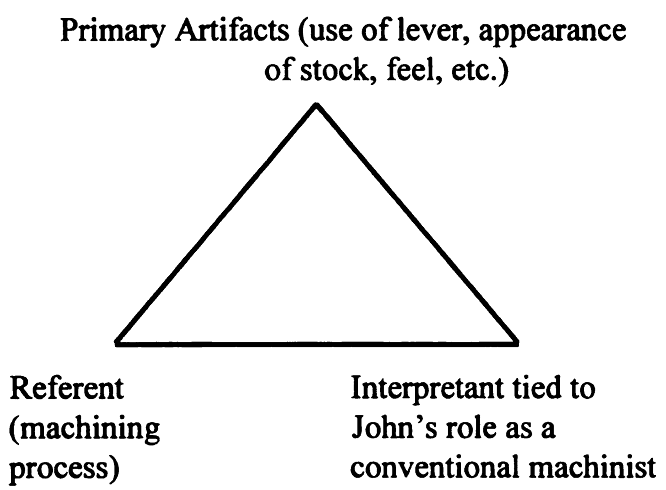



Figure 11: Artifactual relations in a conventional machine role

I now examine an example from CNC machining where I will make comparisons with conventional machining in terms of artifactual relations.

## Translation of Control: Manually Programmed CNC

In manual programming, a machinist constructs a set of computer instructions (program), using CNC program code. The program is usually written on a piece of paper and is then entered into the computer using a computer keyboard. Simple programs can be entered directly into the machine without first writing them on paper. The process of programming is removed in time from the machining processes, which are executed once the program is complete. When writing out the program, the programmer works with descriptions (representations) of the machine and machining processes. The stock (material), tools, control devices, and so on are all specified using secondary artifacts that are associated with machining processes only through social convention.

The following is a portion of an observation of Bill as he constructed the code for a part called a *Die Holder*.

The part that Bill was working on had several features. I will describe his work as he programmed one of the features. [Italics indicate what Bill wrote down. Arrows indicate the aspect of the code that he is verbally referring to.]

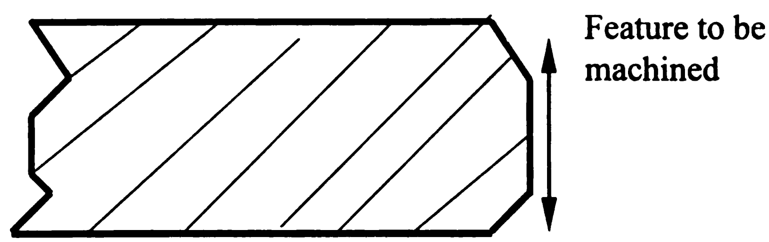



Figure 12: Using CNC

Bill: I will call up a tool [ T refers to a tool]

*N290 T101 M03 S1500 (--80 DEG--)*

Observer: OK.

*N295 G00 X2.5 Z2 M08*

Bill: G00 is a linear movement at a rapid pace.

[*X* and *Z* designate coordinates in space. *M* is a machine control command.]

Observer: I have heard that before.

[He writes some more code. He envisages starting off with a long bar of steel, chopping off a portion of it. That is what he means by "face it off" in the line below. (--Code not shown here)

Bill: And feed it in [gestures in a linear path], into the part. Go to Z=0. And face it off.

Observer: OK.

Bill: G63 is... will cut a chamfer for you.

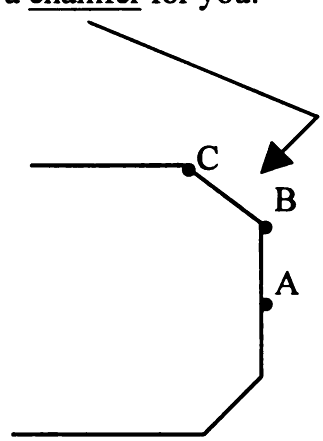



Figure 13: Chamfer

*N315G63*

[Pauses to study notes]

What I am going to do is, I have my part [pointing to diagram], and I want to cut that 45 degree chamfer, and cut a square corner.

[Pause]

Instead of having to program a G01 to here [points to A, *see sketch above*] , a G01 to here [points B], and a G01 to here [points C], I can program a G63 and, and I am going from point A, B, C. My tool is here [points to at A].

[Pauses to look at look at manual].

Bill: I can program this diameter which is two point five [2.5]. X equals two point five [diameter of part]

*N315G63 X2.5*

Observer: OK.

*N315G63 X2.5 P1-45*

Bill: P1, which is a parameter, which is your angle. I want to cut forty-five degrees on this [points to sketch]. So I program P1 minus forty-five. P2 is how deep this chamfer is going to be.

Observer: OK

Bill: Which is, [pause] I want it to be sixty thousandths [60/1000].

[Adds *P2 .06* to previous line]

The example shows Bill defining the machining processes using CNC program code. For example, the code *T101 M03 S1500* was an instruction to take a new tool from a given location and get the machine rotating at 1,500 revolutions per minute; *G00 X2.5 Z2* was an instruction for the machine to move at rapid speed to a location in space defined by the coordinates X=2.5 and Z=2.

The language that Bill used was different from that in conventional machining. He said, for example, "G63 will cut a chamfer for you." It was not Bill who was going to control the cutting process, but the program code. In another line, he said, "I will call up a tool", and that meant writing a line of code, not actually handling a tool. Finally, he also said, "the program, in that one line, it *knows* to take the tool to this point, and return." He assumed that he was interacting with an intelligent machine tool and his role was to instruct the machine to execute the machining processes using symbolic code.

In summary, CNC machining was based on codified representations of tools, materials, and processes. CNC program code is a secondary artifact, whose referent were machining processes. Secondary artifacts are materially arbitrary with respect to their referent. Their relationship with the referent is based on convention, and is unmotivated by any other association. Figure 14 summarizes the artifactual relation.

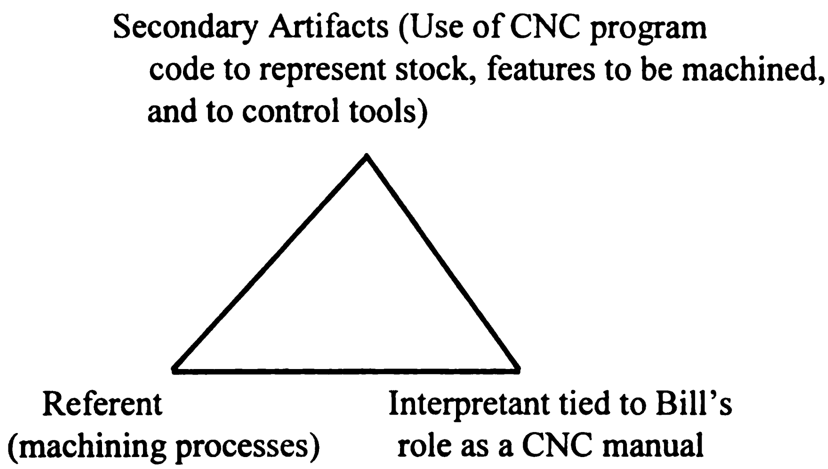



Figure 14: Artifactual relations in CNC manual programming.

I will now compare the artifactual relation in the transition from conventional to CNC manual programming.

<u>The Transition from Conventional to Manually Programmed CNC</u>

In the conventional machining role, the actions of the machinist were mediated by primary artifacts such as the appearance of stock and the movement and feel of the wheel. In CNC machining, machining processes were mediated by codified representations. Those representations were secondary artifacts.

Tom, an apprentice machinist who had made the transition from conventional to CNC manual programming described CNC programming as follows:

> In CNC you need to have a knowledge of how the computer runs the machine. The controller [i.e. computer] actually runs the machine.... On CNC you need to have skill on the computer, machine code, and that kind of thing. (Tom, 10/10/96, p. 14).

This is in contrast to conventional machining where the machinist runs the machine directly, generating machining processes. Figure 15 is a comparison of artifactual relations in the change from conventional to CNC manual programming. The comparison represents the historical transition that machinists at Makro have gone through, rather than the transition of a particular informant tracked over time.

Figure 15 indicates that the transition from conventional machining to CNC manual programming entails a change in the mediation of machining processes. CNC manual programming was mediated by secondary artifacts, while conventional machining work was mediated by primary artifacts. The machining processes (referents) involved in conventional and CNC machining were of the same kind (i.e. drilling holes, cutting of excess metal etc.). Artifactual relations were re-organized through the replacement of primary artifacts by secondary artifacts. A role change was a part of the re-organization.

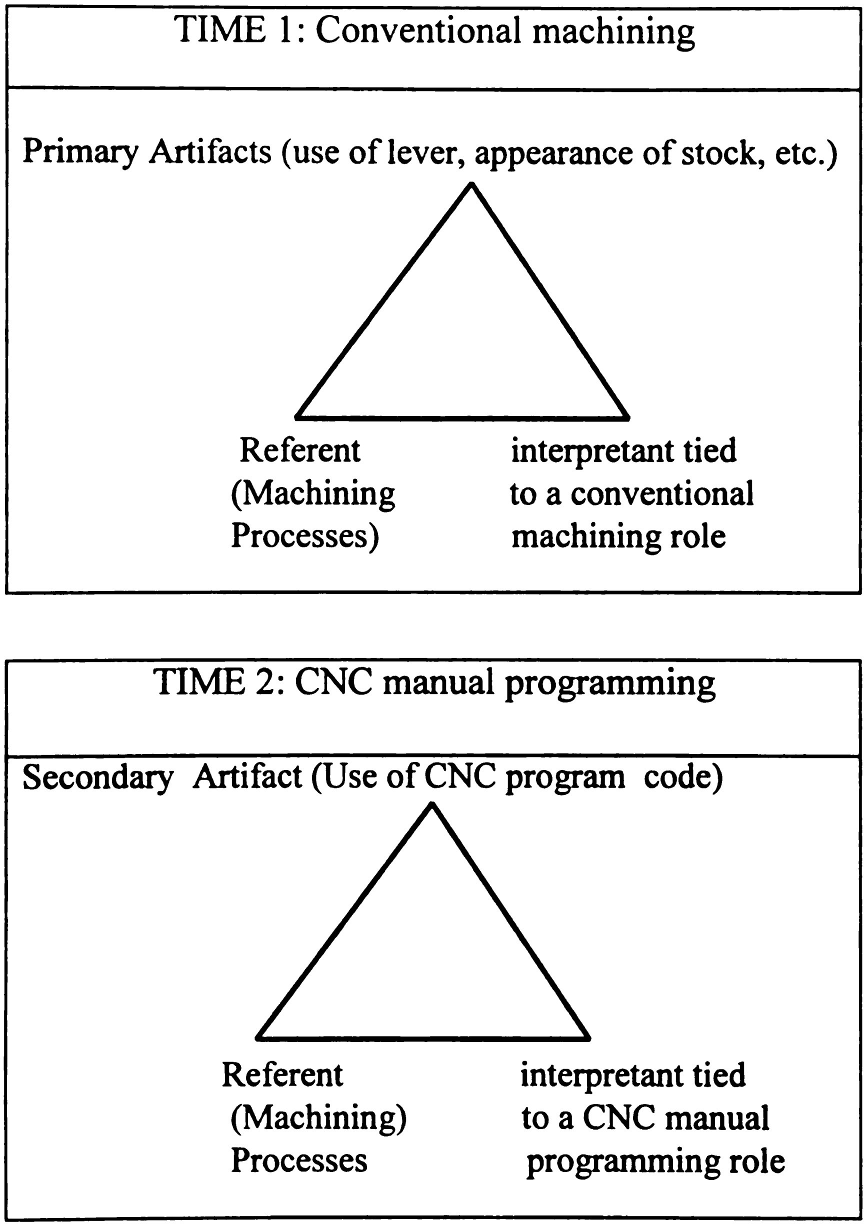



Figure 15: Conventional machining to CNC manual programming.

The change in the artifact and role indicated in figure 15 results in a re-organization of the artifactual relation. I have argued that a re-organization of artifactual relations constitutes a change in knowledge and skill. I take the transition illustrated in figure 15 to be a *transformation* of knowledge and skill. The transformation is defined in terms of a structural change of the artifactual relation. In this instance, the artifactual relation is re-organized by a change in artifact and interpretant, with the referent remaining the same. In the transformation, knowledge of machining processes is carried over the transition. The transition and transformation is based on the *structuring* of a new artifactual relation as a new artifact is placed into a purposeful relation to prior experience of machining processes. The changes in the artifactual relation are *made to happen* in practical situations. What is fundamental to the notion of transformation is the movement between, and an active interrelation and modification of different parts of reality through activity over time (Gose, 1989). The transformations do not exist as isolated units but are tied to activity where goals are shared. The change in artifactual relations is tied to a re-definition of the role of the machinist, from that of a conventional machinist to that of a CNC manual programming. The significance of the change in role is discussed further in chapter 6 when the issue of identity is addressed.

The preceding examples illustrate the transformation of knowledge and skill in the transition from conventional machining to manual CNC programming. An *additional* example to be discussed later will show that some aspects of the transition from conventional to CNC manual programming can be described in different terms, as a continuity of knowledge and skill. That analysis is presented under the section on the control of speeds and feeds. The discussion now turns to the transition in the translation of control from CNC manual programming to computer assisted programming with Unigraphics.

## Translation of Control: From CNC Manual Programming to Unigraphics Programming

In Unigraphics programming, computer technology is used to generate CNC programs using electronic descriptions of the features and dimensions of the part, and the required machining processes. One programmer (Dan) was observed working on a Unigraphics programming system.

Dan was seated at a computer terminal which displayed an electronic drawing of the part to be machined. He was able to manipulate the drawing to view cross-sections, as well as side, front and top views of the part. Programming involved identifying the features to be machined, deciding on the machining processes and tools required, and developing a workable sequence of machining operations. That information was entered into a computer as alphanumeric characters and graphic representations of the part. The programmer then instructed the computer to 'generate' the CNC program code based on the descriptions. The following observation is illustrative of the process.

Dan was developing a program to machine a *fixture* out of a block of steel. A fixture is an accessory used for holding parts while they are being machined. The final part was to have sides of 20 inches square. Dan envisaged that the part would be cut from a square block of steel of side 20.5 by 20.5 inches, reducing it to 20.0 inch sides. In the first part of the observation, Dan discussed how that would be done.

> Dan: We are going to end up with a part twenty inch square. We'll probably end up with twenty point five by twenty point five of rough stock. I am going to cut the outside profile...It's going to get into there to cut around it. I need to know what size of cutter to use. This is a half inch radius corner. So I can take a one inch cutter and that's the biggest cutter I can use and get all the way round...One inch is a pretty good size for cutting all the way round. I will use a one inch endmill to cut all round it
>
> The next thing I want to do is to pick up the tool to make the part. So [going to the terminal], one inch endmill [picking up tool icon with mouse], that's what that means [explaining icon to observer].
>
> Observer: So you keep a list of tools?
>
> (Dan, 11/7/96, p. 51-52)

Dan did not answer the question, but went on to talk about other features of the part and the tools that he had selected for use in cutting the block of steel. The observation highlights the use of a computer based graphical interface. The materials, such as the block of steel and the cutting tools, were manipulated as graphical representations.

Dan moved on to a new section of the program, and began by selecting new 'tools' with which to 'cut' new features on the part. The tools were iconic representations that he picked from the 'tools option' on the computer, using a mouse. The tool he picked was a 'drill.' For each tool option, the system presented default characteristics (e.g. dimensions). Dan examined the options, and in some cases changed them, based on his machining experience. He might for example change the length of the tool, or its hardness. The following text illustrates that process.

> I've got tool number nine done. I am doing number ten now. That's a drill. I pick up the little icon here. I put it down here , on 'new tool.'
> ['new tool' was an option on the screen]
>
> I am going to put a name for it. It's highlighted up here. The size is zero point six two eight [0.628]. It's set up to a default size of three eighths. That's not the diameter I want. The length is two inches, that's good enough. It will probably be longer than that.
>
> The tool point angle is set up to one hundred and eighteen [118] degrees. Generally the included angle on a drill is one hundred and eighteen. [Enters 118 degrees]
>
> (Dan 11/7/96, p. 55- 56)

The process of specifying the tools was repeated for each of the features that had to be machined. Some of the features were plain, flat surfaces to be milled, holes to be drilled, and contours (curves surfaces) that had to be cut. Decisions had to be made about the appropriate sequence of machining the features, the method of machining them, the tools to be used, and the control of those tools.

Before I examine the artifactual relations in Unigraphics programming, I need to discuss the relation between the use of Unigraphics and CNC program code.

## The Relation between Unigraphics and CNC Program Code

The final output from the Unigraphics system was CNC program code. In other words, code of the same type as was used in CNC manual programming. The code was created through the Unigraphics system in a number of stages. First, the input from the graphics interface was translated by the machine into a program language called APT which is an acronym for Automatically Programmed Tools.[1] In the second stage, APT was translated by the machine into CNC program codewhich was then used by machines on the floor to machine parts.

---

1 . In computer terms, APT is a higher level language than CNC program code. In other words, it is further removed from the machine language that controls machining processes, and uses fewer instructions than CNC to achieve the same result. See Noble (1979) for a discussion of the historical origins of APT.

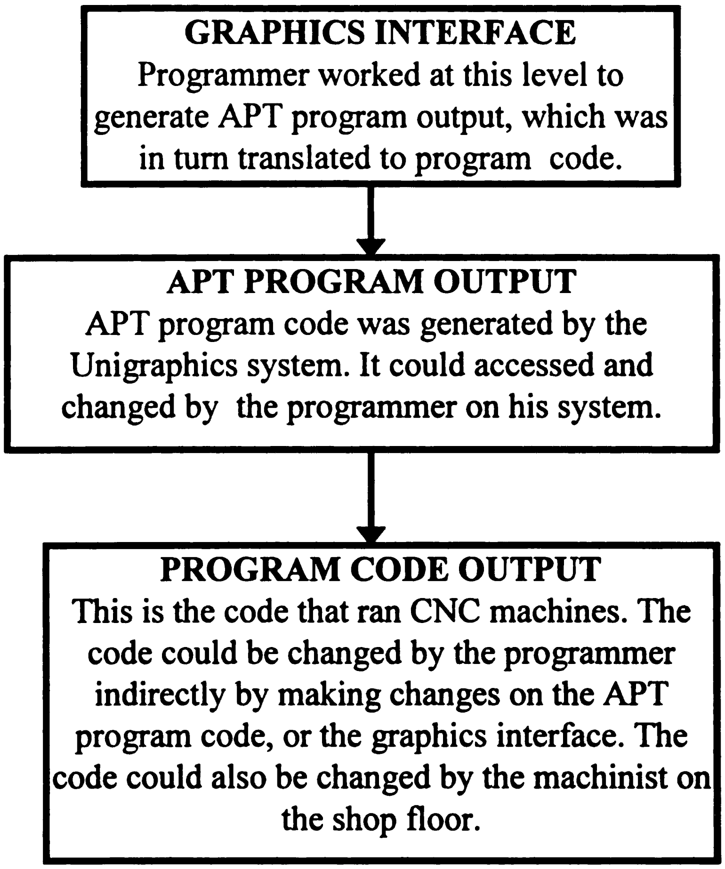



Figure 16: The different levels of the Unigraphics programming system.

The translations, first to APT and then to CNC program code were done by the computer. As Dan put it, "I don't see the language. It's all in the tube". Figure 16 illustrates the different levels of the system.

CNC program code is a secondary artifact, whose referent is the machining process. APT and the graphics interface are artifacts as well, but of a different kind. They both have machining processes as their referent, but only indirectly, through other artifacts. In a Unigraphics system, APT and the graphics interface are in fact *tertiary* artifacts in relation to machining processes. In Chapter 2, I noted that tertiary artifacts are derived from the organization of other artifacts, and only indirectly reference "base" phenomena from which they derive their meaning.

In the process of programming, errors could be generated at the different levels of the system. Some were a result of erroneous input from the programmer through the graphics interface; the more difficult, albeit less frequent errors were generated in the Unigraphics system in the process of translation from the graphics interface to APT, and finally to CNC program code. The ability to work at the three levels of the system, that is graphics interface, APT and CNC program code, was essential and constituted skill in Unigraphics programming. Dan explained this as follows:

> You go to the APT level when you have problems. Then you come back and check your graphics screen to see if there is anything there....You may have problems with a machine and it's not doing what you want it to do. If you look at the graphics screen and you can't see anything that's wrong there, you look at the APT. If you can't find it there, you go to the end file. Generally the end file is CNC stuff [program code]. The operator is looking at that. It isn't the programmer looking at that, but the guy making the part.

The graphics interface made it easier to generate programs. Dan saw some advantages and disadvantages in programming with Unigraphics.

> In some ways it's a lot easier. In other ways it's more complicated. I could sit down and show you how to program a fairly simple part. I could tell you how to program it this afternoon. But if you run into problems with it, for some reason, it is going to get tougher [than in the past] to figure out where the problem is. (11/7/96, p. 57)

As Bernard put it, some aspects of programming had become harder with Unigraphics. He was comparing it to a time when they programmed with a program called SPLIT (which was similar to APT).

> There are some things you have to work around. In some sense we went backwards. We made things harder than it was in the past... For the most part it works really good.

Unigraphics programming required skills in 1) working with a graphics interface in relation to APT program code; 2) working with the graphics interface in relation to CNC program code; and 3) working with APT code in relation to CNC program code. I will discuss each of these in turn and illustrate the artifactual relations.

Figure 17 represents the programmer working on the graphics interface in relation to an APT output. A competent programmer should be able to interpret work on the graphics interface in relation to APT program output. The artifact (use of graphics interface) and the referent (APT code) are both tertiary artifacts *in relation to machining processes.*

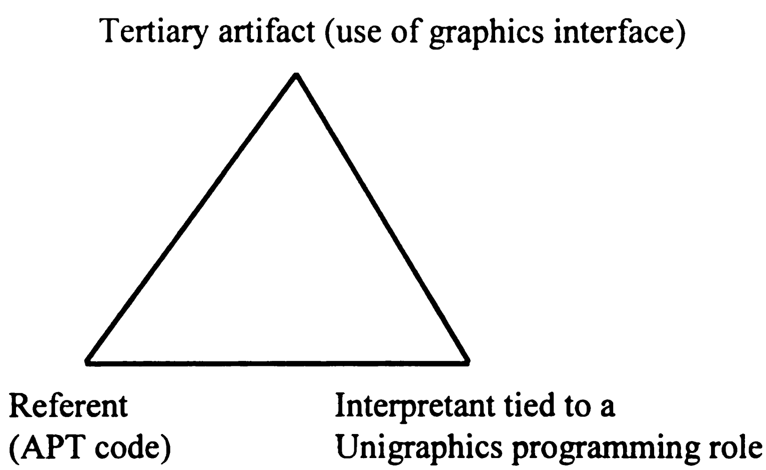



Figure 17: Graphics interface as artifact and APT program code as referent.

A Unigraphics programmer should also be able to work with the graphics interface in relation to CNC program code. On practically every new program, the machine operator identified programming errors. The machine operator corrected some of the errors. The more complex errors were taken to the programmer. The programmer was expected to discuss the CNC program code with the operator and to correct the errors using the Unigraphics system. Unigraphics programmers referred to changing the program in this way as "re-generating the program." Figure 18 represents a programmer working on the graphics interface and interpreting that work in relation to CNC program code. The referent is CNC program code, which is a secondary artifact in relation to machining processes.

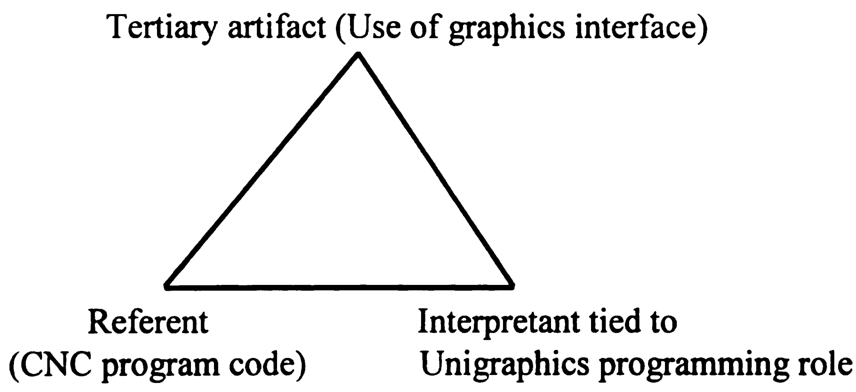



Figure 18: Graphics interface as artifact and CNC program code as referent

In some cases, the programmer was unable to correct program errors using the graphics interface. When that happened he worked on the program at the APT level. This was particularly useful in over-riding built in assumptions of the Unigraphics system. As an example, machinists at Makro did not like the values of speeds and feeds that were generated by the Unigraphics system. They could over-ride these values using the APT code. Figure 19 shows the artifactual relations when programmers operated at the APT level. The referent in this case is CNC program code, which is a secondary artifact in relation to machining processes.

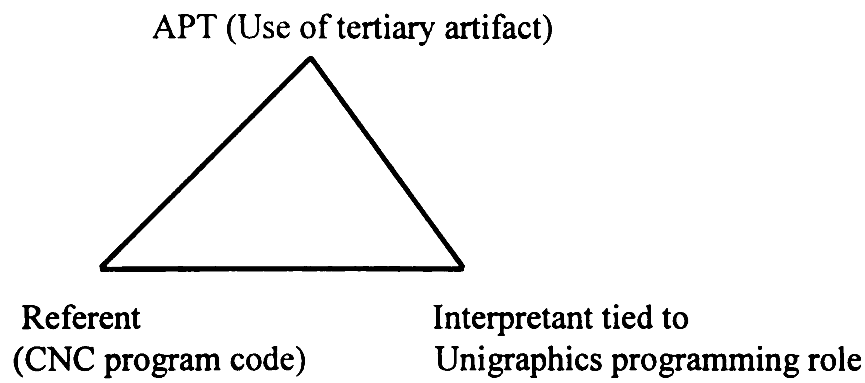



Figure 19: APT program code as artifact and CNC program code as referent

The discussion has shown that Unigraphics programming involved the use of a graphics interface, APT programming code, and CNC programming code, which are different artifacts. The transition from manual programming to Unigraphics programming, therefore, involved different changes in artifactual relations, depending on the aspect(s) of Unigraphics programming that the machinist was working with. Figures 20-22 indicates the three changes in artifactual relations.

In figure 20, the Unigraphics programmer is operating on a graphics interface in relation to APT code. Both the artifact and the referent are tertiary artifacts in relation to machining processes. Neither the artifact, nor the referent has been used in CNC manual programming. The transition illustrates a *discontinuity of knowledge and skill.* A discontinuity occurs in the transition from one machining role to another when an artifact and referent that have not been used before are introduced.

The discontinuity in knowledge and skill was tied to a historical discontinuity in machining activity at Makro. Prior to the introduction of Unigraphics programming, some programmers used an APT-equivalent programming language called SPLIT. SPLIT was phased out when Unigraphics was introduced. Programmers who were skilled in SPLIT programming were selected by management to move to Unigraphics programming when it was first introduced. Most of them opted to become Unigraphics programmers and one of them (Jonathan--see chapter 6) opted to go back to conventional machining. The pioneering Unigraphics programmers therefore understood the relation between APT program code, CNC program code and machining processes. The discontinuity in knowledge and skill existed for those machinists who had no prior experience of working with APT or SPLIT, if and when they made the transition to Unigraphics programming. This means all those machinists who were programming manually at the time of the study. These individuals would need to learn APT programming as part of their transition to Unigraphics. APT programming and its SPLIT equivalent no longer existed outside the Unigraphics system.

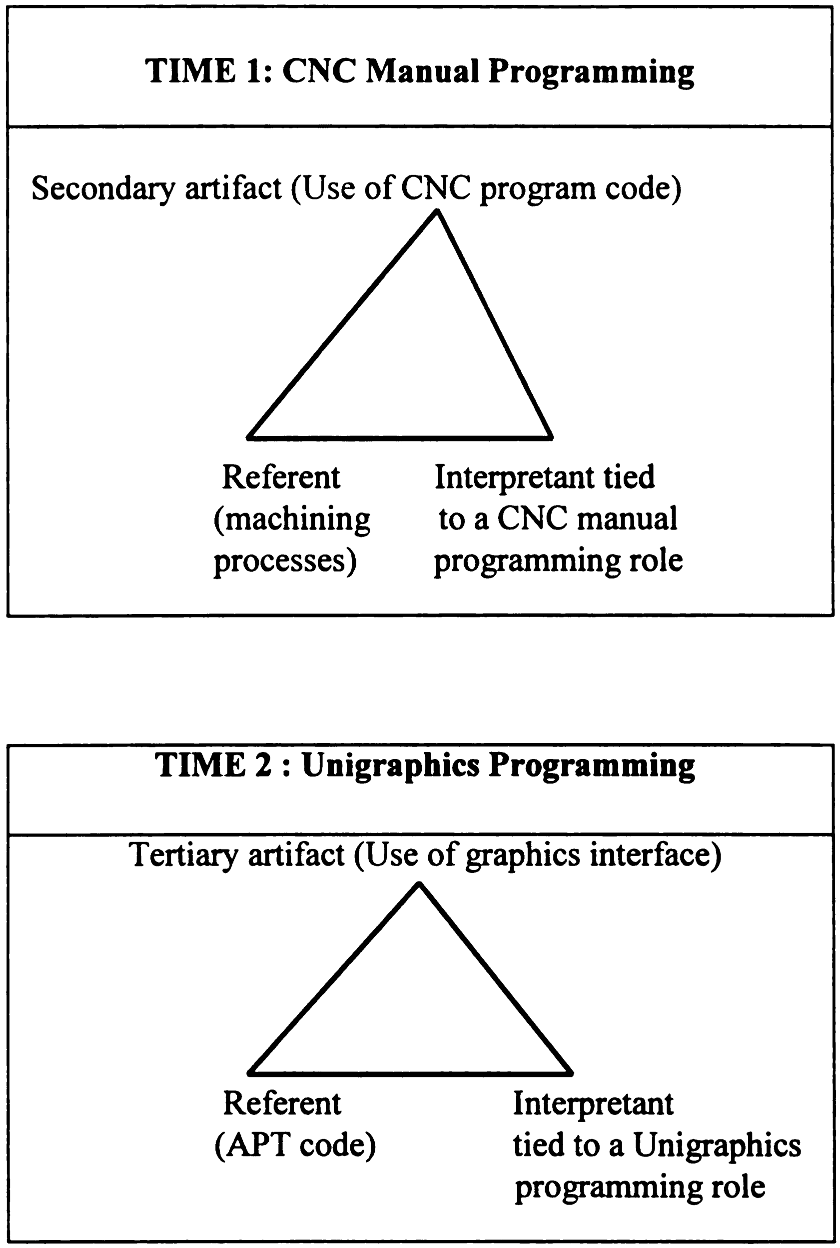



Figure 20: CNC manual programming to Unigraphics programming--Case 1

In figure 21, the Unigraphics programmer is using the graphics interface (artifact) in relation to CNC program code (referent). The artifact is tertiary in relation to machining processes, while the referent is a secondary artifact in relation to the same. The transition involves (1) a re-organization of the artifact-referent relation, and (2) the use of CNC program code across the transition, initially as artifact, and later as referent. I take this transition to be illustrative of a *transformation of knowledge and skill* because of the re-organization, and the use of knowledge of CNC programming which is carried over the transition.

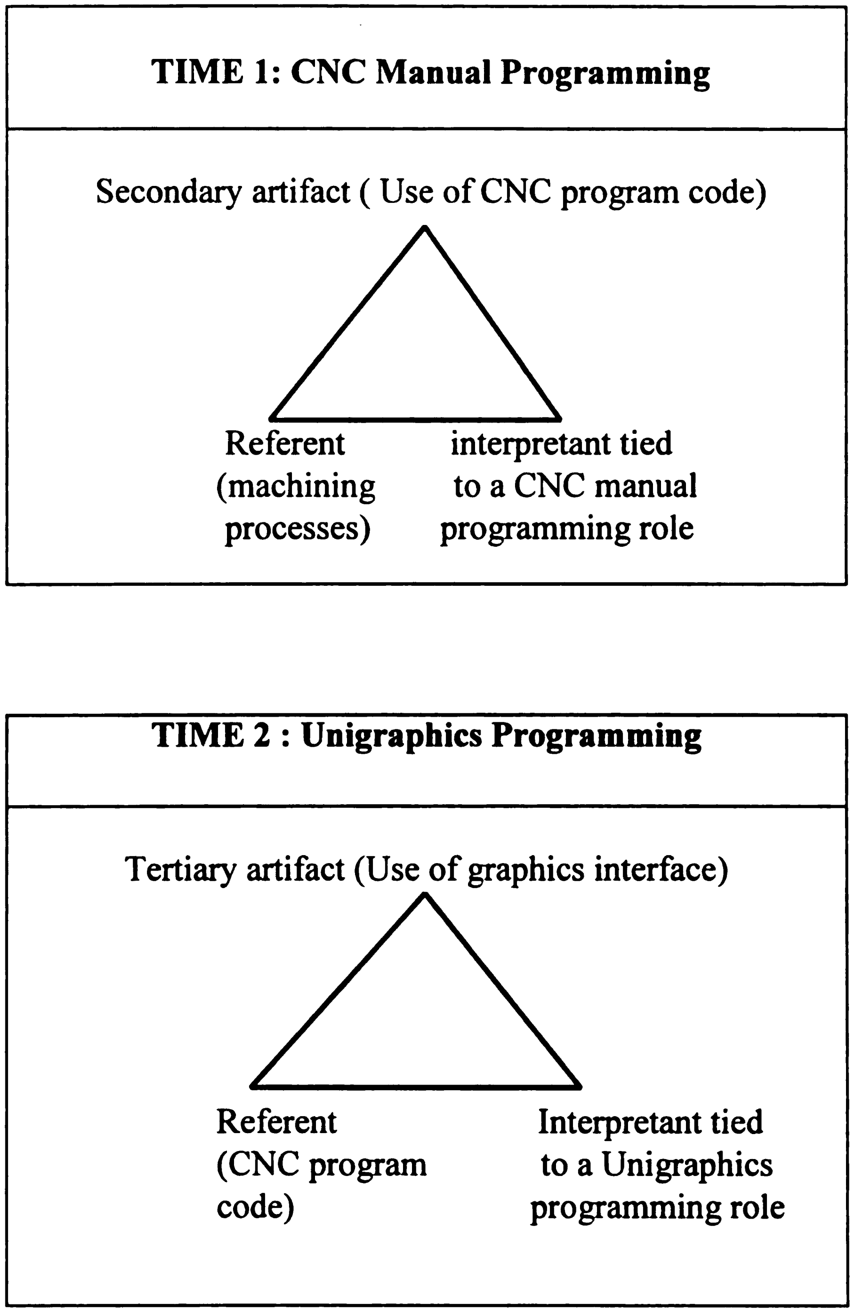



Figure 21: CNC manual programming to Unigraphics programming--Case 2

The discussion now turns to the third aspect of Unigraphics programming. In figure 22, the Unigraphics programmer is working with APT code with CNC program code as referent. As in figure 21, knowledge and skills in CNC manual programming have a role, across the transition, but in terms of a changed artifactual relation. This transition is illustrative of a *transformation of knowledge and skill* because of the re-organization of the artifact-referent-role relation and the use of CNC program code in the two roles.

In summary, the transition from CNC manual programming to Unigraphics programming consists of transformations and discontinuities in knowledge and skill, depending on which features of Unigraphics programming are in use and the history of the individual making the transition. There is no continuity in the transition, although continuity may exist in Unigraphics programming and CNC manual programming as separate activities.

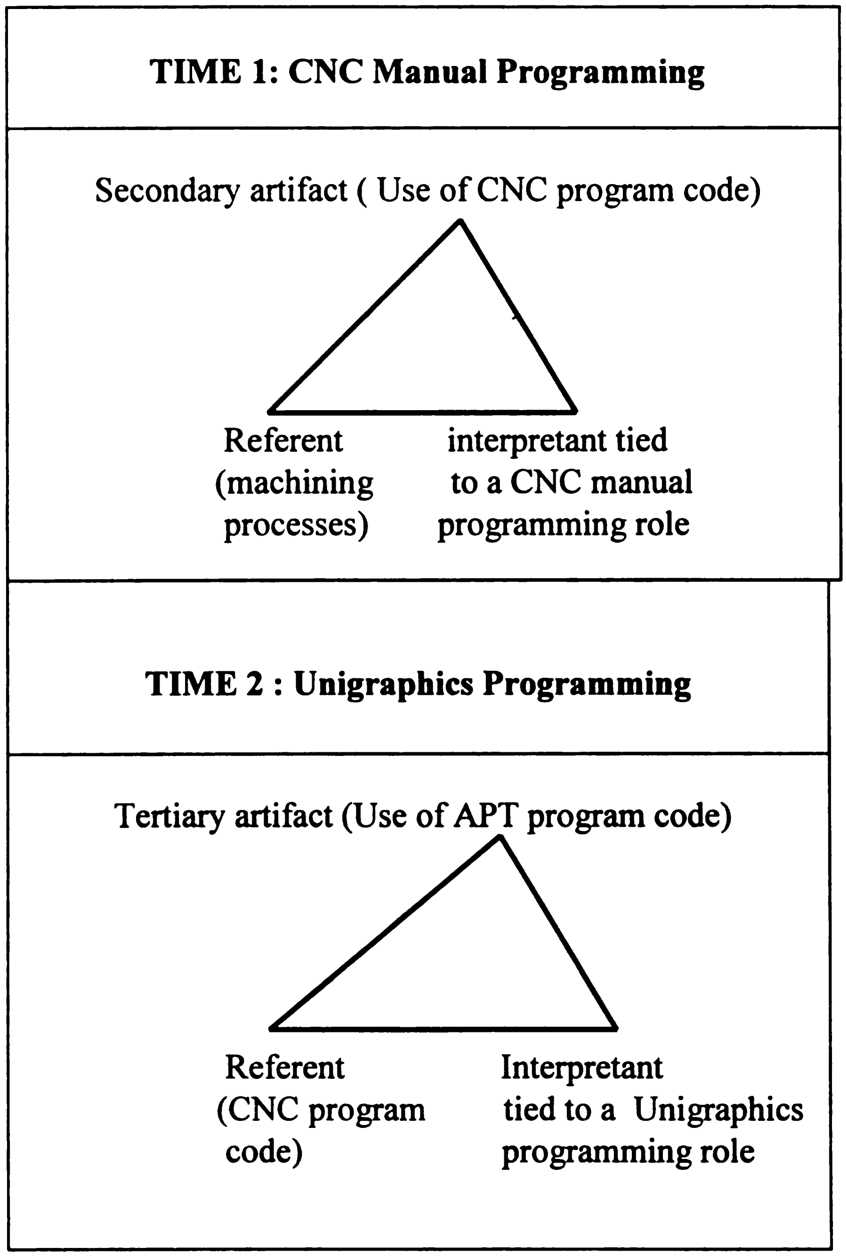



Figure 22: CNC manual programming to Unigraphics programming--Case 3

The meaning of individual artifacts relations was not isolated, but was tied to the machining activity and to the system of artifacts used in machining. In using the Unigraphics system, for example, there was no rapture with the metal cutting history of machining which was the productive base of the machining activity. The relation between APT program code and the graphics interface was therefore tied to machining processes. Specific artifactual relations show that aspects of machining work could be picked apart into ends and means with some certainty. However, the point is that the role of specific features (e.g. APT code) changed across different points in time. In other words, APT code appeared as both artifact and referent. The distinctions and relations between artifacts and referents were therefore localized and momentary, and not global classes of a permanent nature. In particular, the use of Unigraphics illustrates some fluidity in the role of artifacts and referents. This finding finds support in the next transition considered, that is from CNC machine operation to Unigraphics programming.

## Translation of Control: From CNC Machine Operation to Unigraphics Programming

CNC machine operators ran machines using programs generated by Unigraphics programmers. The more experienced operators were also responsible for testing and editing new programs. The analysis of knowledge and skill focuses on the testing and editing aspect of the operators' work.

In testing and editing new programs, operators had to devise strategies for cutting materials effectively, using the program generated by a programmer. They had to deal with the complex behavior of machine tools, for example tool wear, temperature expansion, "judder" (vibration), and variability in materials, in order to ensure that the product was cut to the right dimensions. It was rare for a new program to run without requiring major adjustments.[2] Adjustments were usually needed in such aspects as selection of tools, the rate of cutting materials, preventing collisions between moving cutting tools and accessories (fixtures), dimensions of features, and the sequence of machining processes, among others. CNC machine tools were capable of moving at very high speeds. High speed collisions were the most dreaded error because of they could result in extensive damage costing thousands of dollars. Errors were corrected by checking the behavior of the machine, step by step, against the program code provided and the blue print of the part. The following observation illustrates the process. It centered on Matt and Mark who were working with the program developed by Dan that was the subject of discussion earlier on.

Matt had been a machinist for ten years, four of which were as a CNC operator. He was training Mark, who had machine operating experience but had mostly worked with programs that were already tested and running. He was

---

[2] See for example, Fleck, Webster, and Williams (1990)for a discussion of the complexities of setting up CNC machines to run new programs.

learning how to handle new programs on Matt's machine. The following is a description an early phase in a machining process.

Mark and Matt had just secured the stock (i.e. block of steel) on the machine and were about to begin machining it. They had the program loaded in the computer, a paper printout of the same program, and a technical drawing of the part. They worked with both a printed and an electronic version of the program for two reasons. The printed copy was easier to read than the small screen version on the machine and they could write down changes that they made on the printed version, to pass on to the programmer, who had to amend his version, which the company stored.

In the following observation, Matt was operating the machine. In this testing phase Matt exercised manual control over the rate at which the machine moved using a *dial*. He machined the part one line of code (or instruction) at a time. Where he anticipated a problem, he slowed the machine down or stopped it completely.

He began by center-drilling holes. As he drilled, he listened carefully to the sound. He stopped after each hole to look at the part, the program code, and the technical drawing. As he moved to the second hole, he noticed that it was very close to the first. He stopped the machine.

Mark: Are they that close? [They both studied the technical drawing].

Mark: Evidently. [ The drawing confirmed the observation]

As he moved to the third hole the tool came very close to a clamp holding the part. From a distance, it looked like it might crash into a clamp. Matt stopped the machine, stood up and looked.

Matt: It's good

Mark : A thousandths is as good as a mile, as long as it misses [with a laugh.]

Matt moved to the next hole, and once more came very close to the clamp. He stopped the machine, got up to look and shook his head giving Mark a look of astonishment at how tight it was. He didn't like it to be that tight. But it was good, and the tool cleared the clamp.

Observer: This must be very hard on you?

Matt: That's the fun part.

He explained that that once the program was tested and running, there wasn't much to do, except to watch, and listen, and change the part. He had a hard time staying awake in those situations.

Once center-drilling was completed, the drilling operation began, using a new tool. Matt was at the controls. He studied the movement of the drill, and stopped the machine. He then studied the program code and the numbers on his screen.

The clearance of the drill from the clamp did not look good. "I think we have to move the clamp", he said. Mark climbed into the machine to adjust the clamp.

Matt punched numbers on the control. He was changing the program to increase the distance to which the drill retracted, after drilling a hole. That distance was called the R-plane. He drilled a hole. He paused to study the tool and the program code. He turned to the technical drawing.

Mark: Are we still safe?

Matt: This hole went deeper than the other holes. [pointing to technical drawing and also turning to the screen which displayed data on hole depth.]

Matt decided to change the R-plane again, and punched the changes into the computer unit. He explained that he had to make an adjustment of 25/1000 inches for the thickness of the stock because that amount was going to be ground off once he was finished with the part. After making the adjustment, he paused for a long time, studying the screen of the computer unit, and the technical drawing

Matt: I am going to have a smoke. I am nervous. [And he lit a cigarette.]

Observer: It seems to be going well.

Matt: That is why I'm nervous. The saying is , if it looks too good to be true, then it probably is. [laughing]

Matt was nervous because they had to get the part right the first time. This was a one-of-a-kind part. When machining large batches, it was generally understood that machining the first part was part of the program testing and verification process. The first part could, if necessary, be scrapped. As it turned out, there was a 'fatal' error in the program. The part was scrapped and new stock ordered.

The primary goal of the machining process was to check and edit the CNC program. The machining processes were tightly controlled to ensure that errors could be spotted before the part and/or the machine was damaged. Manual control (for example using dials), was exercised on some aspects of the operation. Observation of the machine behavior in terms of movement and sound was a critical part of the process. The observations highlight the primacy of primary artifacts in the process of testing and editing the program. The primary artifacts indicated in the observation are movement of the machine, observation of the stock, the sound of the machining process, and the use of a feed control dial. These artifacts had CNC program code as their referent. This is the reverse of the process in CNC programming where the program code was an artifact used with machining processes as referent. In practice, the process involves a back and forth process, as program code was used with machining process as referent. Figure 23 illustrates the use of CNC program code as referent.

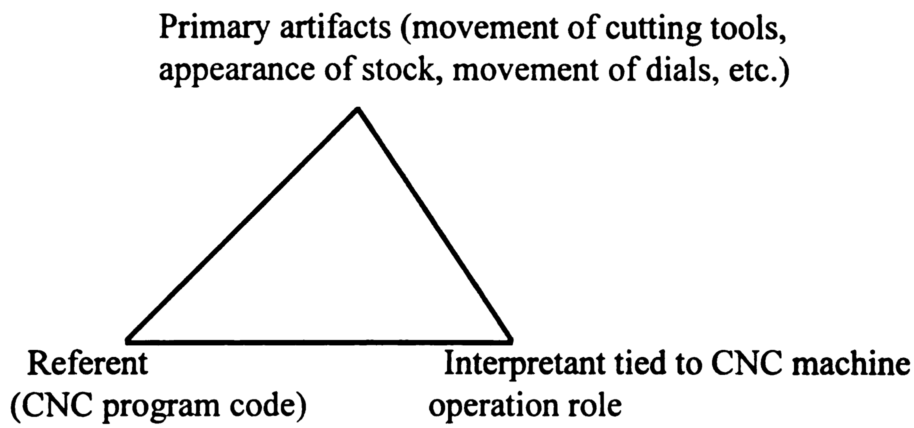



Figure 23: Artifactual relations in machine operation

In this section I analyze the transition from CNC machine operation to Unigraphics programming. As I indicated earlier, Unigraphics programming involved the use of a graphics interface, APT programming code, and CNC programming code, which were different systems of artifacts. The transition from CNC machine operation to Unigraphics programming therefore involved three different changes in artifactual relation. Figures 24-26 illustrates the three different artifactual relations.

The transition as indicated in figure 24 is illustrative of a discontinuity of knowledge and skill. The artifactual relation in Unigraphics programming is new, in terms of the artifact, the referent, and the interpretant. The discontinuity is tied to a historical discontinuity in machining activity at Makro where an APT equivalent programming system called SPLIT was phased out.

In figure 25, the Unigraphics programmer is working with the graphics interface in relation to CNC program code as referent. The graphics interface is a tertiary artifact in relation to machine operations and the CNC program code is a secondary artifact in relation to the same referent. The artifactual relation indicates that knowledge and skill in CNC programming is used in both Unigraphics programming and CNC machine operation. In the transition, there is a change in artifacts, with the referent remaining the same. The changes in artifactual relation are related through the use of the same referent.

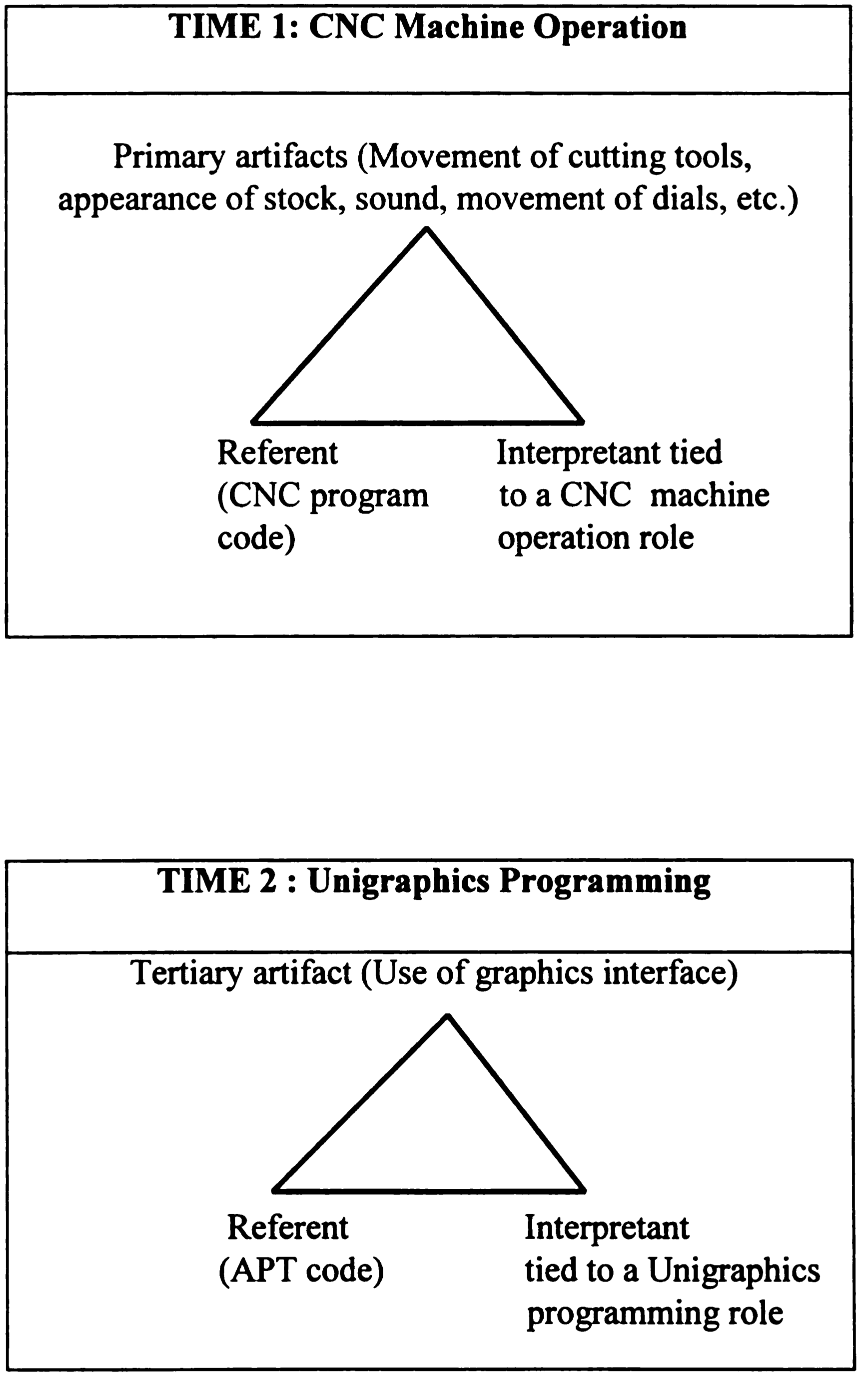



Figure 24: CNC machine operation to Unigraphics programming--Case 1

The transition from CNC manual programming to Unigraphics programming as indicated in figure 25 is illustrative of transformation of knowledge and skill because of the re-organization of the artifact-referent relation and the common use of CNC program code in the two roles.

In figure 26 the Unigraphics programmer is working with APT code in relation to CNC program code as referent. APT is a tertiary artifact in relation to machining processes, while CNC program code is a secondary artifact. During the transition there is a change in artifacts with the referent remaining the same. In both figure 25 and 26, skill in CNC manual programming is used as referent in the artifactual relation. The transition from CNC manual programming to Unigraphics programming as indicated in figure 26 is illustrative of a transformation in knowledge and skill.

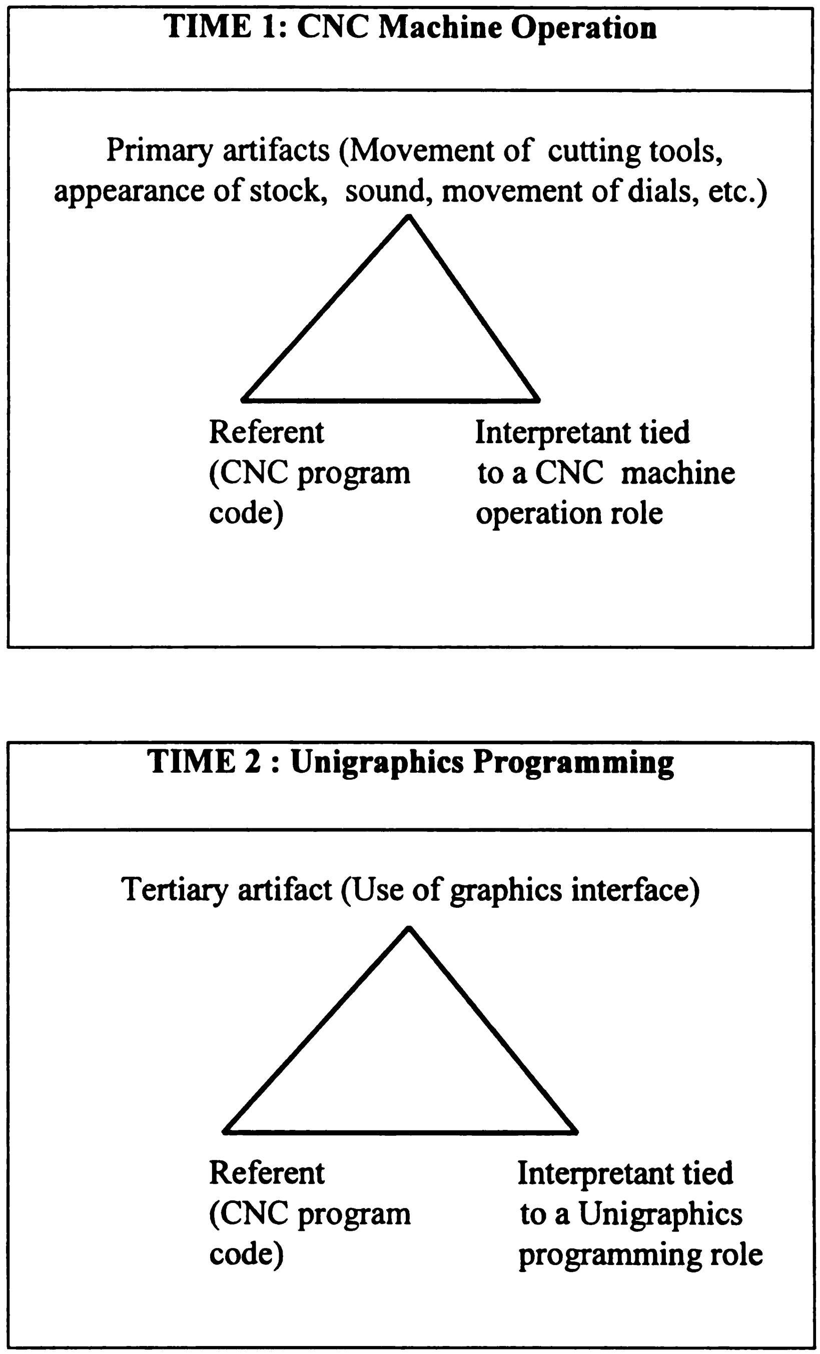



Figure 25: CNC machine operation to Unigraphics programming--Case 2

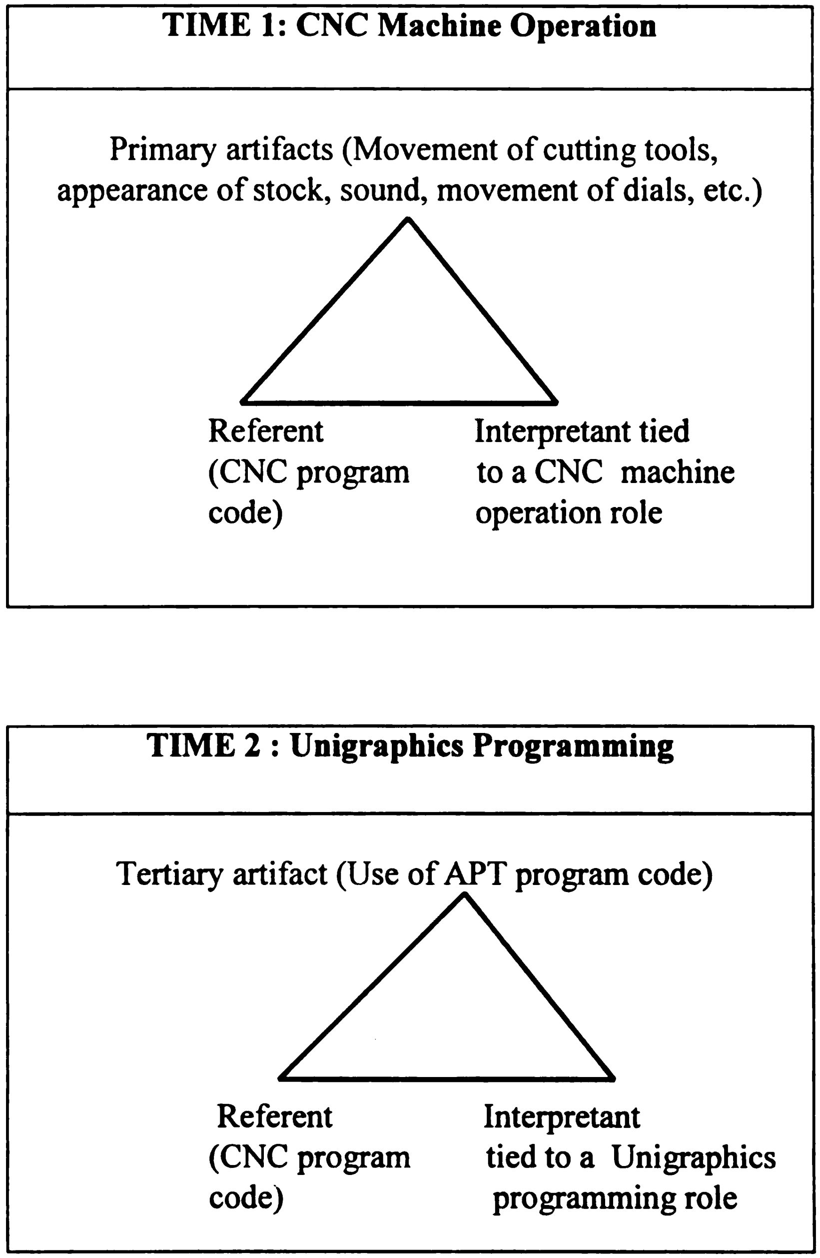



Figure 26: CNC machine operation to Unigraphics programming--Case 3

In summary, the transition from CNC machine operation to Unigraphics programming indicates both transformations and discontinuities in knowledge and skill, depending on which features of Unigraphics programming are in use, and the history of the individual making the transition.

## Summary

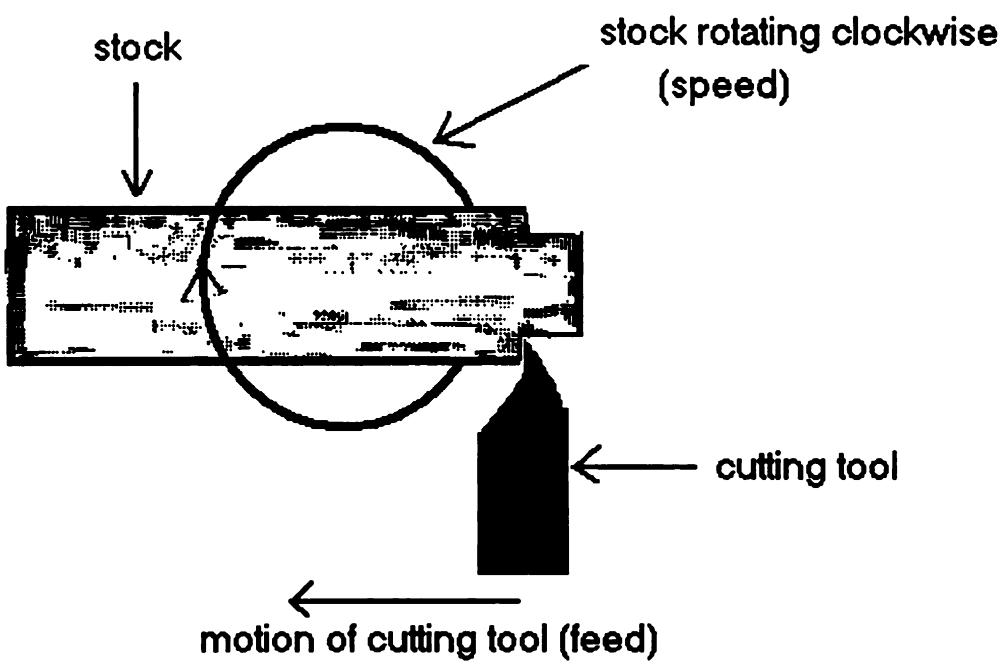
Thus far, the discussion has focused on changes in knowledge and skills in relation to translation of control. The transitions at the site were analyzed in terms of cross-historical comparisons of machinists in distinct work roles. All machinists at Makro began their training on conventional machines, with some of them later moving to CNC.

The findings indicate that in some transitions, individual machinists needed to use both artifacts and referents that were not a part of their prior working history. These are the transitions where I indicated a discontinuity of knowledge and skill. In other transitions that I described, the change was less radical, with some knowledge of artifacts or referents (but not both) carrying over into a new work role. For example, in the transition from conventional machining to CNC manual programming, there was a change in artifacts, while the machining processes that they were used to regulate remained the same. In such cases I indicated a transformation of knowledge and skills. The transition between distinct machining roles depended on the technology involved as well as the experiences of the persons making the transitions. In other words, it was not sorely determined by the technology. This is quite different from using upskilling/downskilling as a model to describe changes in knowledge and skills, and thus focusing on changes in job content only, without due regard to the history of use of technology at the site, or the history of the users. What is emerging is therefore a model that is sensitive to both changes in technology and the context of its use.

I now move on the second and final aspect of knowledge and skill to be examined here: *controlling speeds and feeds.*

## Controlling Speeds and Feeds

The control of what were termed speeds and feeds was an important factor in determining the quality of machining processes. Feeds were a measure of the rate at which stock was fed, past a cutting tool. By speeds, machinists meant the rate of rotation, in a tool-stock relationship. Figure 27 illustrates one example. Speeds were measured in revolutions per minute (rpm). Typical speeds were of the order of hundreds or thousands of revolutions per minute. In the following




Fixtures holding the stock and cutting tool have been omitted.

Figure 27: Illustration of speeds and feeds

discussion, I compare the regulation of speeds and feeds across the different sub-sites and related work roles. The analysis is based on observations and discussions with eight machinists. They were John, who was working as a conventional machinist; Mike who was a manual programmer; Dan, and Bernard who were Unigraphics programmers; Warren who was a CNC machine operator; Tom an apprentice machinist, who was training with Bill on manual programming; and Mark who was training as a CNC machine operator. The discussion begins with conventional machining where the regulation of speeds and feeds was observed and discussed with John.

Controlling Speeds and Feeds in Conventional Machining

John was observed making a part on a conventional lathe. He was cutting the part using a ground piece of *high speed steel*. The discussion with John went as follows:

John: This machine is easy to use.

Observer: How did you decide how fast to run the machine?

John: This?

Observer: Yeah

John: I decide how fast depending on what I am going to cut with.

Observer: OK.

John: That's high speed steel. (referring to the cutting tool. John talked about how he made the tool)

Observer: So are you going to use a formula to work out the speed?

John: Just skill, just you know, experience...Just estimate, you know, this is experience. As long as my chip doesn't turn blue, I am okay. When you start turning blue chips the tool is getting too hot and it will break down....Chips turn blue because of oxygen. They are oxidized on the surface. That is the beginning of rust. That's what it is.

The chips that John was referring to are the bits of metal that are removed from the stock as it is cut. He observed the color of the chips and used it to regulate speed and feed. The use of the color of chips to regulate speed is an example of a primary artifact because it has a non-arbitrary relation to its referent. The use of primary artifacts to regulate speeds as well as feed was also observed with Mike, who was working on a manually programmed CNC machine.

## Controlling Speeds and Feeds in CNC Manual Programming

One of the factors that Mike used to determine speeds and feeds was the hardness of metal. He compared two types of steel, *coldroll* and *D2* steel.

Mike: You got to look at every piece of steel and understand the cutting speed of that steel in your mind.

Observer: But how?

Mike: From experience. That's where the 10 years comes in.

Observer: You have done it before, right?

Mike: Yeah, you learn. You know what you can do. *Coldroll 1018* is fast. You can drill it with a 1/2 inch drill and run through at 800 rpm [revolutions per minute] and just burn it right through. You get into other steels, D2 you start running that fast, you will get the steel hot, it will harden right on the spot.

Observer: What's D2?

Mike: D2 is an a hardened steel.

Observer: How about the feed?

Mike: Your speed and feed go along with each other. If I slow down the speed, then I have to slow the feed because the cutter can only cut so much...If you run your feed too fast and you are going too slow [on speed] it just goes in and it's going to dig in, really hard. And then you will be in trouble too. That will overload the tool and damage it as well as ruining your part.

Observer: Does it matter if you go too slow?

Mike: It's not a problem if you go too slow. Other than if your feed is too fast. If you run your feed too fast and you are going too slow it just goes in and it's going to dig in, really hard. And then you will be in trouble too. That will overload the tool and damage it as well as ruining your part.

The discussion indicates that knowledge of the properties of materials was important in regulating speed and feed. The properties of material (e.g. hardness) were used as a primary artifact to regulate speeds and feeds. The discussion shows that Mike had an in-depth understanding of the relationship between the material and speeds and feeds.

The importance of primary artifacts in the mediation of speeds and feeds was also highlighted in discussions with Unigraphics programmers. Unigraphics programmers were expected to program speeds and feeds but they did not directly use primary artifacts. They made an *initial* determination of speeds and feeds and depended on the machine operator to make the final determination. The determination of speeds and feeds was therefore a shared task, where the primacy of primary artifacts was recognized.

## Selecting Initial Speeds and Feeds in Unigraphics Programming

The Unigraphics system had the capacity to compute speeds and feeds when the type of material to be machined, and the tools to be used were specified. However, programmers did not use these values. Dan explained:

> I am not really happy with this software. The software assumes a production environment where the speeds and feeds tend to be higher. This is a prototype shop, so we are more conservative in our choices of speeds and feeds. Our quality demands are higher here.

Dan selected values based on experience gained over years on the shop floor. It was understood that the values selected by the programmer could be changed by the machine operator. There was nevertheless an understanding between the programmer and the machine operator that the initial values selected would reflect a good understanding of materials and metal cutting processes and generally be within a workable range.

The decision making process for determining speeds and feeds was shared between the programmer and the machine operator, with the machine operator having the final say. A discussion with Bernard (a programmer), and Warren (a CNC machine operator with whom Bernard was working on a program) highlighted this relationship and the primacy of primary artifacts in the decision making process. The discussion went as follows:

Bernard: You get used to knowing what you want. And it may not be a hundred percent correct. But it works real good. You can speed things up, slow them down. You get a feel for it.

Warren: You listen, you feel, and you watch.

Observer: Listen, feel and watch.

Warren: When I first started in the trade, I was always asking, what do you think that will run at? Finally it sunk in that I had to try something. Just try something, and work from there, you know. Then you are going to evolve from there. Whether you are good at it or not, you are going to burn stuff up, you are going to break tools. If you don't, you are not doing anything.

Observer [to Bernard the Programmer]: When you are writing your program, what do you have to help you to choose speeds and feeds?

Bernard: I ask him [Warren] what he wants.

Warren: He sets them out and then I say yeah, I like this, or I like to try this faster, or slower.

Bernard: You do whatever looks good. You get the feel for it.

The selection of speeds and feeds was determined by the quality of the machining process and the use of primary artifacts. Unigraphics programmers made initial decisions on speeds and feeds based on their experience. Machine operators adjusted the values based on operating conditions on the shop floor.

Skilled machinists described the process of selecting speeds and feeds in terms of 'experience.' Speeds and feeds were determined on the basis of operating conditions and the use of primary artifacts. For example, the *feel* of a process, the *color* of metal chips, and sound would indicate whether to speed up or slow down the machine.

In summary, machinists who were directly involved with metal cutting used primary artifacts to regulate speeds and feeds. This use of primary artifacts is illustrative of a continuity of knowledge and skill across machining roles. In the next example, I highlight the case of an apprentice machinist. The case is illustrative of the development of skill in the shop, and how apprentices were initiated into the norms of skilled practice in control of speeds and feeds.

## Control of Speeds and Feeds: Apprentice Machinist

Tom was training with Bill at a CNC manual programming site. In this observation there was a tension between Bill's use of 'experience' to determine speeds and feeds, and Tom's use of standardized charts, tables, and formulae.

Tom was machining a part called a die holder using a new CNC program written by Bill. This is the same die holder which I observed Bill programming, in the first section of the chapter. This excerpt is based on an observation of the first run of the program, when both Tom and Bill were testing the program and looking out for possible programming errors. Where an error was suspected, it was possible to over-ride the program, and to manually control the feed as a precautionary measure.

Tom pressed the Cycle Start button to start the machine operation. The operation was *boring*, which is a process of machining a hole to a precise finish. Tom watched intently as his tool approached the stock which was rotating at a high speed. It was hard to see the part because the machine was closed up and a liquid coolant was splashing over the part inside the machine.

A cutting sound was heard. The tool had made contact with the stock. Tom did not like the sound. He turned up the feed rate, then turned it down gradually, pausing to listen at different positions. He then stopped the machine.

Tom: It doesn't sound right

Bill appeared to agree, but did not say anything. Instead, he went to the controls, turned the machine on, and tried different feeds. He then stopped the machine.

Tom: We are running at 1200 [Looking at the screen listing the program. The running speed was 1200 revolutions per minute.]

Tom pulled out a computation device, which he used for figuring out speeds and feeds. It worked like a slide rule, and was based on standard formulas for determining speeds and feeds.

Tom: According to this, it's nineteen for coldroll. [Pointing to his computation].

By nineteen he meant nineteen hundred or 1,900 rpm, and by coldroll he was referring to the type of steel they were cutting which was *coldroll steel.* At 1200 rpm, they were running below the recommended speed.

Bill: But that's ideal conditions. That bar is sticking out and there is not a lot of support on it.

Observer: [to Bill] What's was the problem?

Observer: [to Bill] What's was the problem?

Bill: It's chattering. It's a long thin bar. I think the problem is the way we are holding it. But we can't change that.

Observer: OK.

Tom and Bill decided to continue with the boring operation. The finished part was a little bumpy. Tom was able to improve the cut using a conventional lathe, where he had more control over how the part was held. As he worked on the lathe, he brought out his computation device again, to figure out the speed and feed.

Observer: [to Tom]What is that for?

Tom: OK. You want to know how fast to run your tool or how fast to spin it. You got a 2 inch diameter piece of coldroll steel here. The surface speed for coldroll is 100. The *surface speed* values are listed in the *Machinery Handbook.* Somebody came up with that, and that's what we use. You set the *diameter* at arrow, say 2 inches. That will give you the speed. This just helps me to, you know, come up with a speed. I haven't worked here long enough to have it all in memory.

Observer: OK.

Tom: A lot of these guys just, [they] have done it so long they know. I just kind of double check myself with this chart to make sure I am not running too fast.

The example illustrates Tom's use of standardized values of speeds and feeds, derived from mathematical formulae. Bill had initially set the speed at less than the recommended value according to the standard formula. This speed was not working well as evidence by the sound of the cutting process. Tom's suggestion was to raise the speed, so that it conformed to the standardized value.

Bill's response was that this would not work because of the peculiar geometry of the part and how it was held. Tom and Bill were referring to different types of artifacts in responding to the problem. Tom's recommendation was at odds with the practice of skilled machinists in the shop. Skilled machinists believed that judgments on speeds and feeds should be based on an analysis of the overall metal cutting conditions, such as metal type, fixtures (how the part is held), size of the machine in use, and so on. While they knew of the standard values, they did not generally use them. This was confirmed in observations with the other skilled machinists. Al, for example, who was a conventional machinist, was keen to show me a formula for computing speeds and feeds but had difficulties locating it in his *Machinery Handbook*. He indicated that he did not use the formula, but depended on 'experience'.

Figure 28 is a comparison of the skill of regulation of speeds and feeds as observed with Tom and the other machinists who were more experienced.

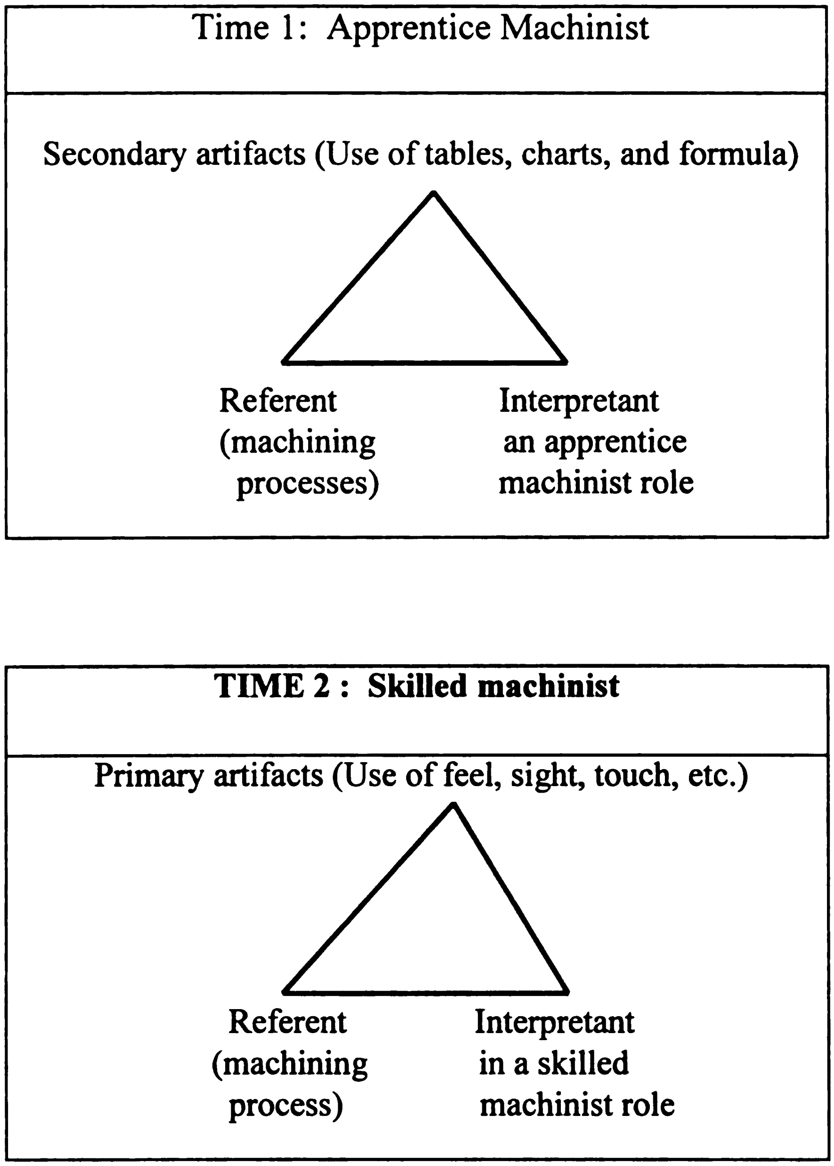



Figure 28: Speeds and feeds: Apprentice to skilled machinist

The comparison highlights the fact that Tom's work was mediated by secondary artifacts, in the form of formulae, charts, and tables. The work of the more experienced machinists was mediated by primary artifacts. Experienced machinists knew of the formulae but they chose not to use them, arguing that the use of primary artifacts (sound, feel, touch, appearance, etc.) was more reliable. Over time, Tom's practice was expected to reflect the norms in the shop.

For skilled machinists, there was continuity across machining roles, in the skill of regulating speeds and feeds. There was one exception identified: It involved a specific machining process called tap drilling. The discussion now turns to that case special case.

## Controlling Speeds and Feeds in Tap Drilling

Tap drilling is a process of cutting threaded holes which can take screws and bolts. Figure 29 illustrates the process.

The tool used for tap drilling is called a tap drill, or simply a tap. The best way of thinking of the process of tap drilling is as the motion of a bolt through a nut. In this analogy, the motion of the bolt is equivalent to that of the tap drill, the difference being that the tap drill actually cuts metal as it moves into the stock. As in the bolt analogy, the tap drill has two motions, a rotary motion, and a linear motion. Tap drilling, like all other forms of machining involves handling two variables, a spindle speed (rotary motion) and a feed rate (linear motion).

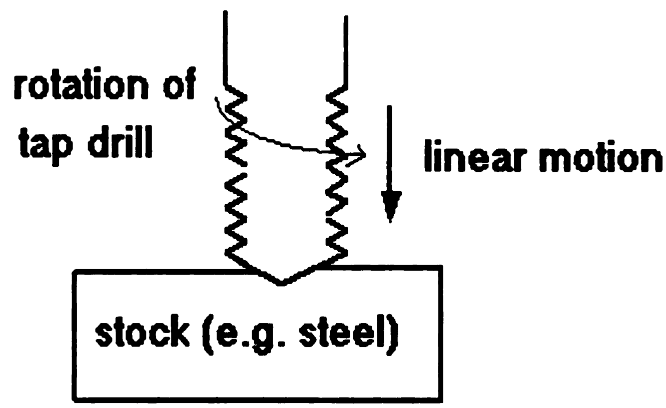



Figure 29: Tap drill and stock

In tap drilling, speed and feed have to be correlated in a precise manner. If they are not, tools may break and the part may be damaged. Machinists are therefore very attentive to tap drilling, particularly on CNC where the control of both speeds and feeds is automated. Tap drilling using a conventional machine was observed in some detail with Mark. The *feed* (linear motion) in manual tap drilling was manually controlled by the machinist, who pushed the tap into the part, using a manually controlled dial or a lever. Mark explained that the control of the feed depended on a sense of feel.

Mark: When you tap manually, you like to go slow. The attitude is you are not going to overdo it [being too slow]. You must then keep up...You just keep up, going like this [indicating the pushing motion on his machine]. You just [pause] and, and, you feel if you are pushing too hard. All you do...all you want to do is stay with it. You don't want to force it.

Mark was demonstrating the process, but had some difficulty in providing an explicit description of the process. Mark went on:

Mark: And that thread will call itself. When it starts, it will actually thread itself, down in there [pointing to the part].

Observer: OK.

Mark: And that's how you tell. You don't want to put a lot of pressure on because if you put a lot of pressure on, then you are forcing it. And if you are forcing it, it will snap.

Observer: How do you know you are putting too much pressure?

Mark: You just, you just kind of feel it as you, uhmn, uhmn. It's hard to explain...Actually it will pull itself through. So all you do is stay with it. You don't push it, you just stay with it.

Observer: You just stay with it.

Mark: Yeah. And when you reverse it, it will bring itself back. [When the stock reverses its direction of spin, the tap will be threaded out of the hole].

Mark was not explicit in his verbal description of the skill, a skill that was based on sensory experiences with primary artifacts. Polanyi (1975) has used the term 'tacit knowledge' for this form of knowing. As we will see in a moment, that knowledge could be codified as explicit mathematical algorithms. But such codified knowledge was not usable when machining conventionally. It was not a substitute for tacit knowledge as long as the control of the process was manual. Machinists could, however, instruct a computer to use computations to do an equivalent function. This was one of the things that Mark was learning to do at the time of the study as he trained with Matt. I now turn to that observation.

## Regulation of Speeds and Feeds on CNC

The process of tap drilling was structurally the same in conventional and CNC machining, with one exception. In CNC, the relation between speed and feed was regulated by program code. In conventional machining, the relation was regulated manually through feel. In practice, this meant setting the machine to run at a particular speed (measured in revolutions per minute), and adjusting the feed rate by feel to achieve the optimum results.

Mark had been an operator for about 10 years. In that time, he had not been involved with the testing and editing of new Unigraphics programs on CNC machines. That work was done by *main operators*. That designation was used informally for operators who were assigned to a machine with the responsibilities of testing and editing new programs assigned to their machine, as well as training other machinists to operate the machine. Prior to the training Mark's work involved running programs developed by Unigraphics programmers and main operators. One aspect of the training involved the regulation of speeds and feeds in tap drilling. The code for tap drilling was generated by the Unigraphics programmer, but operators took care to check it before running the machine. Inappropriate values would cause tool breakage, and probably result in some damage to the part.

Mark: You have no feel with CNC. You have to use a formula for the feed.

Mark had worked on other CNC machines but did not yet understand how to construct the program code for tap drilling.

Mark: I never had to personally use that formula because it has always come out on the manuscript, it's already in the program.

He pulled out the *Machinery's Handbook* to look for the formula but could not find it. He was able to get the formula from Matt who kept a written copy in his pocket. The formula was as indicated below:

<u>Matt's Formula:</u>

Feed rate = (1/TPI)*25.4*RPM [* is my symbol for multiplication]
where TPI is the number of threads per inch;
RPM is the spindle speed in revolutions per minute.
25.4 is a conversion factor. 1 inch = 25.4 millimeters;

In the above formula, the feed rate is in metric (millimeters per minute)

Mark copied the formula onto a page in the *Machinery's Handbook*

Mark: If I was writing programs, I would use this more often. I may never use it, but now I've got it. With tap drilling you can't do feed rate over-ride. If you do that, the tap will snap. Feed rate is correlated to rpm, so you can't change one, without the other.

By over-ride, Mark meant adjusting the feed rate in the middle of a machining process.

Mark understood the behavior of the machine that was appropriate for tap drilling, having performed the same operation conventionally for many years. He had some difficulties codifying that understanding and experience as the following text shows.

After taking down the formula, Mark decided to check it on a line of program code which called for tapping. The programmer had indicated a feed rate of 6, for a tapped hole with 16 threads per inch. Using the formula, he punched numbers into his calculator. He obtained 158.75 which was quite different from the 6 that was on the program printout. Puzzled he went to talk to Matt.

Matt indicated that Mark was on the right track. The problem was that his answer was in metric units rather than English units. In other words, millimeters rather than inches. The program had been written for English units (inches), and the formula had to be modified.

Mark then turned to another line of code, where the feed was also 6, this time using a different tool. The tool had metric threads, in other words, dimensions were in millimeters. It had 1.5 threads per millimeter.

Mark: [to himself] How did he [the programmer] arrive at that? I don't know how he arrived at that.

Mark went over the new formula.

Mark [to himself]: This was if you want to convert from English to metric. Multiply by twenty-four point five [mis-spoke here. It should be **25.4**]. So it does not tell me how to do a metric thread on an English program.

He punched some numbers into a calculator but did not get the feed of 6 that he was looking for.

Mark [to observer]: I'm not sure. If it's a metric thread, I still don't know how to do that. [He decided to go and ask Ed.]

Mark: How do you work this out if it is a metric thread?

Machinist [working with Ed]: You just convert TPI [threads per inch] to metric. 1.5 [threads per inch] is 0.059 [threads per millimeter]. I use that all the time, because my machine doesn't do metric

Mark returned to his bench to work the feed rate, but he got stuck. He was not quite sure how the conversion factor of 0.059 worked. He returned back to Ed, this time with his calculator and Ed provided him with an explanation.

Mark: I have never had to use that. I am getting into this machine. I need to learn that.

Observer [to Ed]: Are there charts for these tap feeds?

Ed: There may be charts for that, I don't know. I just calculate it and enter it into the program.

Mark: If there is a tap drilling problem, that is his [Ed's] fault (laughing).

Ed: I usually multiply what I get from the formula by 0.9. The tap holders compress or expand. They generally expand, and the 0.9 takes care of that. Now I have told you all I know.

Mark: I don't believe that [laughing]

The excerpt highlights the experiences of Mark as he made a transition in one aspect of machining (the regulation of tap drilling). The transition was from the use of primary artifacts to secondary artifacts. Based on his prior experiences with conventional machining, Mark understood the subtleties of the relation between speeds and feeds in machining. He was learning how to achieve the desired result using a different set of artifacts. The discussion highlights the supportive mentoring environment where the learning occurred.

Tap drilling was a special case of the practice of speeds and feeds. When tap drilling with CNC, program code replaced the sense of feel and the levers used by conventional machinists. In conventional machining, the regulation of feed was mediated by primary artifacts. In CNC machining, the same process was mediated by the use program code which is a secondary artifact. There was therefore a change in the mediation. Figure 30 illustrates the development of Mark's knowledge and skills. There was a change in the artifacts, for the same referent, in the shift from a conventional to a CNC machining role. This is illustrative of the transformation of knowledge and skill in the transition from a conventional to a CNC machining role.

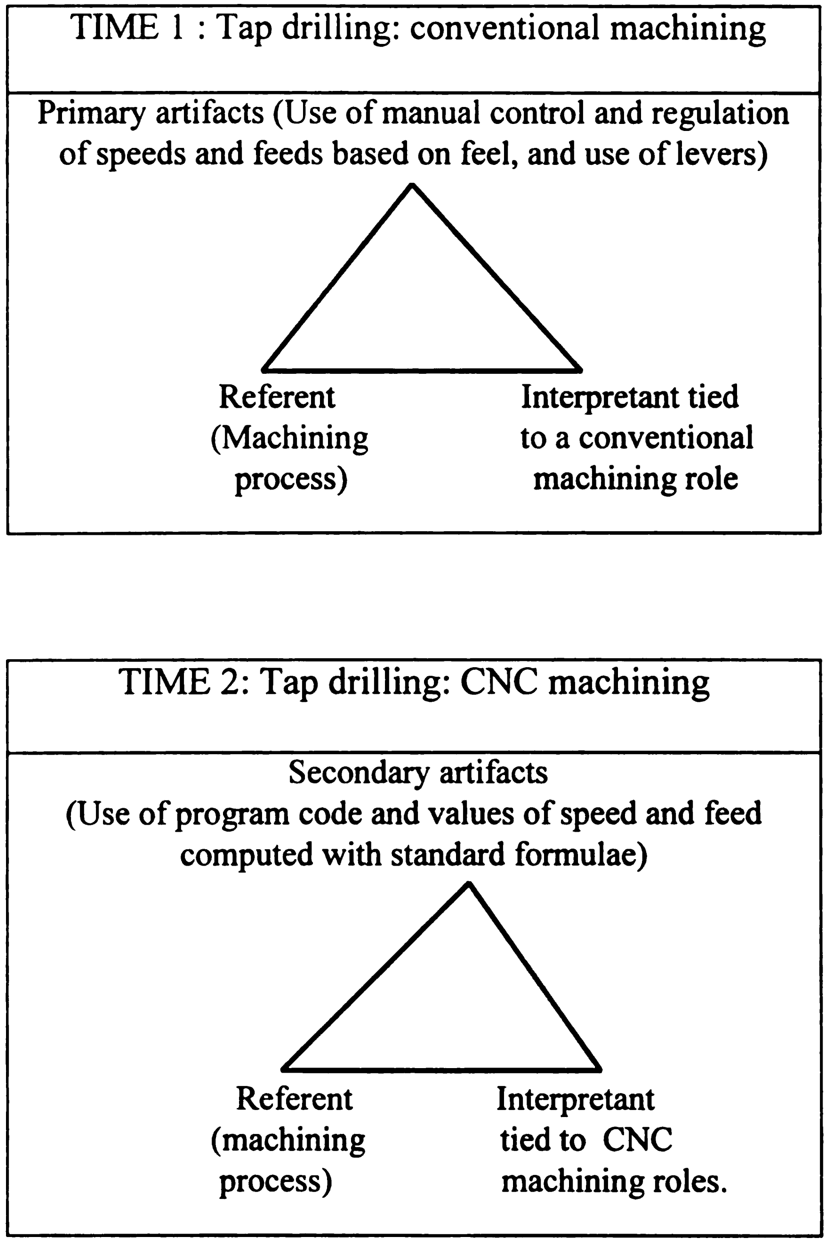



Figure 30: Conventional to CNC machining: tap drilling

## Summary

I have examined the development of knowledge and skills in a changing machining activity. The changes from conventional to CNC machining were associated with the development of new forms of work in a re-organized workplace. The study was based on transitions between work roles that represented different historical points of development of machining activity at Makro. The changes at Makro reflected the historic changes that were occurring in the industry as a whole as CNC technologies increased in importance (Shaiken, 1984).

Changes in knowledge and skills were analyzed in terms of changes in artifactual relations in the transition from one role to another. Artifactual relations were structured around three types of artifacts that were used in the machine shop. They were primary, secondary, and tertiary artifacts. Primary artifacts were primarily used to generate and regulate machining processes in conventional machining. Their defining characteristic was a non-arbitrary relation to their referent. Examples of primary artifacts were dials and wheels that were manually controlled to generate machining processes. Other primary artifacts, such as sound, were also used to regulate machining processes. CNC program code was a secondary artifact because the relation between the code and machining processes was arbitrary, based on convention rather than the intrinsic properties of either the machining processes or the code. Finally, tertiary artifacts were used in Unigraphics programming. They were tertiary in the sense that they were based on the organization of other artifacts, and had no direct relation to machining processes. Artifactual relations are embedded in broader contexts that can be described as institutional, social and historical. Figure 31 illustrates the embedded nature of artifactual relations in machining activity.

The analysis was based on two aspects of machining skill, that is the translation of control, and the regulation of speeds and feeds. There was no one way to describe changes in knowledge and skills between roles. Three categories of change were identified, namely continuity, transformation, and discontinuity. Figure 32 summarizes the findings.

With respect to translation of control, transformation of knowledge and skill was identified in the transition from conventional machining to CNC manual programming, from CNC manual programming to some aspects of Unigraphics programming, and from CNC machine operation to some aspects of Unigraphics programming. Discontinuity was identified in the transition from CNC manual programming, and CNC machine operation, to some aspects of Unigraphics programming. In other words, the transition to Unigraphics was characterized by both transformation and discontinuity, depending on the aspect of Unigraphics that was being examined.

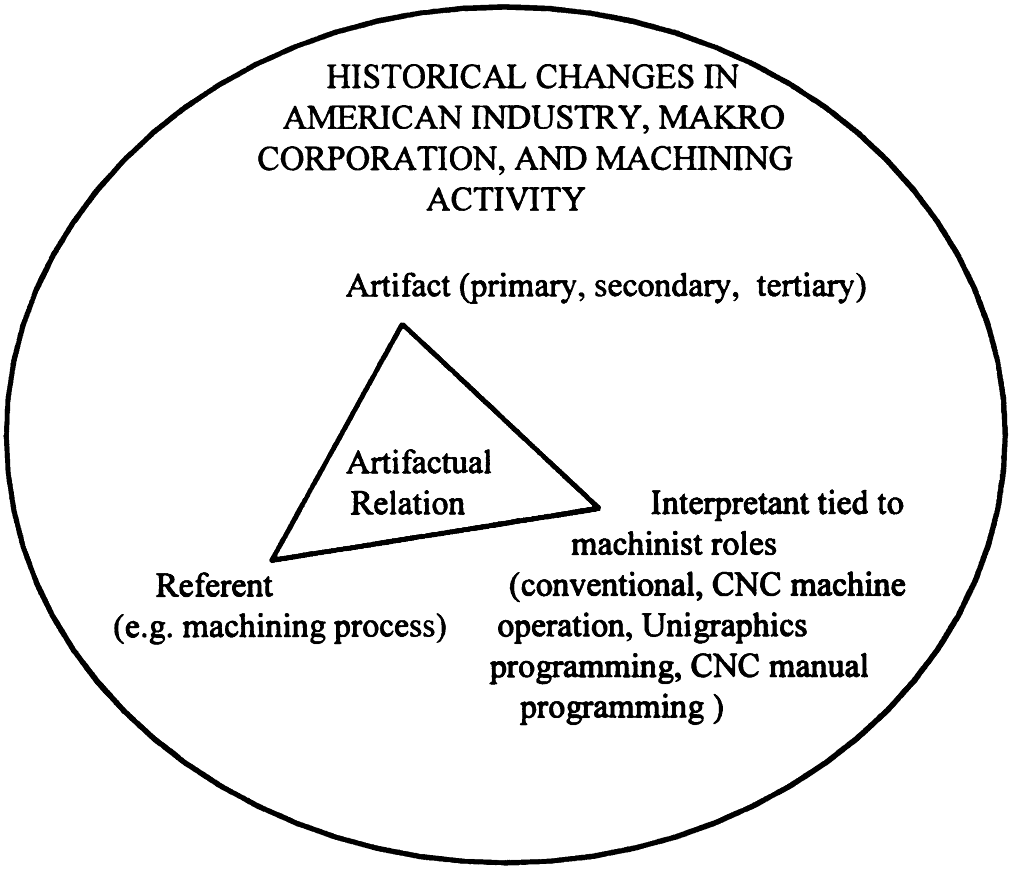



Figure 31: Embedded artifactual relations.

With respect to the regulation of speeds and feeds, the evidence showed the existence of both transformation and continuity of knowledge and skill. The work of skilled machinists on both CNC and conventional machining was mediated by primary artifacts, except on tap drilling operations. Differences were observed between apprentice machinists and skilled machinists in the regulation of speeds and feeds. The apprentice machinist who was observed preferred to use secondary artifacts to regulate speeds and feeds on both conventional and CNC machining. Skilled machinists, on the other hand, preferred the use of primary artifacts to regulate speeds and feeds on both CNC and conventional machining. Although one apprentice was observed, confirmation of the difference between skilled and apprentice machinists was obtained through interviews with skilled machinists who commented on their own development.

With respect to tap drilling, skilled machinists regulated speeds and feeds using secondary artifacts[3] on CNC, and using primary artifacts[4] on conventional machining. The transition from tap drilling in conventional machining to tap drilling on CNC therefore represented a transformation of knowledge and skills.

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3 . That is formulae, tables and charts etc.
4. That is sound, feel, color etc.

| CONTINUITY OF KNOWLEDGE AND SKILL | CHANGES IN KNOWLEDGE AND SKILL |
|---|---|
| Continuity of knowledge and skill has been defined for transitions from one machining role to another where the machinist used the same artifacts and referents in the new and previous roles. For example, conventional and CNC machinists both used primary artifacts (e.g. color and sound) to regulate speeds and feeds in drilling operations. | (1) Transformation of knowledge and skill has been defined for transitions from one machining role to another where work in a new machining role required the use of new artifacts <u>or</u> new referents, with prior experience with either artifacts or referents carrying over into the new role. For example, tap drilling operations were regulated by primary artifacts in conventional machining and secondary artifacts in CNC manual programming. In this instance, the artifacts changed, while the referent (machining processes) was the same across the two roles.<br><br>(2) Discontinuity of knowledge and skill has been defined for transitions from one machining role to another where a new machining role required the machinist to work with both artifacts <u>and</u> referents that he had not worked with in a previous machining role. For example, there were discontinuities in the transition from CNC machine operation to some aspects of Unigraphics programming where the tools used, and the output generated from using those tools was unique to Unigraphics work. |

Figure 32: Changes in knowledge and skills

In other studies, changes in knowledge and skills in changing contexts have been examined in terms of transfer of knowledge, and the relation between changing technology and skill as upskilling and downskilling. I have described changes in knowledge and skills in terms of changes in artifactual relations that are constructed in practice. Artifacts were to be understood in terms of the role that they played in activity, rather than in terms of the intrinsic properties of technology. Changes in knowledge and skills could not be projected solely from the intrinsic properties of the new technology. The cognitive consequences of using technology depended, not only on the way the tools were used, but on the histories of the individuals involved, and the organization of work at the site. The relationship was not technologically deterministic, as implied by the concepts of upskilling and downskilling. The agency for the changes originated from a joint relationship between the changing activity and individual intentional commitments.

As new artifacts were introduced, and the workplace was re-organized, the nature of skilled work changed, becoming more diversified, in contrast to the early years of machining when it was defined solely in terms of conventional machining and the use of primary artifacts. Since the early 1960s, new specialized work roles emerged based on the use of secondary and tertiary artifacts, reflecting changes in machining work and the transformation of machining activity. The changes in knowledge and skill were tied to transitions in work roles where the roles defined the cultural organization of machining activity and its transformation over time. My focus in the next chapter is on the meaning of the changes in knowledge and skills for machinists' conception of themselves as 'skilled' workers. In other words, I assume that the knowledge and skills tied to specific roles had meanings for machinists experiencing the changes. I have framed this as a question of identity. By identity I mean the informants' self-conceptions as skilled machinists in a changing workplace. More to the point, the question is, what does it mean for the machinist to be a 'skilled worker' in a trade where knowledge and skills are changing?

The discussion now turns to Chapter 6 where I examine the development of identity. The discussion is organized around changing machining roles where role is used as an analytical tool for describing the cultural organization of machining activity as it is re-organized and transformed over time.

# CHAPTER 6

# CHANGING WORK AND THE DEVELOPMENT OF IDENTITY

## Introduction

The purpose of this chapter is to examine the development of the identities of *skilled* machinists as their work changed as a result of the introduction of Numerical Control technologies. My use of the term *skilled* is based on interviews at the site where the informants were officially categorized, and also described themselves as 'skilled.'

In considering the development of identity I examined changes in the informants' self-conceptions as 'skilled' workers as the machining activity changed through the introduction of new artifacts and the re-organization of production into new work roles. The analysis of identity is organized around four work roles: conventional machinist, CNC machine operator, CNC manual programmer, and CNC Unigraphics programmer. Each of the roles was tied to a sub-site that represented different historical points of development of machining activity at the site. In Chapter 2, I stated the research question guiding this aspect of the study as follows:

*Are there changes in the identity of skilled machinists related to change from machine control mediated by primary artifacts to that mediated by secondary and tertiary artifacts? If so, what are they, and how are they related to the changes in machining work?*

A total of thirteen workers were interviewed and provided data that is relevant for this section of the study. All but one of the informants were toolmakers which is a grade in the machining trades. Based on an agreement between management and the union, skilled machinists at Makro were paid at the same rate regardless of years of experience. The exception was one informant who was an apprentice machinist.

Four of the informants were working at a conventional machining sub-site. Data from three of them has been included. The data on the fourth, Al, has been excluded except in cases where it was not redundant and added new insights to the research question. Three workers from each of the other three sub-sites provided the remaining data.

The analysis begins with machinists working at the conventional machining sub-site.

## Conventional Machining Sub-Site

Peter had been a machinist for over thirty years, mostly on conventional machines. He also worked for about four years on CNC in the late 1960s. John had been a conventional machinist for just over ten years, and wanted to move on to CNC machining. Jonathan had been machining for nearly thirty-five years, half of which were on CNC. Some months prior to the study, he made a decision to return to conventional machining and was now working there. I discuss each of these cases in terms of how they interpreted changes in machining.

### Peter: A Passion for Conventional Machining

Peter began working as a conventional machinist in the early 1960s. After eight years of conventional machining, he was assigned to Numerical Control[1] (NC) machining, and was one of the pioneer workers on that technology at Makro. He was involved with both programming and machine operation. After four years of that work, he requested to return to conventional machining. He was approaching retirement and did not plan to do any other type of work.

After graduating from high school, Peter initially worked on the family farm.

> I grew up on the farm, [and] worked in the farm administration office. I worked on the farm for years, being able to fix things, and solving

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1 . NC preceded CNC (see Chapter 1).

> problems there. I think that helped me to get the [machining] job. Because of the farming experience that I had. (Peter, 10/8/96, p. 6)

After working for some years on the farm, he decided that he wanted to learn a skilled trade.

> I really applied for welding because my brother was an apprentice welder. I did have some woodworking in high school. But we didn't have metal working machines in the high school I went to. I really didn't have much experience in the trade before I came here. (Peter, 10/8/96, p. 6)

Peter took the apprenticeship examination and was examined on algebra, geometry, and physics. He did well enough to be accepted into the program. Apprenticeship was, and still is a period of training of about four years (or eight thousand hours) of work experience on various aspects of machining and related areas such as heat treatment, welding, and blacksmith work. Peter talked about the changes in technology since his apprenticeship days.

> When they hired me, there were no NC[2] machines, whatsoever. There was no NC at all. Gradually, we started with one machine there, one machine there, now it's almost half. Almost half NC machines. (Peter, 10/8/96, p. 6)

Peter noted that over the years there was an increase in the volume of parts that were machined, mostly on CNC. He also observed that with CNC they were now able to machine more complicated parts. His overall assessment of the changes was negative:

> I think it's taken away the doing it with my own hands. There is no tool making here. You hit the button and the machine does everything. If it's

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2 . The informants used the terms CNC and NC interchangeably.

> doing everything, no turning the handles, cutting with the tools, they even have automatic tool changes, and you are not even changing tools by hand, so it's taken a lot out of the trade. The trade is a lot different. What it is now, from what it used to be. It's not machining anymore, NC. (Peter, 10/8/96, p. 7)

He was particularly critical of the role of machine operators:

> If you are not a programmer and just an operator, you are really not much more than a button pusher. It's taking away from the tool making skill. On conventional machining you have to measure and see that things are working OK. Once you get a good part on the NC you can run for a long, long time, without having to check anything. All the thinking is done for you. (Peter, 10/8/96, p. 4)

In saying this, Peter was concerned about the CNC machine operating role, rather than programming. He did not believe that machine operation was challenging and interesting work. Somebody else (the programmer) did the work for operators. However, as we saw in Chapter 5, not all machine operation work at Makro was routine. The testing of new programs was quite demanding.

Beyond the routine of machine operation work, Peter was concerned that the re-organization of work through CNC no longer permitted machinists to assume full responsibility for the part. In his view, CNC had

> ...taken away from the trade a feeling of taking a hunk of steel and making something good out of it. It takes away a feeling of, 'I did this'. Turning the cranks by hand. The trade is different, definitely different. (Peter, 10/8/96, p. 9)

In saying this, Peter was expressing the importance of ownership of the part, and taking pride in one's work. A sense of ownership was derived from full involvement with the machining process, from start to finish. Peter believed that the younger machinists were more interested in CNC than his generation:

> I feel like I am an old timer. I still would rather do things by hand than I would by pressing buttons. People are different on what they would like to do. The younger people all want to get on NC. (Peter, 10/8/96, p. 4)

The interview with Peter highlights three key issues: First, the importance that he attached to assuming full, rather than shared responsibility for making a part. Second, the importance he placed on doing challenging work. Third, his view that conventional machining, based on working with one's hands, defined authentic skilled machining work. Peter was highly regarded by his co-workers and was responsible for training apprentices on conventional machines. One colleague volunteered that Peter was the best in that shop on the manual lathe: "He can do unbelievable things on it" (Al, 10/9/96, p. 2).

In contrast to Peter, John was a later generation machinist, and was keen to learn CNC. I discuss his case next.

### John: Hope for Advancement Through CNC

John was in his forties, and had been a machinist for twelve years. His interest in machining developed gradually. After graduating from high school he worked as a receiving clerk and as a truck driver. His company ran a machine shop and he took an interest in that kind of work, eventually deciding to train in the trade.

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| John: | You get older you know. You got to do something, rather than a little wage job. So I got into machining. |
| Interviewer: | So why machining? |
| John: | It's interesting. That's the reason I did it. There was a machine shop at the firm where I worked. I used to go in there and have them do something for me. If I needed something fixed, I knew where to go. If you couldn't buy a part they could make you something. And I thought, man, I wish could do this. You look at what they have done, and you say you could do that. That's the way it went. |
| (John, 11/25/96, p. 17) | |

As with Peter, machining attracted John because it was an avenue for expressing creativity through making things. Another important factor was the prospect of a better income. John completed his apprenticeship and worked for five years before coming to Makro where he was attracted by "better conditions, more money, [and a] chance to do something different." He was in his fourth year at Makro. There was some trade off in the move.

> I don't do dies anymore. I used to do dies. Stamping dies and forming dies for building electric motors, bearing, things like that. Here all we do is just make fixtures, and specialized machining. (John, 11/25/96, p. 13)

But he liked the work he was doing and described it as "pretty cool." He hoped to work on CNC when he joined Makro Corporation. "I like it [CNC]. I would like to learn it, but they are not teaching me yet." Although, he had over ten years in the trade, he was relatively new at Makro and that gave him a low seniority ranking. He was frustrated by the seniority system which was the main basis for selecting candidates for training on CNC.

> John: You got to be an old man here [to get training opportunities]. I have the lowest seniority. I will be last.
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> Interviewer: You have to wait for your turn?
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> John: By the time they train everybody in here, who knows how old I will be. What's the point. I thought I was going to learn some of that here, but I haven't.
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> Interviewer: Right.
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> John: That's disappointing. Because I would like to have that.
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> (John, 11/25/96, p. 14)

John' desire to train on CNC was partly based on the belief that he would enjoy the work He also believed that knowledge of CNC would make him more marketable..

> Well, I was hoping I could learn something in here that would be helpful outside the shop, but I haven't really learned much of anything. Other than what I already know...I might have a chance to learn, but till then I am really no better off than I was at my old job except in the pay department. (John, 11/25/96, p. 16)

John's immediate goal was to learn to operate CNC machines. He had a long-term interest to do Unigraphics programming as well, but he wanted to learn to operate machines first.

The restrictions on opportunities to learn CNC created some tensions at Makro, and that was apparent in John's case. This was a shop where all the workers were trained on conventional machining as part of their apprenticeship. CNC was therefore an added extra. Furthermore, access to CNC training was controlled, largely through a seniority system. That control made access to CNC a status issue. The status of CNC was not tied to wages and benefits within the company because all machinists were paid at the same rate. It was important for marketability in a trade where the technology was changing quickly and job security was perceived as tenuous.

I now turn to the case of Jonathan, the third and final conventional machining informant. Jonathan had just moved from CNC machining back to conventional machining.

## Jonathan: A Return to Conventional Machining

Jonathan had been a machinist for thirty-five years. He returned to conventional machining after two decades on CNC. Changes in CNC machining, in particular, increasing specialization and distribution of work across teams, had compelled him to return to conventional machining where he could assume full responsibility for the parts that he machined.

Jonathan described his entry into the trade as accidental. After graduating from high school he intended to study architectural drafting in college. However, he had to wait a year to get into the college. During the wait, he applied for job at a machine shop and was hired as a machinist.

When Jonathan started working on CNC, his work involved both programming and machine operation.

> We had two guys on the machine on a shift. One guy would be programming a job, while the other ran his job. When he got his job finished, I would take the one I was programming and I would run it while he programmed his next job. I liked it because I could program a job and I would go run my own program. I knew what it was. If I could program like that, I would like it. (Jonathan, 10/31/96, p. 16)

Over time, CNC became more specialized. One group of workers programmed and another machined the parts as operators. Jonathan was a leader of a team of operators (main operator). He found the role frustrating.

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| Jonathan: | The machine is only as good as the operator. A CNC machine is no better than the guy running it. Here they seem to have the idea that anybody can run a CNC machine. |
| Interviewer: | Uhmn |
| Jonathan: | So the people that worked on the machine that I was on, from the second and third shift knew nothing about it. They did not learn. They just made it too difficult of a job and too much scrap.<br>And I did no want to have any part of it. So they put me back over here [on conventional machining]. |
| Interviewer: | So it means you start on a part and then somebody has to finish the part and they mess it up? |
| Jonathan: | Or I would set a job up and get the first part OK, with instructions and the next day I would come in and have to re-do the set-up because he didn't understand, he didn't think it through. He didn't know enough to know whether it was right or not. |
| Interviewer: | Right. |
| Jonathan: | If I had a job that ran for a month, I would come in and have to re-set everyday because they would play with the set-up. |
| Interviewer: | So you did not feel that [pause] In some sense you felt that you did not have control over your own work? |
| Jonathan: | That's right. |

(Jonathan, 10/31/96, p. 10)

The codification of machining operations afforded the company opportunities to distribute the responsibility for machining across specialized teams. Jonathan felt that he had lost control. Jonathan's return to conventional machining was motivated by a desire for control over his work and the desire to do what he termed 'creative work.'

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| Jonathan: | I would rather work here. It's more interesting. |
| Interviewer: | Why do you think its more interesting? |
| Jonathan: | Because I have to think. |
| Interviewer: | Oh, you have to think. You didn't feel you were... |
| Jonathan: | A CNC machine, once programmed, you just watch it basically. But here I have to plan every move, the right order for them. I have to do everything. I like it better. |
| (Jonathan, 10/31/96, p. 13) | |

At the time of the observation, Jonathan was machining a part called a *Power Steering Pump Bracket*. The part was quite complex and he was delighted to have it, remarking:

> It's not very often that we get jobs like this. We don't often get this kind of stuff to do. I like to do that. I don't like a no brainer job. I like one that I can think about. (Jonathan, 10/31/96, p. 31)

The decision to assign Jonathan this particular part had, in fact, been an error. The part should have been machined on CNC because of its complexity, and because it had to be machined in a batch of eight. On that kind of job, CNC would be much faster than conventional machining because, once programmed, it afforded repeatability. Supervisors consulted with Jonathan on several occasions, expressing concern that he might not meet the deadline for the completion of the project. What this incident revealed was that the more challenging work tended to be allocated to CNC sub-sites. However, as the interview with Peter showed, machining processes at CNC sites could be quite routine once the program was created and tested. There was therefore a tension inherent in Jonathan's decision to shift from CNC to conventional machining, when the kind of projects that he liked to do were shifting in the opposite direction. But this was a tension that Jonathan was prepared to work through.

Jonathan did not believe that he needed to stay on CNC to improve his marketability. As a skilled machinist, he believed he could always find work. There were rumors that his shop might be re-located to another city.

Jonathan: If the department moves, I will move to the tool-room or the die department

Interviewer: So you have options?

Jonathan: I've got options. I am not moving [laughing]. I am not worried about moving.

(Jonathan, 10/31/96, p. 20)

## Summary: Conventional Machining Role

A number of patterns emerge from these interviews. The first is the importance machinists attached to assuming individual rather than shared responsibility for a part from start to finish. Related to this was the view that skilled work involved working with complex parts. Both Jonathan and Peter expressed this in terms of creativity and challenge. The second issue is the importance of working with one's hands, and getting involved on the machine. That was particularly important for Peter. The interview with John highlighted the point that machining was a fast changing trade, and continuous learning was important in order to keep up with the trade, and ensure marketability. Finally, there was a trend in the machine shop to move challenging work to CNC in the interest of efficiency. That trend would pose a long term problem for workers such as Jonathan, were it not for the fact that they were both approaching retirement. As for John he was from a younger generation and was keen to improve his marketability. One of the reasons he had moved to Makro Corporation was because he expected to have opportunities to learn CNC. That would be important in sustaining his interest in CNC machining work.

The discussion now turns to machine operators, who were machinists who operated CNC machines using programs created by specialist programmers.

## CNC Machine Operators

Three machinists working as machine operators were interviewed. Mark was in his early fifties and had been a machinist for about sixteen years, six of which were on conventional machining. Warren was in his late thirties and had been in the trade for sixteen years as well, three of which were on conventional machining. Matt was in his forties. He began his apprenticeship rather late in life, in his mid-thirties. He had ten years of machining experience, six of which were on conventional machining. Prior to that he had worked on the auto assembly line.

Warren and Matt were *main machine* operators. In other words they were both assigned to a machine on a more or less permanent basis and were leaders of teams of operators. They were responsible for training other operators. One such trainee was Mark, and at the time of the study he was training with Matt. The discussion begins with him.

### Mark: The Trainee

Mark began his machining career at Makro in the early 1980s. Prior to that he had worked as an automotive mechanic, and as quality control inspector on the auto assembly line. He also worked in gage[3] repair which he described as a skilled trade in the inspection category of the auto industry. He was in gage repair for

3 . Gages are devices used to measure the dimensions of parts.

nearly two years before he moved to machining. He explained his move as follows:

> I realized that the trade [gage repair] was what I call a house trade, in other words it's only a trade recognized here. That trade in other divisions was encompassed in a trade called fixture repair...I had the opportunity to come over to this trade. I looked at this trade and said, wow, here is a trade recognized world wide, within every corporation. That would be more beneficial to me. So I came over here. (Mark, 10/24/96, p. 2)

That was in 1980, when he began his machining apprenticeship. His interest in CNC developed rapidly.

> I came over here, and I really enjoyed the work. It was really fun to learn and of-course to make mistakes as you learn, and you get your laughs and everything out of that. But I did notice that everything at the point was already going into computers, more computers. And I think by nature we are resistant to change, you know. But I had to keep telling myself if I want to stay with it until I retire, I've got to learn the new stuff. I am fifty-two years old. Well that's kind of old to start learning new stuff, you know. But I am new at it, and I want to do it. I might be a little slow at learning it, as some of the younger fellows because they grew up with it, you know. But it's important to learn it. That's the future. You are talking about saving man hours of time with computer NC equipment, as compared to the manual equipment, you know. (Mark, 10/24/96, p. 2)

Mark was introduced to CNC when he was still an apprentice. He worked on a CNC lathe and learned how to program it using CNC program code: "That was a fun machine. We got it brand new...They let us experiment with it. We got to make a lot of things that we wanted to make, just for the fun of it." He witnessed the introduction of Unigraphics which was phased in during early 1990s. With that change, Mark assumed the role of an operator. When asked to compare Unigraphics programming with programming before Unigraphics, Mark replied:

> I don't understand Unigraphics at all. So I wouldn't really give a good answer on that. But other than what I have seen in there, it looks like they can do things, move 3-dimensionally and rotate on the screen....But they say it's more efficient to go that route. So that's why they switched over. (Mark, 10/24/96, p. 26)

Mark was ambivalent about whether he should learn Unigraphics programming, or not. He believed he still had a lot to learn as an operator. He was also concerned that learning Unigraphics would require more time than he was prepared to give it, and this was an important consideration as he looked to the future.

Mark: Unigraphics is a whole new ball game, so I have to learn a whole new thing in there,[4] and that's [hesitation] I, I feel I would rather spend my time out here....I've only got maybe sixteen years at most, fourteen years, and if I can stay on top of it out here, I think I will be doing good, you know what I mean.

Interviewer: How do you mean you mean you got sixteen years?

Mark: Before retirement.

Interviewer: Is there a retirement age?

4 . Reference to the office space where programmers were located.

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| Mark: | With our union we have what we call a thirty in-out, thirty years with the company and then you can go and retire with full benefits. When I get to thirty years, I will be sixty-four years old. So I'm thinking that maybe I will go to sixty-five. You get the maximum, with social security added to it. I will be going probably one more year. Unless they come up with a special program. They've got, occasionally they come up with programs to encourage people to retire, to down-size the work force. And if they do that, maybe I will go earlier. Anyway, that will be my time limit. I kind of look at that and gauge, is it worth going into there [programming], learning that, or shall I get my hands on the machines out here and learn, like [I am doing] here. I think this will be better for me. |
| (Mark, 10/24/96, p. 5-6) | |

He continued: "I would like to retire and do a hobby. Do something with the wife." However, he thought he might need to work part time after retirement particularly if the economy changed for the worse. He wondered whether skills in Unigraphics programming would be more beneficial for him in securing a part time job than machine operation skills: "I don't know. I am sticking around here [ machine operation] anyway, for now. Maybe later I will go in there [into Unigraphics programming]. I don't know. We'll see."

If he had a choice in his current work, Mark would have preferred to both write programs and run them on a machine.

> I think, if I could take time out and do it, I would rather write my own programs. Then I know what I have in mind to do, what I want the machine to do. And then from the operator's point of view, I would like to be able to write the program, run the machine. Then I can make the changes the way I want. That type of thing. I think because of the size of the department it's going to become impossible to do that. First of all I would have to learn

> Unigraphics to be able to write my own programs....But to write programs on Unigraphics, that requires more education and training. We got some excellent programmers. We really do. I am satisfied being able to run off their programs. But I would rather be able to write my own and be able to run it. (Mark, 10/24/96, p. 35)

Mark's endorsement of the quality of programs initially appeared to be total, but some reservations were also apparent as the discussion continued. He remarked that some of the programmers did not have an adequate understanding of the machines for which they were writing programs.

> Every programmer should have experience on the floor, at least before they go in there. I would rather have a guy programming for me, who knows what it's like to work out here, because he can make it a little bit easier, or more efficient. Otherwise you get these people that learn from books. They don't know nothing about the equipment and lo and behold you end up with anything. You have to go back in there, and he has got to change the program two or three times to get it even where you begin to work with it to make minor changes, you know...The ideal thing would be to have everybody be able to write their own programs, come out here and run their own machine. (Mark, 10/24/96, p. 37-38)

While that was the ideal, Mark did not believe that it was workable.

> They only got 4 or 5 machines there to be able to program on. We got a lot more machines out here to run. So everybody can't be going in their programming for their part and coming out here to run it. Because of Unigraphics and the special training it takes they can't get everybody programming on Unigraphics to be proficient on it. (Mark, 10/24/96, p. 39)

However, he did feel that more people could be exposed to Unigraphics, to have some understanding of how it works, without having to be proficient programmers. That was something he would be interested in doing.

The introduction of Unigraphics was accompanied by broader changes in the company. Not only were individual machinists specializing in the areas of programming and machine operation, but the work that different divisions of the company were doing had become more specialized. In the past, their division had been responsible for the design and machining for a whole car. Now they were more specialized. Specialization had resulted in a decrease in the 'creative' aspect of work. Mark described this as a "loss of work."

Mark: We have lost a lot of work. But we haven't lost personnel because they kept us busy with the quantity of what we are doing now. Not as much with the variety, but with the quantity.

Interviewer: What does that mean in terms of how you feel about the work?

Mark: From the standpoint of the company it's probably a good thing because its more efficient. We are set up for [engine] blocks and we are set up for [engine] heads. Keep running it, O.K. From the standpoint of interesting work it's not good because it's more interesting to do a few [parts] than to do many because you are always changing. You are always set up with something different and it makes it more interesting. When you have a lot of one part, it's more like production. And a lot of those guys don't like production. It's boring. You are not thinking as much. You just push a button and you wait for it to cut the part You check it out and you make sure everything is right and make your adjustments and the like. But when you did four or five pieces of different items, then it's more interesting. You understand what I am saying.

Interviewer: Yeah

Mark: When you get into production, its the same old thing.

Interviewer: If you have less variety it makes it less interesting?

Mark: For the operator. Once he gets through with the initial one and he has run a few and he knows it's running good then it does. It gets to be boring. It really does. From the standpoint of efficiency it's the best thing for the company. And we've got to think of the health of the company. That's important. So myself, personally, I will live with it, you know, because I am still working [chuckles]. If the company is not making money, we are not going to be working.

(Mark, 10/24/96, p. 40-43)

Before CNC, machinists shared common all-round skills. With CNC, they worked in teams and the work was sub-divided into areas of specialization. Furthermore, the introduction of new tools such as Unigraphics made the process of learning the programming aspect of machining more demanding. Unigraphics was a constantly evolving system of programming with regular updates. Working with Unigraphics therefore required constant learning. At the time of the study the programmers were training on the eleventh version of Unigraphics.

Mark would have preferred to do both Unigraphics programming and machine operation. But that option did not exist under the current organization of work in the shop. Mark's desire to be engaged in the whole machining process was shared by machinists from other sub-sites such as Peter and Jonathan, as indicated earlier. But they handled it differently. For Mark, the primary concern was keeping up with some aspects of CNC and ensuring marketability in a changing workplace.

There was a tension between efficiency and creativity. Efficiency in a prototype shop had come to mean the production of large volumes of identical parts for use in product testing. This approach to favored CNC and the codification of machining processes, rather than conventional machining which was best suited for specialized, one-of-kind type jobs. This was a dilemma that Mark was prepared to live with. He increasingly viewed his work in terms of productivity tied to corporate profits and job security, rather than creativity and challenge.

The discussion now turns to Warren, a highly regarded machine operator, who was nevertheless experiencing frustration with this role and was looking for a different one.

## Warren: The Reluctant Operator

Warren was about thirty-five years old, and began his apprenticeship in 1980. He liked to bring other machinists who were around him into interview discussions. That was helpful because it provided multiple perspectives. In this section I will include information derived from two of Warren's colleagues. The two workers were Bernard, a programmer who had worked with Warren on the program that was currently running, and Rick, a machinist whom Warren was training. Bernard was later interviewed separately and became one of the Unigraphics programmer informants.

Warren became a machinist initially for financial reasons: "I needed a trade. I had a family. I was just starting a family and I went for it. It has done a lot of good things for me" (Warren, 12/4/96, p. 84). He began working on NC equipment as an apprentice: "I'm pretty much an NC operator. I always have been."

He became a main operator on a machine that was bought as used. Because it had been bought used, there was no training or backup support from the manufacturer. Warren was assigned to that machine, and over time he figured out how to run it effectively. He became the local expert on the machine. That gave him some status, but it also created a dilemma for him because he was looking for opportunities to move from machine operation, as the next dialogue shows.

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| Interviewer: | You said you might want to move around. What do you want to do? |
| Warren: | I would like to go back to the floor [i.e. to conventional machining] |
| Interviewer: | OK. |
| Warren: | To freshen up. I'm not doing much of anything here anyway. |
| Interviewer: | So. |
| Warren: | Probably won't happen though. |
| Interviewer: | Why would it not happen? |
| Warren: | You get out here, they try to keep you on CNC. |
| Interviewer: | Oh. |
| Warren: | That's all I've done since I came here. |
| Interviewer: | What do you mean by freshening up? |

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| Warren: | I do the same thing a lot, whereas out there you never know what you are going to get. You might get a complicated part. You got to look at it. Decide what to cut first, what to cut last, when to drill, when to tap it, when to grind. I don't like making these [engine] blocks one after the other. I like doing different things. I like them [supervisors] to come up to me and say will you make this part, make this part. I would rather do that. I don't want to know what I am going do to do every day. |
| (Warren, 12/5/96, p. 3) | |

Warren had become disillusioned with his role as an operator: "When I came out of my apprenticeship I wanted to get more CNC time. But I think now that I was wrong." When asked how much CNC training should be in the apprentice program, he responded that it should be very limited.

> If you go into CNC you are going to end up like me, a button pusher. I am not just a button pusher, but I'm in that category right now. That's why I'm a little unhappy...The more journeymen that you can work with as an apprentice, the better you will be. If you are good on the conventional, you can learn CNC in no time. No problem. No problem. (Warren, 12/5/96, p. 23)

Warren believed he enjoyed his work much more when he was an apprentice, working on conventional machines.

> I see this [CNC operator's job] as a great opportunity. And it's interesting. It's interesting enough. It wasn't my life's dream. I felt if I'm not doing anything, this is fine with me. But then, like anything else you find out [pause] I found myself [pause], I miss my apprenticeship. Just like I said, I'm stuck right here and when I have bad days I just, I like [pause], I could spend my whole life on the apprenticeship and be happy, coming in everyday and not know what I am doing or learn how to do something and

> getting good at it. And that to me is the most interesting part. When I graduated they kind of stuck me on the machine. (Warren, 12/4/96, p. 85)

He believed that individuals who only wanted work as operators were not committed machinists: "Why would you just want to be on a CNC machine. I never asked for it. Did you? [turning to a Rick also working on the CNC]. Did you ask to be on CNC?" Rick responded that he preferred CNC machine operation to working on conventional machines. Rick added:

> Ideally I would like to program and run a job on the NC equipment, from start to finish. What they are doing is they have programmers do the programming, and they [pause], and the operators come out here, push a button and change the part. It is not as satisfying as being able to be involved in the process of programming it, designing it, because you don't use your brain. (12/5/96, p. 15)

With the introduction of Unigraphics, the development of CNC pointed to two areas of specialization, programming and machine operation. Warren was clearly unhappy with machine operation. When asked if he would be interested in programming, he responded as follows:

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|---|---|
| Warren: | I might do that. I don't think I could do it all the time. It might drive me crazy, but I could try it. [laughing] |
| Interviewer: | Yeah, would you... |
| Warren: | I might like it. |
| Interviewer: | Yeah |
| Warren: | I don't think so. |
| Interviewer: | But you don't think so? |
| Warren: | You never know though. |
| Rick: | I don't know if you are like me. The one thing that I do need to do is to produce something with my hands. |
| Interviewer: | Yeah. |
| Rick: | I don't think I could sit and just manipulate numbers and stuff like that all the time. I like to do the complete thing. Program it, get the first one running, and let somebody else run the rest. |

(Warren, 12/5/96, p. 26)

Warren concurred: "I would rather set-up and let someone else run it." By this he meant working with new programs to make the first part of a required batch. "It's not really the best route for the company to go to have one person program it and another run it," he added.

The relationship between programmers and operators was the second issue which came up during the discussion with Warren. During that discussion, Bernard, who had programmed the job that Warren was running, joined in the discussion. One of the issues that emerged was the sometimes difficult working relationship between programmers and operators. There were six programmers, and about three times as many operators.[5] The main criterion by which machinists were selected to fill openings in the programming section was seniority based on number of years of service. However, two machinists who were quite junior became programmers. One such person was Bernard.

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|---|---|
| Bernard: | I think I got lucky. You are lucky to get in there. I was in the right place at the right time. I took classes. It's something I did on my own. |
| Warren: | They do it by seniority and sometimes they don't. Sometimes you get people who have taken an apprenticeship and already had Unigraphics, and they come in and they [management] are like, 'Oh, you know that, try it.' Then guys who have been out on the floor get a little uptight about it, sometimes. |
| (Warren, 12/4/96, p. 32) | |

Bernard took the initiative to learn Unigraphics at community college, rather than taking the training program arranged through the company.

> I kind of got in the back door...I was lucky to get in there like I did because there are other guys that are just as smart, smarter than I am that could be doing the same thing but they are stuck on the floor for some reason. They didn't get the opportunity that I did. (Bernard, 12/4/96, p. 66)

5 Roughly two thirds of the operators worked on the afternoon and night shifts. There were no observations or interviews on those shifts

The number of openings in Unigraphics programming was not large enough to satisfy the demand for programming experience among machinists. That created some tension, with Bernard going so far as to suggest that there was favoritism in the selection of who should become a programmer.

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|---|---|
| Warren: | I think if you do a good job here [on the floor] you will do a good job in there [programming]. That's not the criteria that's followed....I try not to let that bother me. We got guys who are working on the machines who have every right to feel slighted because they should be in there too. |
| Bernard: | Then you get bad attitudes. Then you have people who don't want to work with other people. |

(Warren, 12/4/96, p. 68-69)

The tension between programmers and operators was also manifest around the issue of power defined in who is in charge of the part.

| | |
|---|---|
| Bernard: | Some of the guys, they don't work... they butt head a lot and they don't work well together. |
| Warren: | And they... |
| Bernard: | There is no set procedure of who is in charge. |
| Warren: | It's a problem. It's a problem that shouldn't exist. |
| Interviewer: | Who is charge? |
| Bernard: | Is the operator in charge of the part or is it the programmer? Who gets the last say? |
| Interviewer: | Oh, the operator... |
| Bernard: | The programmer wants the last say. That might be fine, but it may not be the way the operator wants to see things. And he is the one who's got to run the part. He's the one that's kind of responsible for the part. |
| Warren: | He's got to put it on and take it off. |
| Bernard: | Because if it comes off his machine and it's a bad part, why is it a bad part? Well, I drilled the holes wrong. And well, it could be the programmer's fault, or it could be the operator, you know. It's a fine line there. |
| Warren: | A bad operator can make a good programmer look bad. And vice versa. It's a lot easier if you work together. I myself, I've already said I would feel stupid blaming on the programmer. I've seen it done a million times. I'm the one that hits the button. |

(Warren, 12/4/96, p. 44-46)

Warren was concerned that some of the programmers tended to act like white collar workers: "I think that people try to act that way." He wanted to see them spend more time "out here" on the floor, learning how the machines worked, instead of staying in air-conditioned office space:

> You can't have someone who doesn't understand this [machine] doing programming. It can be done, but it's not always pretty. These guys should be right out here, seeing what I need them to do. (Warren, 12/4/96, p. 41)

Warren's views on CNC machine operation had evolved over time. He had clearly enjoyed the work when he first started. He was frustrated because the work had become increasing repetitive.

Warren believed that a return to conventional work would give him more opportunities to do creative work. The complicated parts that he was interested in were moving to CNC. But they were not resulting in creative work, at least for machine operators. Codification of machining processes made it possible for work to be both complex and routine. Indeed, it was in the interests of productivity to routinize complex work.

Warren did not express an interest in programming, although that work would afford him greater opportunities for creativity. For him, parts and not programs were the authentic products of machining work. He was primarily interested in cutting metal and making parts.

The discussion also highlights the tensions which were inherent in the new specializations of machine operation and Unigraphics programming. This was an important issue in this shop where machine operators and Unigraphics programmers were members of the same union, had the same rank of toolmaker, and were earning the same wages. The contest for what was considered meaningful work could be quite strong. The struggle for meaningful work was however paralleled by its re-definition, as it was made more routine, through codification, the use of specialized teams, and the machining of large batches of parts.

The third and final operator interviewed was Matt.

## Matt: Glad to Be an Operator

Matt was in his forties. He had worked in the machining trade for about ten years, three of which were prior to his apprenticeship. On graduating from high school he worked on the auto assembly line. During that time, he was laid off quite often.

> I would work for a year or two, get laid off, work for a year, get laid off. And I got really tired of that because you make really good money and then when you get laid off, you can't find any kind of job to give you that kind of wage outside of the auto industry. And I always felt if I had a skilled trade behind me, and if I could find work that could give me a decent income. (Matt, 12/2/96, p. 2)

His initial attempts to become a machinist were unsuccessful because of difficulties in passing the selection examination. It was only after taking a series of courses in mathematics and science at a community college that he was able to pass the examination.

In his current job Matt worked as a machine operator. As with Warren, he was a main operator. He had no desire to move to programming or to conventional machining. His interest in running machines had some history as the following dialogue shows.

Interviewer: When you were doing your apprenticeship, did you think of CNC as something that you wanted to do more of?

Matt: Oh yeah. I've always liked running machinery, anything that has a control board, switches, lights. I was always interested in doing that even when I worked in production. They had a lot of robotics over there that you had to set up and kind of program those. I was comfortable running machines and understanding how they work, where they were gonna go and how they were going to get there.

Interviewer: Would you say you are more comfortable with CNC than with conventional machining?

Matt: I am, yes.

Interviewer: Oh, you are?

Matt: I am a lot more comfortable with this [pointing to a CNC machine.

(Matt, 12/2/96, p. 13-14)

Matt was interested in learning Unigraphics programming, but was not interested in programming as a career. He did not feel that writing programs, without actually cutting metal and making parts, would be satisfying. For him, the essence of machining was cutting metal and making finished parts. The following dialogue highlights those issues.

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|---|---|
| Interviewer: | What do you think of programming as a career? Is that something you want to get into? |
| Matt: | I don't want to get into it. No. |
| Interviewer: | Oh, really? |
| Matt: | I would like to know more about it. I wouldn't want to do that all the time. I'm not very interested in programming. |
| Interviewer: | Why not? |
| Matt: | I like to run the machines. I like the cutting and tooling side of it. |
| Interviewer: | Why is that more interesting? |
| Matt: | Because I actually get to make the finished part. I like to see the result of my work. I guess with programming you can see the result too but you don't actually make the finished part yourself. |
| Interviewer: | Right. |
| Matt: | It's pride in your work, I think. |

(Matt, 12/2/96, p. 33-35)

As the dialogue shows, pride in one's work was important. It was defined in terms of making finished parts, and not the creation of CNC programs.

Matt did not think that programming at Makro was white collar work. However, he felt that programmers were not open to sharing their expertise.

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| Interviewer: | So in this place where you have programmers and guys on the floor, is the white collar, blue collar distinction important? |
| Matt: | No, because if they [programmers] don't have work in there they come out and work. They spend time on the floor on different jobs. Although we don't get to go in there and do programming when we don't have work out here, which I think, we should get a chance to at least go in and see how to program and how to operate the computer in there. |
| Interviewer: | That's something you would like to do? |
| Matt: | Only to see how it works. I wouldn't like to do that for a living. |
| Interviewer: | If you didn't have work to do here, you couldn't just go in there and spend a day there? How does that work? |
| Matt: | Not necessarily. You can go in there but I think they like to keep their end of it a little bit secret. They won't just say, 'well, this is how you do a drilling pattern, this is how you mill.' They won't show you step by step how they program. They like to keep that their own thing, a little secret. |
| Interviewer: | Why would they want to do it that way? |

| | |
|---|---|
| Matt: | Because it's like their own specialty. They don't want to... It's like being a cook, you don't want to tell everybody your secret recipe. They feel they had to learn it on their own, you know. They don't want to give you a year's worth of their time and effort in ten seconds. 'It took me a year to figure out how to do this. This is how I did it.' |
| Interviewer: | How about on the floor here. Are people open to teaching each other? |
| Matt: | I think so. To a larger degree than with programming. On the floor and running NC equipment. |
| Interviewer: | Yeah |
| Matt: | On the floor and running CNC equipment everybody still has their hold backs, but they don't want to give somebody all the information they know. |

(Matt, 12/2/96, p. 37-40)

Occasionally Matt worked on conventional machines:

> I go there to do fixtures or something I need at home. I like to stay informed on that because if I ever get laid off I might not get a job running CNC equipment in a shop. So I should know about conventional machining also. (Matt, 12/2/96, p. 48)

Matt was happy with his work, but he was also looking ahead and planning for the possibility of retrenchment. That was an important issue, not just with him, but with most of the other informants, particularly the younger generation of machinists. The informants were very conscious of their skills and the relationship of those skills to changes in the trade. For Matt, maintaining his options open meant keeping his skills in conventional machining updated. Even though he did not particularly enjoy conventional machining, he made a point of doing it on a regular basis.

Matt preferred to work as an operator because this involved cutting metal. He would have liked to program as well, as long as that also included working on the machines and cutting metal. Cutting metal and working with the finished part was a matter of taking pride in one's work. Along with other informants, Matt believed that skilled machining work should involve metal cutting. Unlike other informants (for example, Warren, Mark and Jonathan), Matt was quite comfortable with his area of specialization. Of the three machine operators interviewed, he was the most junior in terms of machining experience. At the time of the study, his work was more varied than Warren's. He remarked, "I get bored when I run the same parts over and over. To me that's more like production." The more varied nature of Matt's work at the time of the study, and his relatively junior status may account for his enthusiasm for machine operation work, in contrast to the other two informants.

## Summary: CNC Machine Operation

Machine operation work tended to be repetitive, and skilled machinists had difficulties coming to terms with it. They preferred work that combined programming and machine operation. However, there was a realization that such work would not be available at Makro where both programming and machining operation had become specialized. Given these constraints, the informants expressed the desire to be more knowledgeable about Unigraphics programming, without becoming specialist programmers. The interviews highlight the importance that machinists attached to some involvement with the whole process of machining. Furthermore, for all three, the part, and not the program, was the most important product of the machining process. The informants believed that the changes in machining work at Makro were good for competitiveness and productivity and job security, but they were not necessarily the best route for them as skilled machinists. There was a tension between productivity tied to work specializations and roles, and the informants' views that skilled machining should be based on all-round skill.

I will now discuss the Unigraphics programmers.

## The Programmers

The programmers interviewed were Ed, Bernard, and Dan. Ed had been working at Makro for nearly forty years, the longest period of service of all the informants. I was interested in him as a programmer, and also as an informant with a broad understanding of the history of the plant. Of the three programmers that I interviewed, he spent the most time on the shop floor working with machine operators. Other programmers tended to spend most of their time in an air-conditioned office space. Ed explained why he spent time on the shop floor.

> I spend a lot of time out here because I want to follow the job and make sure it is a good part. I do more of that than most programmers. I just feel that's the way it should be done (Ed, 10/8/96, p. 1)

Ed was a highly regarded machinist, and on several occasions other machinists said that they regarded his work as exemplary.

The second informant was Dan, who had been programming for close to fifteen years. The third was Bernard who had been programming for less than two years. I will discuss each of their cases in turn, beginning with Ed.

## Ed: The Machinist's Machinist

Ed had been programming for twenty-five of his forty years at Makro. Prior to programming, he worked as a machine operator as well as a conventional machinist. Although he had been programming for twenty-five years, he was hesitant to describe himself solely as a programmer.

> We have people who think they are [just programmers]. They don't go out of that room [referring to an air conditioned office space]. They just stay right in there. Technically they are not just programmers. They could be asked to run the machine at any time and once in a while they are. But predominantly they program. I very seldom run the machines anymore so I have to call myself a programmer. Otherwise I am not an operator because I don't run the machines anymore. But I spend a lot of time out here checking parts. I don't sit in there unless I have something to do in there. So that's the way I learn. Other people do it differently. I like to keep my hands on the process. (Ed, 10/8/96, p. 2)

Ed worked as a CNC machine operator at a time when the machines were programmed by engineers. Over time, union workers took over this responsibility. I asked Ed if this change had improved the quality of programming. He responded:

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|---|---|
| Ed: | It wasn't a question of how good a job they [white collar workers] did. It's just that the union felt that this was our work. Salaried people were doing our work. So through negotiation we won the right to do it. |
| Interviewer: | Right. OK. You feel the same, that this should be your work. Not salaried people's work? |
| Ed: | Yeah. That's what we do around here. They were doing what we traditionally have done as part of our trade. |

(Ed, 12/3/96, p. 40)

He strongly believed that skilled machinists should, as collective assume responsibility for all aspects of machining work and guard against "loss of work" in the changing workplace. Ed talked about the changes in machining work.

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|---|---|
| Interviewer: | What did you think of the change from working on conventional machining to CNC in terms of the work that you did? |

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|---|---|
| Ed: | At the time it was kind of exciting. There was something challenging. It made a lot of difference in our work though. As far as making the job interesting, I'm not sure it was as great as we originally thought. Now we are doing more production type work. Initially, if we had ten parts to make we would do it over there [on conventional machines]. Or a hundred parts, we would do it over there too. But now we just put it on the NC machine and once you prove [test] the program all you have to do is monitor your tools and make sure they are sharp, and you keep monitoring your part...So it's a lot different. |
| (Ed, 12/3/96, p. 5-6) | |

Later he added:

> When we used to do it manually, in a sense every job was a challenge. And that kind of made it interesting. Every job is a little different. You got to figure how to set it up, how to machine it, even how to check it (Ed, 12/3/96, p. 8)

Ed noted that CNC machines were faster than conventional machines. They had reduced the time required to develop new products (lead time). He believed that they needed CNC machines to stay competitive "even if they are not as interesting to run." He personally enjoyed his work because it combined programming with some involvement with machine operation.

> I like a little variety. I don't find it particularly interesting to just sit in front of the tube [i.e. computer] all the time. But at the same time running NC machines can be just doing the same thing all the time. It can be a little bit tiring too. Almost gets to be like production, you know. (Ed, 12/3/96, p. 8)

Ed emphasized the importance of a commitment to quality work, and that meant total involvement, including getting one's hands dirty on the machines.

> You got to keep at the back of your mind, you are still a toolmaker and you still got to make accurate parts. You still got your responsibility for doing that. Some operators forget that. They just try to keep making parts. The good machinist cares...I think you got to not worry about getting your hands dirty. If you get in here, you are going to get dirty. So you got to have that mentality that you don't care about that. (Ed, 10/8/96, p. 4)

Ed saw himself as a member of a team, and not as an individual toolmaker:

> We have some loners who don't work with other people, but it's a handicap. You got to be able to work with other people. Communication is very important. Many times because of a lack of communication a part gets scrapped. (Ed, 12/3/96, p. 13)

Access to programming was controlled. The company strategy was to have a small corps of well trained programmers working with teams of operators. As Ed saw it:

> We have a lot of young ambitious people, who would like to learn every facet of the trade. We would like to teach them. If all those guys are in there [programming] then I am going to lose my efficiency. I need to be involved in it all the time. So if they are involved in it, then I am going to be less involved, then I am going to lose my efficiency. It's a kind of a touchy situation (Ed, 10/8/96, p. 5).

Machinists at Makro were paid at the same rate, regardless of their area of specialization. In this sense, all machining work was accorded the same economic status. However, access to programming was tightly regulated, much more so than access to other areas. In any case, as Matt (the operator) pointed out, programmers were the least open to sharing their expertise. Access to programming became a status issue. This was a source of frustration for machinists desiring to be involved in all aspects of the trade. From a productivity perspective, there was no compelling reason for the company to train more workers in programming. What was needed was a small corp of efficient programmers. There was a tension between the view that skilled machinists should be involved in all aspects of machining work, and the commitment to productivity in a competitive environment. At the time of the study, high productivity appeared to be best served through specialization. This re-organization placed higher demands on teamwork, effective communication, and commitment to quality. According to Ed, some skilled machinists were having difficulties retaining a commitment to quality in the re-organized workplace, where responsibility for quality were diffused across a team. The same concerns were raised earlier on by Jonathan, who returned to conventional machining.

## Bernard: Breaking Through Barriers

Bernard enjoyed his work and was glad to be a programmer. For Bernard, as with the other machinists, job security was an important consideration. There were rumors that his unit might be moved to another city and this worried him. The following dialogue highlights this concern:

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|---|---|
| Interviewer: | What kind of changes do you see happening over the next few years? |
| Bernard: | In this plant? |
| Interviewer: | Yeah. |
| Bernard: | I hate to guess. I have to assume that we won't be here in two years. |
| Interviewer: | In two years? |
| Bernard: | I don't know. You hear rumors. |
| Interviewer: | Oh, really. |
| Bernard: | But it's hard to say with this company. It's a sad thing. But it's not my decision. |

(Bernard, 12/6/96, p. 42)

Bernard believed that skills in Unigraphics programming improved his job security.

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|---|---|
| Bernard: | The thing with programming is, if you are good, you can go just about anywhere and get a good job. You don't have to worry about this company laying you off and not having a job. You just got a lot of security with a toolmaker background. |
| Interviewer: | Do you have any regrets that you went into machining? |
| Bernard: | Oh, no. This is a good trade. |

(Bernard, 12/6/96, p. 5).

He was also looking at options outside machining. and was taking college classes in mechanical engineering : "I don't know if I will make that or not. Looking to change jobs I guess. Go from here to an engineering job."

Bernard preferred programming to working on the CNC machines, cutting metal.

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|---|---|
| Interviewer: | It sounds like you enjoy doing programming. |
| Bernard: | Oh, yeah, I would rather be here than working on the floor. I don't mind working on the floor either you know. It's just different. |
| Interviewer: | Why is it [programming] something that you enjoy? |
| Bernard: | Well, the technology is going this way. So you got more job security I think, if you know how to do this stuff. If you know this stuff you got better opportunities to do different places. If you are just a machine operator, you can get a job somewhere to be a machine operator. But if you have programming you have a better opportunity to get a better job somewhere. So it opens up more doors. |
| Interviewer: | Some people have said programming is more like white collar work. What do you think? |
| Bernard: | You are not getting dirty. You can sit here and just work on the computer. It takes lot of knowledge. You got to train for it. I guess you have a higher degree of training than somebody on the floor would have. And so you could say it's white collar. But in our shop, I don't believe it is. Sure we are separated a little bit. I guess we have a good job in one sense. |
| Interviewer: | In what sense? |

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|---|---|
| Bernard: | We don't work on the floor. There is air conditioning in here. We can sit in here. We are not sweating. We are not getting our hands dirty. |
| (Bernard, 12/6/96, p. 24-25). | |

Bernard was one of the leading programmers in the shop before the introduction of Unigraphics. He had programmed with SPLIT, a forerunner of Unigraphics. For five years he wrote programs for a machine that he operated together with a team of other machinists. At that time, programming was more integrated with machine operation.

> They only had a couple of guys that were really considered just programmers. I don't think we had any people that were considered programmers. Everybody programmed theirown machine. You only had one guy on a machine that programmed it. Not everybody that ran the machine programmed it. One guy that programmed and ran it, and two or three guys that ran the program on other shifts. (Bernard, 12/6/96, p. 20).

The emergence of unionized specialist programmers who did not work on the machines was a recent development.

> But it's only been within the last two years that we kind of have guys who only specialize in programming. We are too lazy to work I guess...Most people think [that]. [Laughing]. (Bernard, 12/6/96, p. 22).

When Unigraphics programming was introduced, Bernard was not included in the group selected for training. A higher seniority person, with less programming experience, had been selected in his place. He decided to go to a community college to learn Unigraphics programming and gradually worked himself into a programming position.

| | |
|---|---|
| Bernard: | About the past year, the machine that I ran quit running. It got so bad. Well, I didn't have a machine to run. And I started programming the cylinder blocks in here to run on the big mill with one guy on another shift who wanted me to help him program it. So I programmed it, and he helped me. He knew what he wanted to see, the numbers, and how the machine is running, and I did the programming in Unigraphics and got the stuff running. That machine ran really good. We were getting good [engine] blocks. And since then I have pretty much only programmed jobs. |
| Interviewer: | OK |
| Bernard: | And a few other guys in here, that's basically all they do now. They've been at it a little bit longer. |

(Bernard, 12/6/96, p. 21-22)

Bernard had mixed views about the limited programming opportunities in the shop. On one hand he felt that the number of programmers should be limited to give opportunities to those who programmed to be efficient. On the other hand, he felt that it was rather unfair to deprive aspiring programmers of opportunities.

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| Bernard: | They are working on the floor or on the machines because of their [low] seniority or because of their situation they didn't get invited in. I guess. So I don't think the people in here are any smarter than people on the floor. It's just that we got a break. The opportunity came our way so [pause] |
| Interviewer: | Right. |
| Bernard: | Perhaps we got lucky. |

(Bernard, 12/6/96, p. 23)

I suggested that some people enjoyed working on conventional machines and wanted to stay there, to which he responded:

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|---|---|
| Bernard: | Oh, yeah. Some people don't want to be here either. Not everybody wants to be here. I was just saying some people like to be here but they don't have opportunities to be here. |
| Interviewer: | Right. |
| Bernard: | It makes it bad for those people. Maybe they could do as good a job as we do. It's not like we are superior in any way. |

(Bernard, 12/6/96, p. 24)

Bernard was asked to rank three work sites in terms of his preferences, that is Unigraphics programming, machine operation, and conventional machining. The dialogue below indicates his views.

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|---|---|
| Bernard: | I would rather program, and the second thing I would rather do is work on an NC machine. |
| Interviewer: | Rather than conventional? |
| Bernard: | Conventional work would be the last choice. |
| Interviewer: | Why would it be the last choice? |
| Bernard: | Well, you are standing up, cranking handles. You usually get more dirtier. Sometimes it's fun to make a part by hand too. It seems like you accomplish more than when you just let the machine run it. |
| Interviewer: | Yeah |
| Bernard: | I would rather be where the new technology is, instead of the old stuff because our generation is not the same as it was twenty or thirty years ago. We are doing things differently. We have better equipment. |

(Bernard, 12/6/96, p. 40)

He acknowledged that conventional machining could be interesting. Furthermore, he went on to define his interest in CNC technology primarily in terms of keeping up with the new technology rather than in terms of interest in the process of programming itself. His ambivalence was apparent, later in the discussion when he was asked whether the programming role should remain separated from the machine operation role. The following extract indicates his thinking:

| | |
|---|---|
| Interviewer: | Do you think that in the long term programming and operation should become more separate categories of work? |
| Bernard: | I don't know. I don't know if it's good to have regular programmers and they are never on the floor. I myself enjoy programming a machine and then running that machine. That's what I enjoy doing. |
| Interviewer: | So if you had that option, is that what you would do? |
| Bernard: | If I had that option I would run the machine and program. |
| Interviewer: | Oh, that's what you would prefer? |
| Bernard: | Yes. I did it in the past and that's what I enjoy doing. |
| Interviewer: | That's different... You were just saying... |
| Bernard: | Yeah, I know I just said I wouldn't like to be out there on the floor but when you run your own machine, you run it everyday. If you program it you are going to take time away to program that job, then take it out and test it out. If things aren't right you can go back and program it some more, take it back out and run it. Then you are going to know exactly what's going on. Instead of having someone test your program, come in and tell you what's wrong, and then trying to figure it out. You don't see the machine run, so you are not sure if there is something wrong, or it's the way you want it to be. And when you are running your own job you can make things the way you want it to be, and program it that way. And then you got people that are going to help you on the part. So you get to do a little bit of both. |

(Bernard, 12/6/96, p. 37-39)

Given the current specializations in the shop, Bernard preferred to program, rather than to operate machines. Clearly, if these two aspects of machining were not split into different work roles, he would prefer to write his own programs and run them on a CNC machine. In proposing the integration of programming and operation, Bernard shared Ed's views. But he derived more satisfaction out of programming than Ed, who had made the decision to be more actively involved with machines on the floor. Bernard was quite comfortable with his specialized work, but he also believed that specialization in programming, without machine operation work, was not the ideal arrangement for himself as a skilled machinist. The ideal arrangement would be where he mostly programmed, with some involvement in metal cutting. He was different from machinists like Peter and Jonathan, in not having much interest in conventional machining. Bernard was relatively young compared to Peter and Jonathan. He believed that conventional machining was a technology of the past and had little to offer him in terms of his career advancement.

I now turn to the third programmer, Dan.

## Dan: Keeping Up With Change

Dan was glad to be a machinist: "Kind of lucky on my part. I got into something I enjoy. I like to make things." He first worked with CNC when he was an apprentice, running programs developed by others. He became interested in programming and took the initiative to ask one of the programmers to teach him. "I wanted to be a programmer. It looked interesting to me." For some time after Dan learned to program, he remained classified as a machine operator: "Eventually I got enough seniority and became a programmer."

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| Interviewer: | When was that when you became a programmer? |
| Dan: | I kind of worked into it. I can't really put a date on it. I was gradually doing more programming all the time. I started probably in 1982. By 1987 I was pretty much a programmer. |

(Dan, 11/7/96, p. 50)

Dan believed the programming was more like white collar work: It was more like office work, and was "not dirty." However, he personally did not mind getting his hands dirty: "It's dirty, but it has always been dirty." For him, getting one's hands dirty was part of the trade. Nevertheless, he only occasionally worked on the machines. While he enjoyed programming, he was somewhat nostalgic about the past when there was more conventional machining, and he referred to the past as "the good old days."

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| Interviewer: | You were saying something about the good old days? |
| Dan: | We are doing as good. It's the way your memory looks at the past. But in the past you took more pride in your work. You made the whole part. It's your baby. With NC you haven't made the whole part. You can't point to a part and say I did this. In the past, there was more pride in one's work. |
| (Dan, 11/8/96, p. 5) | |

With the introduction of CNC, Dan believed that machinists were not always as attentive to their work. But productivity, in terms of volume of parts machined, had gone up. He reflected on the change this way:

> There are good and bad thing about it [change]...With NC you have more people responsible. If you have more than one person responsible for a job, the quality tends to be lower. Not that quality is bad on NC. But the people on NC do not necessarily watch their work closely. On NC you tend not to check your work closely. As quantity goes up, the amount of time you can devote to a part goes down. With NC people are getting a little more specialized. With NC a person with less knowledge can make parts. In the past it took broader knowledge to do the job. Knowledge is still there, but it's spread out. You don't know as much. (Dan, 11/8/96, p. 4)

Machining work as a shared responsibility, and the machining of large batches of parts was a new development for skilled machinists, who preferred small batches, and individual responsibility for all aspects of machining work. Establishing effective communication within teams was proving to be a key problem.

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| Dan: | Some people don't pass information. There are people that don't get along with each other. He [machine operator] makes the change out there [on the floor] and he doesn't like me. He is not going to talk to me. We run into that. That's a problem, a personal problem. You know how those things work [laughing]. |
| Interviewer: | Interesting. |
| Dan: | Communication can be a problem. It doesn't crop up an awful lot. Maybe twice or three times a year we run into a real problem. We actually lost things we have had to make again. |

(Dan, 11/7/96, p. 47).

The interview with Dan raises several important points. As a programmer he was part of a team, where the skills needed to make parts were distributed. Dan appears to think that the distributed nature of machining work means that machinists do not know as much about the trade as they used to when they assumed full responsibility for the part as conventional machinists. However, there are qualitative differences in the knowledge across the different specializations, as the discussion in chapter 5 indicated. It is true that skilled machinists on CNC mostly shared the responsibility for making parts, and conventional generally did not. But it does not mean that CNC machinists had less knowledge and skill because quantitative comparisons are inappropriate when the *type* of knowledge is changing.

The evidence from different informants shows skilled machinists were, to varying degrees, finding the re-organization of work around specialized teams difficult. They had difficulties taking pride in their work when it was not organized around individual skill. As Dan saw it, skilled work meant getting one's "hands dirty", as well as programming.

## Summary: Unigraphics Programming Role

There is a common thread running through the interviews with machinists working as programmers, as well as those who were working as machine operators and conventional machinists. In all cases, the informants expressed the desire for involvement with the entire machining process. The team approach used in CNC was in conflict with the informants' advocacy for all-round skill.

For all three programmers, learning was an important part of the work. As Bernard put it, one had to keep up with the "new stuff". Ongoing changes in technology and job insecurities compelled machinists to see themselves as learners.

There was a tension between preserving the traditional view of skilled practice centered around individuals and embracing new technologies and new forms of organization that appeared necessary to sustain competitiveness for individuals on the job market, and for the corporation in a global market. The informants negotiated that tension individually and collectively. As a collective, they were involved in all aspects to the work. Ed who was a programmer, and Peter, who had no interest in programming could also say that programming was "our work". As individuals, they also negotiated their work. For Bernard, Ed, and Dan, this meant working as programmers. As we saw earlier, for Peter and Jonathan, this meant returning to conventional machining.

The discussion now turns to manual programmers.

## Manual Programmers

In this section I analyze data from machinists who were working as CNC manual programmers at the time of the study. Manual programmers both programmed and operated their machines. As such, they were involved in the entire machining process. Three individuals are included in the discussion. Only one of them had been a manual programmer for an extended period of time. The other two were transitional in that work role and happened to be working at these sites at the time of the study.

Most of the machining work at Makro was programmed on Unigraphics, rather than manually. Unigraphics was more efficient for handling complex parts such as engines blocks, which were the main products of the shop. The parts I observed being programmed manually were small, relatively simple.

The informants at the manual programming sub-site were Mike, Tom, and Bill.

Mike: Preparing to Go into Business

Mike was in his forties and had been in the trade for slightly over twenty years. His first encounter with machining was as teenager when he befriended a neighbor who owned a machine shop. Through that friendship, he developed a passion for machining. Before coming to his present job he was a die maker for over a decade, within the same company. He was transferred to his current job when the project that he was working on came to and end. Mike had his own machine shop in his home.

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| Mike: | I do a lot of motorcycle parts for guys. I do engine repair, and things like that. I got a cylinder head thing that I do. I do cylinder heads at my house. And stuff like that. |
| Interviewer: | Cylinder heads, that is a kind of a big job. |
| Interviewer: | Yeah it is. You take all the valves out and replace everything. But there aren't a lot of people doing that, so you can get a lot of people [i.e. customers] |
| Interviewer: | How long does it take to do a job like that? |
| Mike: | It takes a long time. It's not easy work. Well, a week. You might have like twelve hours. |

(Mike, 10/1/96, p. 10)

Mike was impressed with the small CNC machine that he was using at work, and was planning to acquire a similar machine for his shop in the long run.

He saw himself retiring in about ten years and had plans to go into his own machining business full-time.

> If you got to compete on the outside, if you are going to build parts, the only way you can compete is with NC. If you are doing it by hand there is no way you can compete. (Mike, 10/1/96, p. 11)

Mike explained that CNC made it easier to cut complex surfaces such as contours (curved surfaces).

> And it does it perfectly, and it does every point, and it repeats. It eliminates set-up time because you can do more at one time. Whereas the other way, you are doing a lot breaks in your set-up and stuff like that. So it allows you to do it much quicker. You can do it competitively because, if you can't do it like that, the next guy is going to beat you on the job. You are not going to get the jobs. You are going to work for nothing. (Mike, 10/1/96, p. 11)

Mike did not have an interest in becoming a Unigraphics programmer.

> I don't like sitting in a chair all day. I am not a person to sit in a chair. I took some computer classes at college, and I don't like sitting one spot all day. I feel a lot more comfortable moving around. (Mike, 10/1/96, p. 13)

He however thought that he might do some programming if he got tired of working on his machine: "I would like to go in for a while. But I don't want it as a permanent job. It would be too boring for me." He preferred to work on the machines, and to make parts because this was related to his hobby: "I make a lot of tools for myself. I work at home a lot. And I do a lot of repair work." He liked his job because he was programming his own parts and making them as well. That was something he could not do as a Unigraphics programmer. While Mike expressed the view that he was not interested in programming as a career, he was more open to the possibility of working as a CNC operator.

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| Interviewer: | Are there things that you would like to learn before you retire? |
| Mike: | Well, there is different machines that I would like to get into some of the other NC machines and run them. But right now, I want to stay where I am at. |
| Interviewer: | Why would you want to get into the other machines? |
| Mike: | Oh, I just want to learn them. Just for my knowledge. See, if you get laid off and you go to the outside there is a lot of NC work out there. People that run machines, NC operators. So it would be beneficial for me to learn the other machines, the G codes and all that are different from mine. Just so if the guy [new employer] doesn't have that machine then I can get a job on something else. |

(Mike, 10/1/96, p. 12)

The concern with being laid off influenced his interest in machine operation. This was a concern shared with other informants and it influenced their thinking about their work, and the kind of work experiences that they desired to have.

Mike was working at a sub-site that was not involved with the core business of the machine shop. As I noted earlier, the main development work with engines was done on CNC. However, Mike was satisfied with his work because he wrote his own programs and then used them to machine parts. The tasks that he worked on were varied, and came in small batches, and that made the work interesting and challenging. It was important for him to be involved in all aspects of machining because of his business plans.

## Bill: Moving Around

Bill worked mostly as an CNC machine operator, and most of that work was on the large CNC machines linked to Unigraphics programming. At the time of the study Bill was working on a CNC lathe where he wrote his own programs and machined parts. He was also training an apprentice machinist. The apprentice participated in the study and his interview is discussed following this.

Although Bill programmed and operated the machine he was working on, he described himself as an operator. He was asked to clarify what his role was.

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| Interviewer: | So are you a programmer or an operator? What's the distinction here? |
| Bill: | I am an operator |
| Interviewer: | But you are writing a program? |
| Bill: | If I knew the difference, I would explain it to you. |
| Interviewer: | Is that your official... |

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|---|---|
| Bill: | I think I am listed in there office as an operator. I would have to look if they have programmer-operators with some programming experience and operators with no programming experience. It depends on the machine also. This [his machine] is set up so you can program. And it's quite easy for the operator to have a chance to program. |
| (Bill, 10/10/96, p. 32-33) | |

Bill worked for years as an operator, and only occasionally on machines where he combined the programming and machine operation functions. He therefore identified more with the operator's role. However, he preferred the kind of work that combined machine operation and programming.

> The perfect situation is to be able to write your own program and run the part. I think you will find that from most of the people here. Just being strictly an operator is [pause] it gets kind of tedious after a while, especially if you are running a lot of parts.. All you are doing is changing the part, cycle starting the machine[6], changing the part, and cycle start. It's almost like a production type job. (Bill, 10/10/96, p. 34-35)

Bill's views about machine operation were consistent with the views of the other informants. There was some hint of indignation that programmers were carving out a new role for themselves and were increasingly reluctant to be involved with the machines.

> The programmers, they like to stay in there and program all the time. They don't ... Some of them, they would like to come out here and run the machines, I think. (Bill, 10/10/96, p. 35)

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[6]. The Cycle Start button was used to execute programs.

Bill was not interested in working as a Unigraphics programmer.

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| Bill: | I don't really have a desire to go into programming. |
| Interviewer: | Why not? |
| Bill: | I don't think I can sit at a computer for eight hours. I like to get up and do things. |
| (Bill, 10/10/96, p. 42) | |

With Bill, as well as the other informants, there was a striking lack of interest in Unigraphics programming as a career. On the other hand, there was an interest in learning to program with Unigraphics.

Bill preferred work that involved both programming and machine operation. The site where he was working afforded him that kind of work. However, that work was of a supportive nature, and was not central to the work of the company. For him, the future was with either Unigraphics programming, or CNC machine operation. That future was dictated by the economics of the industry. There was a tension between the kind of work that Bill enjoyed and the options that were viable in a long term commitment to Makro.

Finally I turn to Tom, an apprentice who was training with Bill at the time of the study.

Tom: Learning the Trade

Tom was different from the other informants because he was an apprentice machinist. He was in his mid-thirties, and was about the same age as some of the skilled machinists in the shop. Before coming to the machine shop, he was on the automotive assembly line at Makro for fifteen years. His interest in machining started in high school. His initial attempts to enter the trade were unsuccessful because of difficulties with the selection examination. To improve his chances, he enrolled in a community college program where he took classes in mathematics and physics. This helped him to do well enough in the examination to be accepted for apprenticeship training.

As part of his apprenticeship, Tom had to take a range of college classes at a local community college. At the time of the study he had completed nearly nine thousand hours of practical training. Most of that was on conventional machining, with some CNC work, as well as one hundred and sixty hours of welding, one hundred and sixty hours of heat treatment, and one hundred and sixty hours of blacksmith work. The goal of the program was to produce a machinist skilled in all aspects of the trade. In some ways there was a tension between his training in all aspects of the trade, and the growing specialization in machining. Tom expressed his views on skill as follows:

> I like working with my hands. I like making things. It's something that interests me. To me the trade is not something I did because I had nothing else to do. It's something I wanted to do. Most of the guys who are good

> machinists are in the trade because they want to be there. Not because the pay is good, or anything like that...I love doing this kind of work. And I don't think I want to do anything else. (Tom, 10/10/96, p. 7)

Given a choice between CNC work and conventional work, Tom said: "I don't particularly like one more than the other. They each have their own place." He explained the difference this way:

> In CNC you need to have a knowledge of how the computer runs the machine. The controller [i.e. computer] actually runs the machine. One aspect of conventional machining is to be able to run your skill as a craftsman. But on CNC you need to have skill on the computer, machine code, and that kind of thing. (Tom, 10/10/96, p. 14)

He said that running programs was "all right, but it gets boring. If I am going to make something on a CNC machine, I would like to write the program." He had mixed views about programming as a line of specialization, and had a preference for conventional machining:

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| Tom: | Well, programming doesn't really interest me. I like to program where I can do it right at the PC, at the machine. I don't like to get into the big, big programs they are running there and doing them in a programming room. I, as far as conventional and CNC, I like the conventional machines. It's more of a craft. |
| Interviewer: | If you are a programmer you don't get your hands dirty. What do you think of that? |
| Tom: | Dirt washes off [laughing]. I don't mind wearing an apron. I can wash my hands. I like to understand what I am doing. To be able to come up to a machine, put something in there, and when I'm done, have a part. Being dirty doesn't even come into it. |

Interviewer: Right

Tom: Doesn't matter to me.

(Tom, 10/10/96, p. 18-19)

During his apprenticeship, Tom had not worked on Unigraphics programming. He expressed an interest in learning it.

> I want to take it because I want to be able to understand it. And that's what our company is using. It would just be a skill that would make me employable, if it comes down to me moving--not move from this company but to another plant. Getting a job offer in a different area. I can say I know how to run Unigraphics. (Tom, 10/10/96, p. 23)

He shared the uncertainties of the other workers, and believed that Unigraphics would make him more marketable.

For Tom, skilled machining was primarily defined in terms of conventional machining. He preferred to work with his hands, manually turning wheels, dials and knobs, and to be intimately involved with the part, from start to finish. His notion of working with his hands was similar to the perspective expressed by Peter, the conventional machinist who was discussed earlier. But Peter and Tom were different generations of machinists. The belief that conventional machined defined skilled work cut across generations. As we saw earlier, this belief was also expressed by Warren a relatively young machinist working as a machine operator.

However, this was counter balanced by the younger generation of machinists' belief that programming experience increased their employability.

In summary, Tom's interest in Unigraphics programming was influenced by trends in the industry. He was concerned about job security, and wanted to learn Unigraphics programming to ensure marketability.

## Summary: Manual Programming

The main focus of the work at Makro was on complex and large parts such as engines blocks. Unigraphics programming, which was used to program these parts, was therefore more important to the company than manual programming.

The informants indicated that involvement in the whole process of machining was important. The part was viewed as the most important part of the machining process. Programming was a means to that end.

The informants were keen to learn new aspects of machining in order to keep up with change. That came across quite clearly with Tom and Mike. That is consistent with the findings from the other informants. For both Mike and Tom, learning was a necessity to ensure marketability in a changing workplace. In Tom's case, there was a tension between his desire to ensure competitiveness on the job market by training in CNC technologies and his belief that conventional machining was the ideal work for skilled machinists. Had he been nearing retirement, he might have been more comfortable working as a conventional machinist like Peter and Jonathan. He was just entering the trade and had to negotiate for the work that gave him the best prospects for continued employment in a changing trade.

## Summary

The informants were reflectively conscious of themselves as 'skilled' machinists and craftsman. There were several aspects to the craftsman identity. These were:

(a) involvement in all aspects of machining, rather than specialization in one aspect, such as programming or machine operation. This was expressed as assuming full responsibility for the part, from start to finish. Craftsmanship was tied to a sense of "ownership" of the part. In CNC work the part was regarded as a more authentic product of machining work than the program.

(b) The second aspect of craftsmanship is related to the first. It was the view that skilled work should involve doing some hands on work on the machine, or getting one's "hands dirty." Some involvement in metal cutting was viewed as a defining feature of craftsmanship.

(c) The third aspect was having opportunities to plan and execute challenging tasks. It was not enough to be involved in all aspects of a machining job. Some concern was expressed that the most challenging work was assigned to CNC machinists, in particular those working on Unigraphics programming and machine operation. However, machine operators expressed concern that the machine operation aspect was mostly routine.

(d) Finally, craftsmanship was also understood to be the capacity to consistently make good parts by working at high levels of tolerance (precision). The production of high precision parts depended on skill. It also depended on the right attitude to work, or what the informants referred to taking "pride" in, or "caring" about one's work.

In summary, the defining elements of craftsmanship were working with precision and taking pride in one's work, planning and executing challenging tasks, involvement in metal cutting processes (getting one's hands dirty), and assuming full responsibility for parts. Craftsmanship was the exercise of both skill and autonomy. Shaiken (1984) has noted that skilled machinists are protective of their right to use valued skills, and of autonomy in selecting machining procedures.

Craftsmanship was primarily understood in terms of individual skill and autonomy. This view was increasingly incongruous with changes in machining work at Makro, where work CNC work was organized around teams, and specializations, rather than individuals. Machinists who worked on conventional machining which was organized around individual all-round skill found that the more challenging work was assigned to Unigraphics programmers and CNC operators. Furthermore, the work of CNC operators, who machined the more complex parts was mostly repetitive because of the production of large batches of parts.

There was evidence of a change in how machinists understood craftsmanship, in the light of changes in the trade. Machinists, and in particular, CNC machinists, were forging a new sense of identity as members of a teams rather than individual craftsman. Working in teams entailed assuming collective responsibility for machining work and taking pride in the products produced by the collective rather than the individual. This did not come easily to skilled machinists, as the interviews indicated.

Beyond the responsibility for specific tasks that were allocated to specialized individuals, machinists as a collective assumed responsibility for the machining work at Makro as a whole. For example, programming was viewed as a machinist responsibility even by machinists who were working on conventional machines. Machinists collectively guarded against 'loss of work' to white collar workers, for example. Machining was their collective responsibility, over and above the distinctions and specializations. The overall responsibility for all aspects of machining defined their collective skill, and was a continued source of power and solidarity.

The ongoing changes in technology and job insecurities compelled the informants to see themselves as learners. Learning was a means for keeping up with changes in the trade and ensuring marketability. One of the reasons that John had moved to Makro was to look for opportunities to learn the new technologies. Bernard had taken the initiative to take classes in Unigraphics and as a result secured a programming job. One had to keep up with the 'new stuff' as he called it. Mark was learning machine operation with Matt. He wanted to ensure that he kept up with the changes too.

These changes define what I will term the *emergent* understanding of craftsmanship, in contrast to the *traditional* understanding, based on individual all-round skill. This was a more collective rather than individual understanding of craftsmanship. The changes in technology and associated changes in knowledge and skill generated an ongoing tension between craftsmanship defined in terms of individual skills and autonomy, and craftsmanship as collective skills, exercised by a technically sophisticated team, where skills were distributed and differentiated. The use of secondary and tertiary artifacts to control machining processes afforded this distribution and differentiation.

The data indicates that the changes in machining and associated changes in skills were encountered with some regret by the informants. The development of identity occurred in a societal and institutional setting that placed limits on individual choice in the development of identity as craftsman. There was a history of the machining activity tied to automobile manufacturing at Makro and the global market, which interacted with the an independent histories machinists exercising their skills in the machine shop. Skilled machinists at Makro were embedded in a historical activity that was changing. As Fay (1987) has argued:

> humans are embedded in situations which delimit their range of possible actions, and which determine the outcomes of these actions. There is a givenness to the conditions of their existence which stands in opposition to their desire for autonomy. (p. 197).

The study illustrates that the development of identity is tied to activity and “may in fundamental ways change from activity to activity, depending on the way, in each activity, the purpose, form, cultural tools, and contexts are coordinated” (Penuel and Wertsch, 1995, p. 84).

# CHAPTER 7

# CONCLUSIONS AND IMPLICATIONS

## Introduction

The purpose of the study was to examine the development of the knowledge, skills and identities of machinists and its relation to historical changes in the work activity of machining. In doing so, I addressed three interrelated problems. The first was how to formulate a model of worker development in the context of changes in machining. The effects of technological change have been characterized as an upgrading and downgrading of skills, or as upskilling and downskilling (Shaiken, 1984; Spenner, 1988; Ehn, 1988). Upskilling means that changes in technology cause an increase in the range of skill requirements and a higher average of skills are needed from the labor force. This embodies a form of technological determinism that is based on an inadequate empirical understanding of what happens to workers' learning and development in the process of technological change.

The second problem was to provide a satisfactory conceptualization of how knowledge and skills generalize from one situation to another. The relation between changing contexts and learning has been considered in terms of transfer, and primarily as the application of prior learning in new contexts. When viewed in this way, the introduction of new technology is seen as an opportunity for the *application* of prior knowledge in new situations, rather than the genesis of new knowledge or development. The construct of transfer does not adequately deal with how individuals develop in an ongoing activity such as machining that is transformed through the introduction of new technology.

The third problem that I addressed is the relation between the development of knowledge and skill and the development of identity. Research in educational psychology has tended to disassociate the development of knowledge and skill from considerations of identity. This is in part because of the school-based emphasis of educational psychology research and the dominant perception of schools as institutions where knowledge is disassociated from who one is, or is becoming. The separation is also influenced by a dominant cognitivist program that marginalizes self-consciousness, and assumes that "cognition can proceed without consciousness, for there is no essential or necessary connection between them" (Varela, Thompson & Rosch, 1993, p. 51).

## Machining as a Site for the Study of Learning and Development

Machining is an economically critical activity undergoing rapid technological change (Shaiken, 1984; Adler & Borys, 1989; Noble, 1979). Previous studies have highlighted its importance as a site for developing new conceptual models of worker learning (Martin and Scribner, 1991; Martin & Beach, 1992; Hungwe & Beach, 1995).

The introduction of CNC at Makro was a response to global competition in the automobile industry. Global changes were paralleled by organizational change and new corporate goals at Makro. Production was re-organized and streamlined. There were ongoing changes in machining technology and a corresponding re-organization of work into new work roles (e.g. CNC programmer and CNC machine operator). The focus of the study was on changes at the individual level in terms of knowledge, skills, and identity and how they related to changes in machining activity.

The psychological development of machinists occurred in a dynamic and complex societal and historical context. There were 'macro level' (societal, institutional) changes that occurred in parallel to 'micro level' changes (activity development, individual development). The 'macro' and 'micro' level changes were in some ways different aspects of the same reality. In other words, one level could not be fully understood without understanding the other. For example, changes in machine tools and the re-organization of work on the shopfloor was a local response to global competition and to trends in the industry as a whole. The study showed that there were multiple levels of changes in the situations that gave shape to psychological changes.

## Methodological Issues

The study was designed as a cross-historical comparison of machinists in distinct work roles. The roles had emerged as a result of the re-organization of the workplace, afforded by the utilization of new artifacts such as CNC program code. Comparisons of individuals in distinct roles were used to analyze historical transitions from one role to another, rather than tracking the same individuals over time as their machining roles changed. Cross-historical comparison was appropriate because the different machining roles mirrored different historical points of development of machining activity at Makro. The four roles that were identified were conventional machining, CNC machine operator, CNC programmer, and Unigraphics programmer.

Artifacts (e.g. CNC program code) were products of cultural evolution and derived their meaning from their historical use in activity (Wartofsky, 1979). Machining artifacts had referents (e.g. machining processes) that they were functionally tied to. Interpretants, on the other hand, were the *meanings* of artifact-referent relations made by machinist in specific work roles. The analysis of changes in knowledge and skill was based on the use of artifactual relations as the unit of analysis. I defined the artifactual relation as a semiotic triad of artifact, referent, and interpretant, and used changes in artifactual relations to describe changes in knowledge and skill.

By using the artifactual relation as a unit of analysis, I tied meaning to historical situations, rather than to intrinsic properties of objects/tools. I rejected the dualistic division between the individual psychological and cultural properties in situations of action. The cultural properties and the individual psychological properties were analyzed as different aspects of the same unit. The development and use of artifactual relations as a unit of analysis is a methodological contribution to the study of learning and development in technologically changing activities. I also examined changes in self-conception, or identity, over time for individuals in distinct machining roles that represented different historical points of development of machining activity at the site.

I now review the findings, beginning with changes in knowledge and skill.

## Changes in Knowledge and Skill

Changes in knowledge and skills were analyzed in terms of changes in artifactual relations during the transition from one role to another. Artifactual relations were structured around three types of artifacts that were used in the machine shop: primary, secondary, and tertiary. Primary artifacts were used to generate and regulate machining processes in conventional machining. Their defining characteristic was a non-arbitrary material relation to their referent. Examples of primary artifacts were dials and wheels that were manually controlled to generate machining processes. Other primary artifacts, such as sound, were also used to regulate machining processes. CNC program code was a secondary artifact because the relation between the code and machining processes was materially arbitrary, based on convention rather than the intrinsic properties of either the machining processes or the code. Finally, tertiary artifacts were used in Unigraphics programming. They were tertiary in the sense that they were based on the organization of other artifacts, and had no direct relation to machining processes.

There was no one way to describe changes in knowledge and skill between roles. Three categories of change were identified, namely continuity, transformation, and discontinuity. Continuity: In some aspects of machining, machinists in different roles used the same artifacts and referents to achieve equivalent outcomes. For example, primary artifacts such as *sound* and *colo*r of metal were used in both conventional and CNC machining to regulate the rate of metal cutting in some operations. Cases where the same artifacts and referents were used to achieve equivalent outcomes, but in different machining roles, defined a continuity of knowledge across machining roles.

Transformation: In some cases, machinists in different roles used different types of artifacts to achieve equivalent outcomes. The transition from one role to another, when it occurred, would therefore involve learning to use new artifacts tied to machining processes that were understood in terms of past experience. In one example, drilling operations were performed manually in conventional machining, using primary artifacts. The same process was regulated by program code in CNC work, which was a secondary artifact. The transition from conventional to CNC work, when it occurred, would involve a transformation of knowledge. Some knowledge and skill from one role would be carried over, but transformed in terms of meaning, because of the introduction of a different type of artifact.

Discontinuity: In some cases there were no common elements, in terms of artifacts and referents, between two roles. The transition from one role to another, when it occurred, would involve the use of artifacts and referents that were not part of the working history of the individual making the transition. Such examples were cited in some aspects of the transition from CNC manual programming and CNC machine operation to Unigraphics programming. Unigraphics programming, for example, did not involve metal cutting work on the machines, but rather the creation of code. *At some levels of this work,* neither the artifacts used, nor the output of that work had a direct link to the work carried out on the shop floor by CNC manual programmers. The transition from CNC work on the shop floor, to Unigraphics programming would involve the use of artifacts and referents, at some levels of the system, that were not part of the work history of the machinist making the transition. Discontinuity did not mean a rupture with the metal cutting history of machining which was the productive base of the machining activity. The meaning of individual artifacts relations was not isolated, but was tied to the machining activity and to the system of artifacts used in machining. However, the role of specific features, e.g. APT code used in Unigraphics programming, changed across different points in time. For example, APT program code was used as both artifact and referent at different points in time, depending on the goals of the task. The distinctions and relations between artifacts and referents were therefore localized and momentary, and not global classes of a permanent nature. In particular, the findings illustrated some fluidity in the role of artifacts and referents.

Artifacts, as is generally the case with semiotic signs, were to be understood in terms of the role that they played in activity, rather than in terms of their intrinsic properties. Leont'ev (1981b) makes the same point when he argues that signs attain their meaning through activity. These findings refine this point further, by demonstrating that the meaning of artifacts *within* as well as across activities can be fluid, rather than fixed, depending on the goals of specific tasks (Leont'ev, 1981b). I will elaborate on this point shortly. For the moment, I review the findings on identity.

## Changes in Identity

The study showed that new identities were *produced* in a changing machining activity, related to the development of knowledge and skill. The main historical changes in machine activity can be summarized as follows. First, there is a change from the use of primary artifacts to the use of secondary and tertiary artifacts. Second, there is a shift from all-round craft work to a differentiated skill structure based on work specialization. Third, in some cases, there was a shift from 'creative work' where tasks were challenging, to repetitive work using computer controlled tools. This shift created a psychological tension for machinists, a tension between tradition and change, new work and old work.

In considering the changes in identity I examined how the informants' self-conceptions as *skilled* workers developed over time as the machining activity changed. My use of the term *skilled* was based on ethnographic inquiry at the site. The informants invariably described themselves as 'skilled.' The term was used in two senses. In one sense, it was used to describe the level of competence of a category of machinists. In another sense, 'skilled' was also used to designate a status whereby a professional hierarchy was presumed. 'Unskilled' machining work was associated with 'production type shops' where workers produced large volumes of interchangeable parts for industry. 'Unskilled work' was described as repetitive and routine, while 'skilled work' was challenging and creative.

One quality of 'skilled' work was taking pride in one's work. In 'skilled' work, the financial rewards of work were important, but the quality of work was equally important. Another attribute of 'skilled' work was autonomy on the shop floor: working with minimum supervision from management. A third aspect of 'skilled' work was solidarity, or a sense of membership and commitment to a community of 'skilled workers', with an important history in the trade. Machinists had a historical understanding of their trade which provided the basis on which they interpreted their work experiences in a changing trade. By historical understanding, I mean an understanding of the history of their trade, its work traditions, and their place in it. Identity developed in the tension between new and old machining work. The relation, as diagrammed in figure 33, is semiotic, based on a triad of a sign, referent and interpretant (see for example, Silverman, 1983). In other words, machinists interpreted new work roles (as a sign), based on some historical understanding of skilled work (as referent), and came to some understanding (or self-concept) of themselves as skilled workers in a changing workplace. Put differently, changes in identity refer to changes in the meaning of skilled machining work, over time, for individuals experiencing the changes.

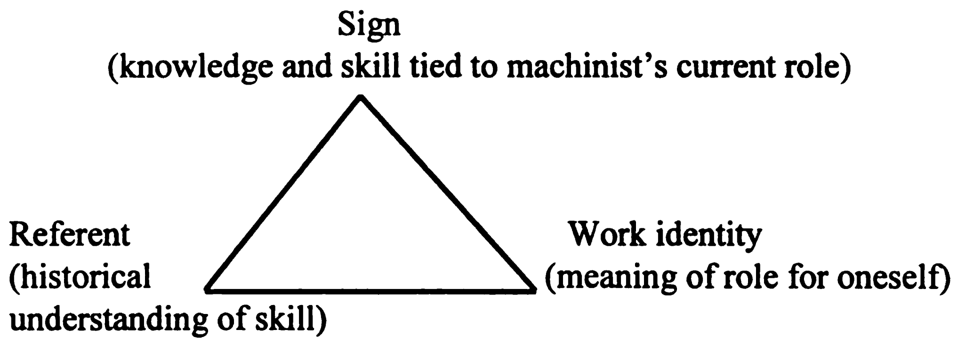


Figure 33: The development of identity

If, as I claim, machinists at Makro had a historical understanding of their trade, it raises the question of how this understanding arose? My observations suggest that their understanding came from their training when they were initiated into the trade. The notion of skilled work as all-round skill was deeply embedded in the apprenticeship program. An interview with Tom, who was completing his apprenticeship program, confirmed that the apprenticeship training program was in many ways very traditional. Tom had to complete a minimum of eight thousand hours of practical training. Most of the training was on conventional machining, with some CNC work. There were one hundred and sixty hours of welding, one hundred and sixty hours of heat treatment, and one hundred and sixty hours of blacksmith work. The goal of the program was to produce an all-round machinist skilled in all aspects of the trade. There was a tension between apprenticeship training based on all-round skill and the growing specialization in the trade. It is within these contradictory tendencies that the identities of machinists developed as they sought to make sense of their changing experiences.

Machinists interpreted changes in their work in terms of craftsmanship. Briefly, the defining elements of craftsmanship were working with precision and taking pride in one's work, planning and executing challenging tasks, involvement in metal cutting processes (getting one's hands dirty), and assuming full responsibility for parts. Craftsmanship was the exercise of both skill and autonomy. The findings indicate a tension between a historical craftsmanship identity defined in terms of individual skills and autonomy, and an emergent craftsmanship identity defined in terms of differentiated and complementary skills exercised by a technically sophisticated team.

While there were changes in identity within the changing activity, such changes were a re-construction of historical identities. For example, Unigraphics programmers whose work did not involve metal cutting continued to believe that the part, rather than the program, was the defining product of machining work. In this sense, there was no rupture with the tradition, but a transformation of a shared understanding of the history of their trade and their place in it. These changes define the emergent craftsmanship identity, in contrast to a traditional craftsmanship based on individual skill and autonomy.

Assertions of identity involved valuation of work experiences. The assertion of identity functioned, in part, as a political act. For example, workers asserted solidarity and rights to certain kinds of work experiences. Machinists at Makro collectively negotiated the right to program CNC, which had initially been taken from them. At a more individual level, there were expressions of frustrations with some work roles, especially CNC machine operation, which tended to be categorized as 'unskilled' work. In some cases, these frustrations resulted in role changes, as workers sought more satisfactory work experiences. In this study, the analysis of development in terms of identity opened new avenues for a critique of changes in machining at Makro. A narrow focus on knowledge and skill may in fact miss the broader significance of changes in work for the development of individuals. Changes in worker identity should be an important consideration for policy formulation during times of rapid societal change, where changes generate uncertainties and potential conflicts between stakeholders.

The changes in machining described in this study were both rapid and quite recent, having occurred within the working history of the skilled machinists interviewed and observed at Makro. Thus there was an overlap between the changes in machining and the working history of individuals. The study therefore affords the opportunity to examine ways of characterizing individual change in relation to activities that are themselves changing rather than static.

Beyond the specific findings on knowledge, skill, and identity development that I have discussed, the study has implications in two other related areas, namely how we conceptualize the relation between individual development and activities that are changing, and the relation between activity systems and new technology. I will discuss each of these in turn.

## Individual Change in Relation to Activities That Are Changing

Two central issues have been established. First, there were cognitive changes associated with the introduction of new technologies in an ongoing activity. Second, the changes in knowledge and skill could not be understood solely as properties coming from the new technology. The cognitive consequences of using new technology depended, not only on the way the tools were used, but on the histories of the individuals involved, and the organization of work at the site. The relationship was not technologically deterministic, as implied by the concepts of upskilling and downskilling. As Martin & Scribner (1991) put it:

> A cognitive analysis of the impact of new technologies...must be concerned with the varieties of ways such technologies are drawn into ongoing activities" (p. 583).

The motive force for developmental changes was not derived from an isolated individual autonomy, or environmental determinism. The agency for the changes originated from a joint relationship between the changing activity and individual intentional commitments. The findings indicate what Gose (1989) calls "a limited, self-directed movement within existing cultural forms as they develop historically" (p. 117).

It was necessary to look at the societal aspects that give rise to, and are in turn sustained by the activities in which the work of individual is situated for psychological development. The properties of technology only have:

> potential effects on social and psychological processes, but the realization of those effects in turn is dependent on existing, historically created social and psychological factors. The relationship is reciprocal, not one way (Martin & Scribner, 1991, p. 585)

As machining activity changed, psychological functions changed so that workers could continue to act with relevance within a changing reality. Changes in machining activity were a 'catalyst' for changes in psychological functions. In other words, the changes would not have occurred, but for the changes in machining activity. The study highlights the social origins of cognitive functions.

While the focus of this study was on a changing activity and individual development, it is important to note that the 'stability' of environmental factors still involves a changing relation. Vygotsky makes this point forcefully, using child development as a case in point:

> Even when the environment remains little changed, the very fact that the child changes in the process of development, results in a situation where the role and meaning of the environmental factors, which seemingly have remained unchanged, in actual fact do undergo a change, and the same environmental factors which may have one meaning and play a certain role during a given age, two years on begin to have a different meaning and to play a different role because the child has changed; in other words, the child's relation to these particular environmental factors has altered (Vygotsky, 1994, p. 339)

In some ways, this argument is beyond the scope of this study. However, Vygotsky's argument is important as it calls for sophisticated conceptualizations of the relation between activity and individual, *as a general rule.*

I will now discuss the implications of the study for conceptualizing the relation between activity systems and new technology.

## Relation Between Activity Systems and New Technology

By activity, I mean societally motivated phenomena that exists to meet specific needs (Leont'ev, 1981). Machining is an example of such an activity. Activity, when so construed, is a coordinating entity that organizes the use of technology and the conditions of its use in order to realize specific societal purposes. The findings show that the introduction of new technologies contributed to the changes the machining activity. In particular, the introduction of computer technologies laid the basis for a radical re-organization of production. It made it possible to re-organize machining work into a programming and machine operation aspect, carried out by different individuals in different locations and different times.

The changes in machining activity were tied to institutional and societal changes. There was a trend toward standardization of parts to meet the potentially conflicting goals of raising the quality of production and containing the development costs of new automobile models. Global changes were paralleled by local institutional changes that included new corporate goals and organizational change. At the machine shop level, there were changes in machining technology, and the introduction of training programs tied to emergent corporate goals. The development of machining activity therefore occurred in a social and historical context of changes.

Changes in technology were a necessary condition for the changes in activity that took place. However, this was not a deterministic relation, because there were a range options that were available about how to organize the use of the technology in the process of adoption. In other words,

> new technology provides, in theory, and increasingly so in reality, options as to work organization and human resources development. There is no technological determination in terms of a given technology requiring a given work organization and skill structure. (Bengtsson, 1991, p. 1088-89)

The study also showed that the meaning of specific tools was not fixed, but depended on how they were appropriated and used in specific situations. For example the function of APT code (which is part of the Unigraphics system) changed in different situations. In some instances it functioned as an artifact when used as a tool to generate CNC program code. In other situations, it was of interest as a product of operations on the Unigraphics interface. This example indicates that the meanings of objects/tools depended on their use in specific situations and were potentially fluid. In other words, the same objects/tools could assume different meanings within the same activity. Learning, therefore, involved coming to understand and make use of the varied ways in which the same reality could be used in activity. Machinists had to learn to use reality in a flexible and fluid manner. This fluidity raises questions for a theory of transfer. To which reality does a theory of transfer refer to when the meaning of the same object/tool meaning can be flexible? Models of upskilling/downskilling are also inadequate for dealing with flexible meaning because they assume that technology has meaning solely in terms of its intrinsic properties, rather than in terms of socially mediated purposes. What is needed is an understanding of *how* new tools are used in situations to realize specific ends.

Beyond the theoretical issues discussed in the study, there is the practical question of how these findings can be used to facilitate transitions in an industry that continues to experience rapid change.

## Options for 'Improving' Transitions in the Workplace

Interviews with management and machinists at Makro indicated that continuous changes in machining technology were anticipated. The thrust of the changes would be towards greater automation of machining processes in order to reduce the duration of the design and development process. The ongoing changes in machining made it necessary to develop ongoing training programs. Prior to the introduction of CNC technologies, machining was a trade where the knowledge and skill base was stable, and the training provided through the apprenticeship program was adequate to prepare a machinist for a life-long career. The ongoing changes in the trade now made it necessary for machinists to have access to training throughout their careers. The findings highlight the importance of investing in training programs in a changing workplace.

The findings indicated a tension between work specialization and a craftsmanship identity. This was particularly important for machinists working as CNC machine operators, where the work tended to be repetitive. It is questionable whether CNC machine operation, as a work role for *skilled* machinists, was sustainable in the long term, if the trend towards automation and repetitive work continued as anticipated. In principle, the more routine aspects of CNC machine operation could be done by less skilled workers. Management at Makro was interested in that option. However, such an initiative was likely to be opposed by the machinist union which was wary of 'loss of work.' In summary, it appeared that changes would continue to take place at Makro, and in the industry as a whole, but their form was unpredictable and would depend on negotiations between workers and management.

With regard to knowledge and skill, the main difficulties in transitions appeared to be from CNC machine operation and manual programming, to Unigraphics programming. Warren, who was a CNC machine operator, commented on the transition to Unigraphics programming as follows: "You have to go to school, training, whatever, and I haven't taken any classes on it." In a separate discussion, Mark who was also a CNC machine operator, had this to say:

> I don't understand Unigraphics at all...But other than what I have seen in there, it looks like they can do things 3-dimensionally and rotate on the screen. You know what I mean. So its a totally new system that I would have to learn it to comment intelligently. But they say it's more efficient to go that route. So that's why they switched over (Mark, 10/24/96, p. 3)

As indicated in Chapter 5, the transition from CNC machine operation and manual programming to Unigraphics programming involved both transformations and discontinuities in knowledge and skill, depending on the features of Unigraphics programming that were in use, and the history of the individual making the transition. The discontinuity occurred because there were two features of the Unigraphics system that were not used on the shop floor. These were the Unigraphics interface and APT program code that was generated by operating on the interface. When these were used in relation to each other, one as artifact and the other as referent, machinists coming from the shop floor would be severely handicapped interpreting the process. A successful transition from the shopfloor to Unigraphics programming would require the bridging of *discontinuities* created by the introduction of artifacts and referents that were not part of the work history of machinists working on the shop floor. This could be facilitated by providing an initial experience in APT programming, separate from the Unigraphics system.

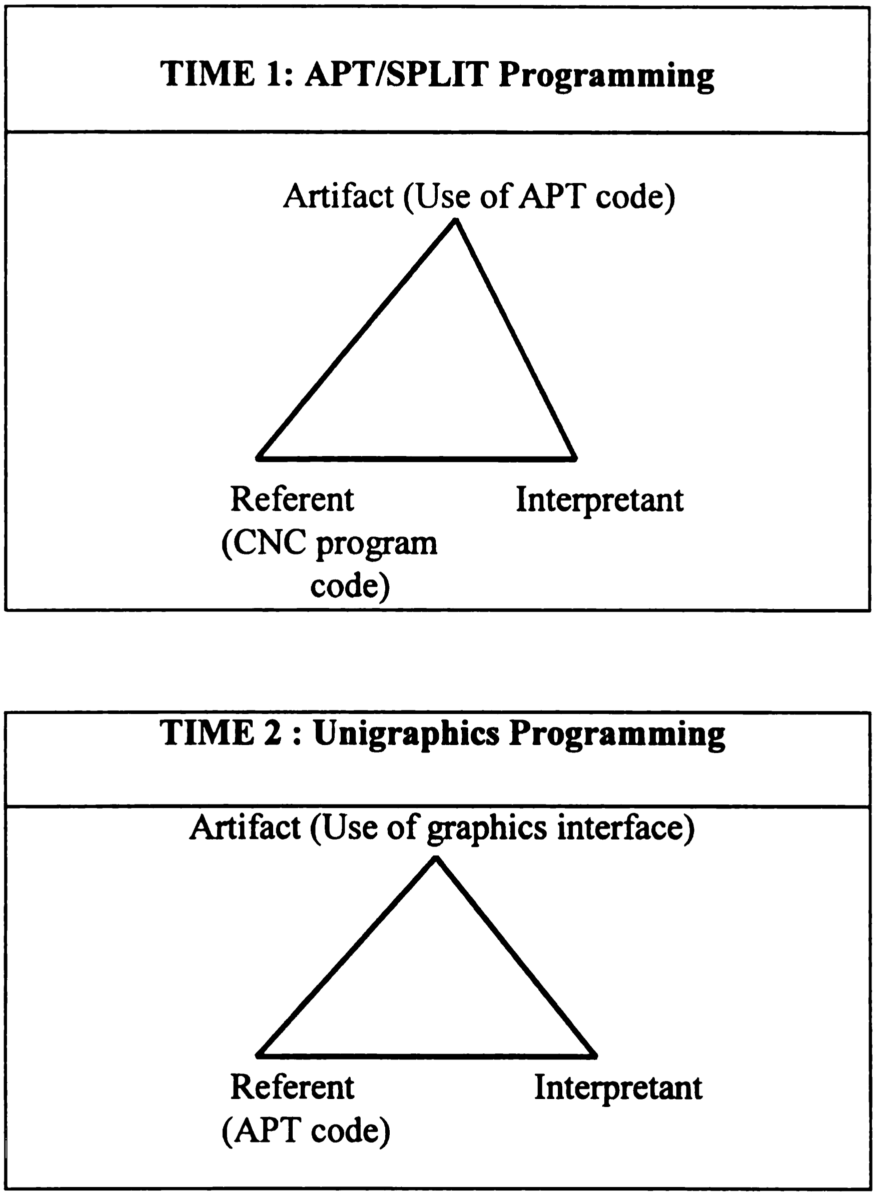


Figure 34: Two stage transition to Unigraphics programming

Alternatively, training could be provided in an APT equivalent program such as SPLIT. In the first phase, machinists with prior experience with CNC program code would use APT to generate CNC program code. This would provide them with an opportunity to use APT code with a referent that they understood. They would come to understand APT program code. Once they understood APT program code, the next stage would be to work on a Unigraphics interface, using it to generate APT code. At this stage, they would use their understanding of APT to interpret their work on the Unigraphics interface. The strategy would effectively break the transition into two phases, using an intermediate transition that is based on a transformation of knowledge and skill. Figure 34 summarizes the transitions that would be involved. The option to use APT/SPLIT to machine parts existed on the shop floor, but was phased out when Unigraphics was introduced.

## Implications for Future Research

The study provides an alternative conceptualization of how knowledge and skill generalize from one situation to another. The relation between changing contexts and learning has been considered in terms of transfer and the application of prior learning in new contexts in other studies. Changes in knowledge and skill have been explained in terms of changes in the environment, or alternatively in terms of individual changes 'in the head.' This imposes meanings on situations apriori, without reference to the historical activity that gives direction to work and the individuals who interpret work situations. This approach is based on what Latour (1999) calls an "in there" psychology" that assumes an "out there nature" (p. 22).

In other studies, upskilling/downskilling have been used as a model to describe changes in knowledge and skill tied to changes in technology. For example, the US Department of Labor's Dictionary of Occupational Titles (DOT) uses a range of measures and aggregates the data to determine skill requirements in changing workplaces. Skills are measured directly or quantitative measures are inferred using indirect methods (Spenner, 1988). I have questioned the validity of this as a model for the development of knowledge and skill for several reasons. First, the model does not focus on individuals but changes in job content. In any case, there are problems in referring to psychological development in terms of changes in 'quantity' as is implied by the terms upskilling and downskilling. My findings indicated that there was some re-organization of cognitive processes tied to changes in technology. In other words, there were changes in the properties and structure of cognitive processes based on changes in artifactual relations. I have therefore drawn a distinction between quantitative changes that are incremental (i.e. more or less of the same), and qualitative changes that are derived from structural changes in cognitive processes. I have therefore found it problematic to use upskilling/downskilling as a model for individual learning because the model is blind to qualitative changes. A further consideration is that if downskilling is used to describe changes in knowledge and skill, this would imply a decrease in the knowledge and skill of an individual due to changes in technology. That is unsatisfactory. There is no compelling reason for assuming that a particular individual's capabilities would decrease because of changes in job content. The findings indicate that workers who believed that their capabilities exceeded the knowledge and skill demands of their job experienced frustration and identity dilemmas, which is quite different from saying that they were deskilled.

The findings are supportive of the relatively recent view that learning should be studied more broadly in terms of the development of competencies as well as changes in self-conceptions (Litowitz, 1993; Packer, 1993; Varela, Thompson & Rosch, 1993). Litowitz (1993) for instance argues that "mastering activities and establishing a sense of oneself are not two distinct lines of development but are, rather, entwined in complex ways--that one can not 'study' one without the other" (p. 184). Varela, Thompson & Rosch (1993) believe that "cognition and consciousness--especially self-consciousness--belong together in the same domain."

The problem of 'transfer' that I addressed is both important and enduring. Dewey, for example, posed this as the educational problem of how to ensure that what is learned "in the way of knowledge and skill in one situation becomes an instrument of understanding and dealing effectively with the situations which follow" (Dewey, 1963, p. 44). More generally, he was interested in the question of how students could "become acquainted with the past in such a way that the acquaintance is potent in appreciation of the living present" (p. 23). Beyond the specifics of the 'transfer' question, there is the larger issue of the relation between environmental and individual factors in learning and development. One strand of educational theory has tended to subordinate the environment or context of education to those conditions that are presumed to reside in the individual being educated. Another strand has worked from the opposite premise. Dewey (1963) described the history of educational theory as "marked by opposition between the idea that education is development from within and that it is formation from without" (p. 17). This study makes a methodological contribution to the study of learning and development by introducing and using units of analysis that include both the environment and individual capacities. Further research in this direction should be encouraged. My focus was on learning and development within a changing activity. Other research can track the use of artifacts (texts, symbol systems, technologies) in transitions across institutions such as the family, work, and school, where there are presumably changes in artifactual relations because of changes in roles or the referents. We will be better able to understand and support human development in relation to cultural experience through such research.

# APPENDICES

# APPENDIX A

# INTERVIEW QUESTIONS

## INTERVIEW QUESTIONS

(a) Machinists

1. Describe to me, in as much detail as possible, the story of how you became a machinist.

2. Could you tell me your educational and training history, since leaving high school.

3. Could you tell me your working history, beginning with your first job.

4. Why did you become a machinist?

5. How have you seen machining change since you entered the trade?

6. Machining has sometimes been described as dirty and dangerous. Would you describe it this way as well. Does this apply to CNC as well?

7. How has the work in this machine shop changed since you came here?

8. Do you think that the introduction of computer control in machining has changed the status of the trade? If so how?

9. How has the introduction of CNC technologies changed what you need to know to be a good toolmaker. Do you think that these changes are positive? Why?

10. For programmers and CNC machine operators: If a program crashes, and tools or a whole machine is damaged, who is responsible?

11. Do you believe that programming and operation should be two separate job categories?

12. What changes in machine tools do you see occurring in this machine shop over the next years? How do you think those changes will influence your own work?

13. What changes in products do you see occurring in this machine shop over the next years? How do you think those changes will influence your own work?

14. Are there areas of machining that you would like to learn more about? Why? What would be the best place to get that experience?

15. Are there work experiences within this shop that you would like to have now, but can not? Why?

16. Are there other sections within this work site that you would like to work in, in future? If so, why?

17. What do you like about your present job?

18. What do you not like about your present job?

19. How well do you think that machinists have been able to hold good incomes over the years? Do you see that changing in the future?

20. Would you advise a younger person to go into the trade? Why or why not?

21. How likely is it that you will leave this company and move to another machine shop at some point in your career? How have your expectations on this matter influenced the choices you have made about your learning on the job?

(b) <u>Machine Shop Supervisor</u>

1. There are three types of machine tools in this machine shop: 1) conventional machines, 2) a small CNC machine operated by one person, and 3) large CNC machines for which there are specialist programmers and operators. What is the contribution of each of these technologies to the work in this shop?

2. What is the reason for having a programmer/operator distinction in the machine shop? Is that going to continue to be the case in future?

3. What was the reason for the recent introduction of smaller CNC machines which are programmed and operated by one individual? How important is that technology going to be in future?

4. Why are all workers paid the same regardless of years of service, and type of skill? Is that how you would like to have it?

5. How would you like to see the machining technology in this shop changing over the next ten years? Do you think that will be possible? Why or why not?

6. How has the type of work that the machine shop does changed over time? Are you happy with the changes?

7. What changes do you anticipate in future? Why?

- Is there anything that you need to do about machinery to plan for those changes?

- Is there anything that you need to do about worker knowledge and skills to plan for those changes?

APPENDIX B

OBSERVATION SCHEDULE

OBSERVATION SCHEDULE

Date:
Beginning time: End time:

Informant:

Machine type:

Brief description the job:

Was there a blueprint/sketch (check one)

Source of job:

| SUMMARIES OF TALK<br><br>(The main body of talk was be recorded through audio tape) | DESCRIPTION of machinist's actions: planning, setting up, tramming, editing program, etc. | USE OF ARTIFACTS: gestures, blueprints, dials, knobs, program code etc |
|---|---|---|
| | | |

# APPENDIX C

## UNIVERSITY COMMITTEE ON RESEARCH INVOLVING HUMAN OR ANIMAL SUBJECTS

# UNIVERSITY COMMITTEE ON RESEARCH INVOLVING HUMAN OR ANIMAL SUBJECTS

MICHIGAN STATE UNIVERSITY

October 11, 1996

TO: Kedmon Hungwe
1310-C University Village
East Lansing, MI 48823

RE:

| | |
|---|---|
| IRB#: | 96-597 |
| TITLE: | BECOMING A MACHINIST IN A CHANGING INDUSTRY |
| REVISION REQUESTED: | N/A |
| CATEGORY: | 1-C,D |
| APPROVAL DATE: | 10/09/96 |

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete. I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the UCRIHS approved this project and any revisions listed above.

**RENEWAL:** UCRIHS approval is valid for one calendar year, beginning with the approval date shown above. Investigators planning to continue a project beyond one year must use the green renewal form (enclosed with the original approval letter or when a project is renewed) to seek updated certification. There is a maximum of four such expedited renewals possible. Investigators wishing to continue a project beyond that time need to submit it again for complete review.

**REVISIONS:** UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. If this is done at the time of renewal, please use the green renewal form. To revise an approved protocol at any other time during the year, send your written request to the UCRIHS Chair, requesting revised approval and referencing the project's IRB # and title. Include in your request a description of the change and any revised instruments, consent forms or advertisements that are applicable.

**PROBLEMS/ CHANGES:** Should either of the following arise during the course of the work, investigators must notify UCRIHS promptly: (1) problems (unexpected side effects, complaints, etc.) involving human subjects or (2) changes in the research environment or new information indicating greater risk to the human subjects than existed when the protocol was previously reviewed and approved.

If we can be of any future help, please do not hesitate to contact us at (517)355-2180 or FAX (517)432-1171.

Sincerely,

David E. Wright, Ph.D.
UCRIHS Chair

DEW:bed

cc: King D. Beach

OFFICE OF
RESEARCH
AND
GRADUATE
STUDIES

University Committee on
Research Involving
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