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The effectiveness of computer simulation in training programmers for computer numerical control machining

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The effectiveness of computer simulation in training programmers for computer numerical control machining

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CHAPTER I. INTRODUCTION

When man learned that mechanical power could be applied to driving tools, the Industrial Revolution was ignited. During the Industrial Revolution, the evolution of machine tools was greatly accelerated. The subsequent desire for increased productivity then led to the recent development of automatically controlled machine tools.

Numerically controlled machine tools, commonly called as numerical control machine tools, were first developed in 1952 at the Massachusetts Institute of Technology (MIT) laboratories. In 1949, the United States Air Force sponsored research to develop machine tools that could be programmed to produce parts of different sizes and dimensions automatically. This research program was initiated in response to the increasing cost and complexity of aircraft parts.

As a result, a numerical control machine tool was developed that could produce a number of different complex parts on the same machine by simply changing a computer program and retooling. The numerical control machine tool also reduced the chances of human error by producing each piece in exactly the same way.

There are two major components of numerical control machine tools. One is the electronic controller, and the other is the machine tool itself. The electronic controller has pre-programmed commands that tell the machine tool what to do, when to do it, and where to do it.

For example, the program could contain commands that could cause the machine to move a drill bit to a certain position over a workpiece, turn the drill on, and then drill a hole. It may then command the drill to withdraw, move to another location, drill another hole, and to continue this procedure, drilling as many holes as instructed. If holes of different size diameters are needed, the controller could command the machine tool to automatically change drill sizes.

Various other machine tools for turning, milling, planing, sawing, forming, shaping, reaming, boring, and grinding could also be incorporated with the numerical controller.

The more recent advent of Computer Numerical Control (CNC) systems has resulted in more powerful applications of computers in manufacturing. But what are the differences between Numerical Control (NC) and CNC?

The term numerical control means that a machine tool can be operated automatically by means of a medium (a paper tape, for example). The tool will do only what it is programmed to do by the tape which controls it. But the term Computer Numerical Control (CNC) machine refers to a microcomputer which is joined to an NC machine. This makes the machine more versatile because it can store information in a memory bank. This memory bank retains what is on the NC tape and repeats it without the tape having to be rewound each time. NC machines and CNC machines are different in their memory function and different in ways to make a similar new program. In an NC machine, it is necessary to make a new tape for a new program, even if the new program is similar to the old one, while, in a CNC machine, the minor change of the existing program in the memory bank may be enough to make a new program. A CNC machine tool costs more, but the operator has greater flexibility in producing the part. For example, if a tool gets dull, the operator can manually change the feed rate of the cutter to maintain a smooth cut; if a tool gets worn, the operator can manually key in compensation values to maintain the accuracy.

Due to manpower needs in the manufacturing industry, computer numerical control machine tool operation is expected to be the fastest job-growth area among machine tool operators in the next decade. This growth is needed because of world-wide production competition, continuous advances in machine technology, and the demand for greater precision and higher quality products at a lower cost. The result is a growing use of computer numerical machine tools.

Thirty years ago, only large companies could afford numerical control machines. The aerospace industry was the largest customer of NC machines. Today, large companies still retain the majority of NC and CNC installations; however, many medium and small enterprises and machine shops now must purchase CNC equipment in order to maintain good competitive ability.

The development and application of advanced manufacturing technology is often referred to as the "Second Industrial Revolution" and is perceived as being critical to the survival of the manufacturing industry. At the heart of advanced manufacturing technology are computer numerical control machines. The successful application of CNC machines is a key element of manufacturing automation, especially in the area of metal machining.

According to the Bureau of Labor Statistics, among machine tool operators, the demand for numerical control machine tool operators is relatively high (Figure 1). The number of numerical control machine tool operators was expected to rise by about 45% in the 1982 to 1995 period.

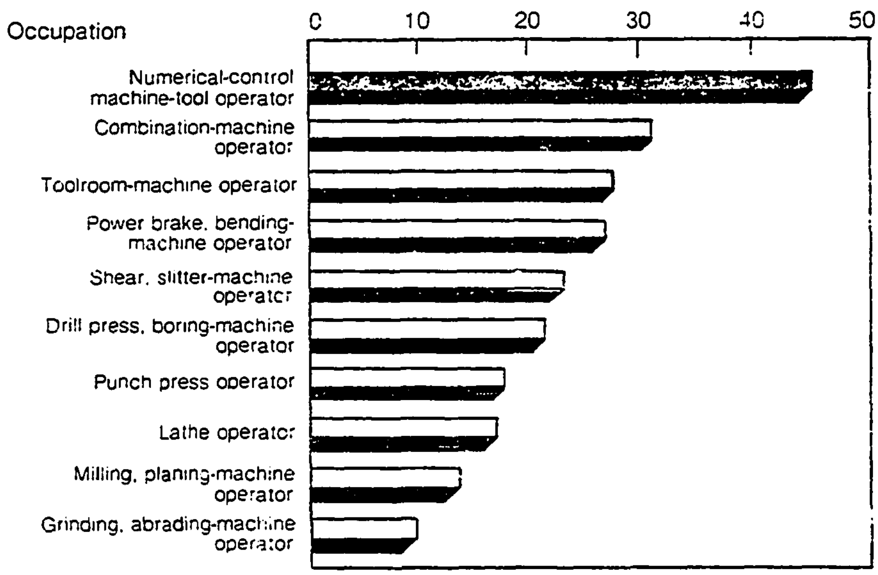

Figure 1. Projected percent change in machine operators employment, 1982-1995

To prepare young students for a career within modern industry, it is advisable for educational programs to include both theory and practice of the CNC technology.

Basically, vocational technical education programs should be able to supply the needs of the society and the community. In an industrialized community, schools should be able to supply qualified skilled workers, technicians, or engineers for industry. There is an urgent need for the implementation of numerical control curricula to high schools, community colleges, and universities.

In the past ten years, CNC curricula have spread from the college and university levels to some senior as well as junior high schools. Although there are still many schools that do not have CNC equipment, in the foreseeable future these schools will be able to access CNC machines. It is obvious that there is a growing awareness of the need for education in the field of CNC technology.

The CNC machine is still a high-priced equipment item for local schools, even though the price has been gradually decreasing. How to make a CNC machine tool more effective as an instructional device is the responsibility of educators.

The other aspect an educator must take into account is the issue of safety in the use of CNC machine tools, as any mistake or programming error could cause very serious damage to the machine tool or cause personal injury. Verifying the accuracy of the prepared CNC programs before sending them into the CNC machine is of vital importance -- one of the most important jobs for the CNC lab instructors.

The CNC program simulator is designed specifically for CNC trainees. This is a microcomputer which is used to simulate the CNC program. The simulation package can detect possible mistakes in the program, and can display the tool path on the computer screen. The advantage of the CNC program simulator is that, by checking a CNC program on a microcomputer screen before sending the program to a CNC machine tool, the student and the teacher can be sure that the program is error-free; this prevents mistakes happening on the CNC machine tool.

For most of the local schools or technical training centers, the budget is always limited. It is not likely for a school to have more than one CNC machine of the same type. That means probably not every student has a chance to run a complete program on a CNC machine tool. However, low-priced microcomputer simulators can reduce the time students use on the CNC machine tool. If students write programs and simulate them on simulators instead of on a CNC machine tool, the student will then have more time to share on an available CNC machine tool.

The experimenter was interested in the effectiveness of the CNC machine tool simulators. The question to be answered is: "Is there any achievement difference between a computer-assisted program verification approach and an instructor verification approach?"

Personal computers are now relatively inexpensive pieces of equipment. But, for some schools, it is not economically possible to obtain a sufficient supply of simulation computers. In this case, probably more than one student will be expected to share a computer. According to Johnson, Johnson, and Stanne (1985):

> One student to a computer is the usual rule ... Many teachers and software designers automatically assume that all CAI should be structured individualistically. The assumption that learning works best when one student works with one computer remains largely unquestioned. The possible use of computer-assisted cooperative ... instruction is largely ignored. (p. 668)

So, the next question to consider was: "Can we identify any significant difference in achievement between the students who work alone and the students who work in groups of two?"

Statement of the Problem

The problem of this study was to investigate the effectiveness of different instruction methods, including computer simulations in teaching programming skills for computer numerical control machine programmers in metal-working laboratories.

Purposes of the Study

The purposes of this study were (1) to investigate the effectiveness of microcomputer simulation and (2) to compare the difference in skill mastery and in the need for a teacher's assistance among the students who work on a microcomputer with a partner, those who work on a microcomputer individually,and those who do not use a microcomputer in learning CNC programming skills.

Objectives of the Study

The objectives of this study were:

1. To investigate the differences in the mastery of programming skills between students who use a microcomputer individually to simulate CNC programs and students who do not use a microcomputer simulation package.
2. To compare the mastery of CNC programming skills between students who use a microcomputer simulator with a partner and students who use a microcomputer simulator alone.
3. To investigate the possible effect of the previous experiences in computer concepts, mathematics, and mechanical drafting classes upon the mastery of programming skills for a CNC machine.
4. To compare the need for assistance in learning programming skills among the students who use a microcomputer simulator with a partner, those who use a microcomputer alone, and those who do not use a microcomputer simulator.

Assumptions of the Study

This study was based upon the following assumptions:

1. Computer numerical control is an important concept for students majoring in mechanical design and manufacturing in technical schools.

2. The subjects who completed this experiment did not have prior instruction in the CNC concept.
3. The subjects involved in this study had knowledge in trigonometry.
4. The subjects who were selected in this study have already developed skills and had knowledge of traditional milling machine operations.
5. Students in technical schools have had mechanical drafting classes before taking a CNC programming class.
6. The procedure for selecting the research subjects was valid and the results could be generalized to the general population.
7. Any uncontrolled variables of the study were uniformly distributed over the entire sample.

Limitation of the Study

The participating classes of this study were limited to those students who had a CNC class during the spring semester of the 1988-1989 school year at National Yunlin Institute of Technology in Taiwan.

Procedure of the Study

The procedure of the study consisted of the following:

1. Reviewing related literature concerning teaching

strategies in programming for computer numerical control machine tools.

2. Reviewing literature concerning the effect of group size on CAI classes.
3. Identifying the population and sample for the study.
4. Developing pretest and posttest instruments.
5. Gathering research data.
6. Analyzing the data through the SAS package.
7. Interpreting the findings.
8. Writing the summaries, conclusions, and recommendations.

Definition of Terms

1. Kuder-Richardson Formula 20

   The Kuder-Richardson Formula 20 is based upon the correlation between a test composed of K observed items and a theoretical (unobserved) parallel test of k items parallel to those of the observed test. The Kuder-Richardson Formula is expressed as

$$rI,II=(1-\Sigma Sg^2/Sx^2)\ /\ (k-1)$$

   Where K is the number of test items, Sx^2 is the total variance of the test, Sg^2 is the item variances.

2. Analysis of Variance (ANOVA)

   An exploratory test designed to detect evidence of any differences among a set of group means. If there is sufficient evidence, the sizes of the differences between various pairs of means can then be estimated.

3. Hawthorne Effect

The term Hawthorne Effect refers to any situation in which the experimental conditions are such that the mere fact that the subject is participating in an experiment or is receiving special attention tends to improve performance.

4. John Henry Effect

The John Henry Effect refers to a situation often found in educational research in which a control group, when placed in competition with an experimental group using a new method or procedure that threatens to replace the control procedure, performs above its usual average.

5. Computer concepts class

The course contents of computer concepts class include the basic concepts of microcomputers, minicomputers, as well as main frame computers, and the basic programming skills in BASIC language.

5. Simulation

Simulation is the representation of a system by a device that imitates the behavior of that system. A CNC program simulation is the representation of cutting tool movement on a microcomputer screen.

6. Computer numerical control (CNC) machine tool

   A computer numerical control machine tool is a machine tool which is controlled by a computerized numerical controller. A program of machine operating commands which is comprised of organized and documented symbolic codes, is necessary to command the machine movement.

CHAPTER II. REVIEW OF RELATED LITERATURE

This review of related literature focuses upon three major topics relevant to the problem being studied. They are the previous works related to (1) the effectiveness of computer assisted instruction in classroom work, (2) comparisons of teaching methods in training CNC programmers, and (3) group size effect upon the computer-assisted learning process.

The Effectiveness of Computer-Assisted Instruction Upon Classroom Work

Computers were expected to serve as infinitely patient tutors, and as scrupulous examiners. Teachers would be free to work individually with their students; students would be free to follow their own paths and learning schedules.

Chambers and Bork (1980) sponsored research to assess the current and projected usage of computers in U. S. public secondary and elementary schools, with special emphasis on the use of computers in computer-assisted learning. Part of the overall assessment was to determine factors impeding the use of computer-assisted learning so that guidelines could be established to facilitate computer use. A sample of 974 school districts was selected to represent the total population of U. S. public school districts.

Analyses of collected data indicated that ninety percent of the districts were currently using computers in 1980. Instructional usage was reported by seventy-four percent. The figures for projected computer usage in the classroom were much higher than the current figure.

According to the report, major usage in the secondary schools occurred in the areas of Mathematics, Natural Sciences, Business, and Language Arts. Most usage involved drills and practice. However, projections indicated an increasing use of computers in Social Sciences in secondary schools, growth at the elementary school level, and a shift from drills and practice to tutorials and simulations.

Many studies have been conducted in an attempt to determine the effectiveness of computers in education. Some investigators concluded an equal or more positive result for computer-assisted instruction in classroom work than traditional instruction.

Thomas (1979) conducted research regarding the effectiveness of computer-assisted instruction in secondary schools. He concluded that computer-assisted instruction leads to achievement levels equal to or higher than traditional instruction, as well as to favorable attitudes and significant savings of time and money.

Milton Taylor's research (1987) focused upon the implementation and evaluation of a computer simulation game in a university course. In his study, the experimenter randomly assigned college students to a treatment group and a delayed treatment group. He compared lectures combined with the computer simulation game to lectures alone by testing a broad range of measures (attitudinal, attendance, achievement, and information seeking behavior).

He concluded that students responded favorably to the computer simulation game. He also found that students who participated earlier in the semester using the computer simulation game responded more favorably to the computer simulation game than those who participated later.

Elizabeth Ann Steinick (1985) conducted research to evaluate the effectiveness of computer-assisted instruction in training vocational agriculture instructors to perform numerical calculations related to swine production. The pretest-posttest control group design was utilized. A survey was used to collect additional data used in determining other factors related to the instructors' abilities to learn the material by computer assisted instruction. The test contained the swine analysis and sow productivity indexing. One of Steinick's major discoveries was the following:

> When comparing the conventional method of teaching against microcomputer-assisted instruction, the control group scores on the concept portions of the test were significantly higher than the treatment group scores. (p. 69)

Steinick also found that the method of teaching significantly affected the posttest scores when problem solving was taught. She further concluded that microcomputer-assisted instruction is superior to conventional methods of instruction when problem solving was taught.

On the other hand, quite a few studies concluded that there were no significant differences in students' achievement whether traditional instruction or computer-aided instruction had been used.

Kockler and Netusil (1974) compared students' attitudes toward computers and toward mathematics as well as students' achievements using and not using computer-assisted instruction in a freshman mathematics course at Iowa State University. They found no significant differences in students' achievement between the two methods; however, attitudes toward instruction were significantly more positive for students who used computers.

Boettcher, Alderson, and Saccucci (1981), from the University of Delaware, investigated the effectiveness of computer-assisted instruction. They compared the effects of computer-assisted instruction versus printed instruction on student learning in the cognitive categories of knowledge and application.

The study investigated the learning outcomes of 83 baccalaureate nursing students randomly assigned to a CAI group or to a group taught with printed programmed instruction (PI). Lessons in psychopharmacological nursing were developed, which presented the same learning material for both teaching modalities in the cognitive categories of knowledge and application. The actual contents of the lessons were identical and only the instruction modality varied.

Through the use of a pretest-posttest control group design, the evaluation of learning outcomes in these two categories was undertaken. The results of the investigation revealed no significant differences between the groups in posttest scores related to either cognitive category or application; both groups of subjects made equally significant gains in the amount of knowledge and application learned.

This finding suggested that computer-assisted instruction could be as effective as a more traditional instructional modality in teaching both factual content and application of learned material when both media used the same instructional approach.

Bass, Ries and Sharpe (1986) conducted research regarding teaching basic skills through microcomputer-assisted instruction. Remedial elementary school students in grades four to six were given supplementary microcomputer-assisted instruction in reading and mathematics. Students' performance was assessed with a pretest-posttest nonequivalent control group design using standardized achievement and effective tests. Although all microcomputer experimental groups showed statistically significant pretest-posttest gains in reading and mathematics, the control groups using conventional instructional methods also showed similar gains. Analysis of covariance of achievement gains revealed only one experimental group, sixth grade reading, to be statistically superior to the control groups' performance. No significant changes in students' attitudes toward schooling or sense of control over their own performance were detected.

Some experimenters were interested in studying the efficiency of time and cost of computer-aided instruction versus traditional instruction.

Morrison and Witmer (1983), of the U. S. Army Research Institute, conducted a comparative evaluation of computer-based and print-based job performance aids. They developed a computer-based job aid from a previously developed print-based aid and compared task performance of soldiers using the two kinds of aids.

The main body of the print-based job aid consisted of step-by-step procedures for performing each M1 tank gunner's task. The print-based job aid was a ring-bound plastic covered booklet. Steps were numbered and listed in the sequence they were to be performed. Because of certain contingencies which can exist between task steps and the status of certain controls and indicators, an algorithmic format rather than a straight sequential listing was used. At certain points in the procedure, therefore, soldiers were asked questions concerning the phase of operation of status of controls and indicators. Based on their answers, the soldiers were required to follow branching to an appropriately numbered step.

The computer-based job aid used an Apple II-plus microcomputer. The wording and format of the job aid program were the same as the print-based aid. The most important difference when comparing with the print-based job aid was that the computer-based program automatically branched to appropriate steps when the soldiers responded to questions posed by the program.

The experimenters expected that the computer-based job-performance aid would produce desired results faster and more accurately than the print-based aid because of the automation of task sequencing and branching. The results did not support these expectations. There were no differences in task completion time between the job aids.

Computer application in an aviation training environment was investigated by Trollip and Johnson (1982), of the Aviation Research Laboratory, at the University of Illinois at Urbana-Champaign.

The experimenters reported that simulation has, for a long time, offered a partial solution to training needs in aviation. This is especially true in flight training where high aircraft acquisition and operating cost prohibit extensive use of real equipment. Simulation offers the potential of lowering training costs by minimizing the need for real equipment and by maximizing the learning effectiveness of real equipment when it is used.

Simulation increases the opportunities for individualized instruction while providing an environment that is safe for trainees and nondestructive to real equipment. They concluded that

> As flying and training costs escalate, an increasing use of computer-based training technology will be introduced. This will make the instructional process more efficient in terms of both time and cost. In addition, having such technology available will allow the institute to embark on a course of greater individualization of instruction with all its benefits. (p. 226)

Many similar studies have been conducted in comparing the effectiveness of computer-assisted instruction for classroom work to traditional instruction methods. Most of these studies concluded that students utilizing computer-assisted instruction had higher than or at least the same achievement level as the students using traditional instruction.

Burns and Bozeman's meta-analysis (1981) of 40 computer-assisted instruction studies in elementary and secondary schools revealed that the use of computers in drill and practice modes was more effective than traditional methods of instruction.

Roblyer (1985) synthesized twelve research reviews on instructional computing published between 1972 and 1985. Her findings were that:

1. Supplemental computer-based instruction showed greater learning effects than replacement CAI.
2. Use of CAI resulted in a significant reduction in instructional time and in more favorable attitudes toward computers.
3. Highest achievement effects were found in elementary grades, with mathematics CAI showing more gains than reading/language arts CAI.
4. Younger and remedial students seemed to learn better from drill and practice CAI than from tutorial CAI.
5. In general, computer-based instruction resulted in small to moderate increases in achievement than traditional instruction.

Comparisons of Teaching Methods in Training Numerical Control Machining Programmers

Previous studies related to comparisons of teaching methods in training CNC programmers are relatively rare.

Pine (1973) investigated the effects of teaching numerical control concepts via simulator versus non-simulator activities by evaluating levels of achievement, programming proficiency, and attitudes of high school students.

He developed a simple NC X-Y table as a simulator or model to teach numerical control concepts. One hundred and twenty metal working students enrolled in high school industrial arts programs in the Columbus, Ohio, area were selected as research subjects.

Students were randomly assigned to an experimental group and a control group. Students in both groups studied numerical control concepts by using an instructional package. The package included lesson plans, handouts, laboratory activity instruction sheets, transparencies, charts, sample NC products, and a sixteen mm film. Students in the experimental group also used the X-Y table as a model of an NC system during the teaching-learning process, while students in the control group did not use the X-Y table.

The researcher concluded that simulator-aided concepts development activities did not significantly affect achievement, programming performance, and attitudes of high school industrial arts metal working students. However, the complete instructional package as presented to both groups provides an effective program for developing students' attitudes toward the study of numerical control.

In this study, no real numerical control machines were used. The most important function of this study was to examine the effectiveness of teaching numerical control concepts without a real numerical control machine.

Biekert (1971) organized an experimental comparison of two methods of teaching NC manual programming concepts: visual media versus hands-on equipment. A hands-on equipment approach utilizing existing NC equipment was tested on a group of industrial arts teacher education students, while another group used a visual media approach without the utilization of existing equipment. He concluded that, based on the analysis of posttest data, college students enrolled in a general metals course generated relatively similar levels of interest in numerical control from a visual media and a hands-on method for a 20-hour instructional unit. He also pointed out that both the hands-on and the visual media methods of instruction generated positive interest for numerical control as a result of the twenty hours of instruction.

Olling (1974) conducted a study which compared two different methods of teaching computer-assisted part programming principles to undergraduate mechanical technology students: computer verification verses instructor program verification. Fifty-two undergraduate students majoring in the department of Mechanical Technology at

Bradley University, Peoria, Illinois were selected as samples. Treatments of the experimental and control groups were conducted over a period of six weeks, and consisted of twenty hours of instruction. A medium-sized computer was used for the experimental group. The AD-APT language was selected as the CNC programming language for this study.

The author concluded that both methods were equally effective in teaching computer-assisted numerical control part programming principles to undergraduate students enrolled in numerical control courses in four-year baccalaureate technology programs. Therefore the author suggested that the use of a computer is not essential in the teaching of programming principles.

There are dozens of programming languages for numerical control machines. Some companies designed their own language to accommodate their own machines. A list of standard command codes for numerical control machines was published by British Standards in 1972. These codes soon became an international language for NC or CNC machines.

Currently, although many different languages are still used in programming for NC and CNC machines, the British international codes are the only ones commonly recognized by most NC or CNC controllers. Programs in different languages must be converted to these codes before they can be executed by NC or CNC machine tools.

Group Size Effect upon the Computer-Assisted Learning Process

How many students can effectively use a microcomputer at one time? As more and more microcomputers are being used in the teaching-learning process, can this process still be effective if more than one student is assigned to a computer? Microcomputer users in education have begun to explore the variables of student-microcomputer interaction. Many questions have been raised, such as: Should this interaction be only an individual process? If groups are used, how many students should be involved in a group?

At the annual meeting of the American Educational Research Association, Okey and Majer (1976) presented a paper about the effectiveness and efficiency of individual and small group learning with computer-assisted instruction. Sixty undergraduate students in elementary teaching methods classes were selected for the study and assigned at random to one of three treatment groups. Nearly all of the subjects had not had previous experience using CAI.

The three groups of students received instruction at PLATO IV computer terminals complete with screen, key board, and microfiche capabilities. Students in the first group studied alone, those in the second group studied in pairs, and those in the third group studied in groups of three or four. Each individual student, pair, trio, or quartet was scheduled for three hours of computer-terminal time in two sessions. Group learners were told to select one person to be the keyboard operator and to rotate the assignment so that each person in the group spent the same amount of time entering responses during each session.

The results demonstrated no significant differences among the three groups in either cognitive achievement or attitude toward the content of the CAI materials. There were, however, highly significant differences in study time.

The experimenters concluded that

> ... learning can take place equally effectively and more efficiently with multiple users. Having three or four students sit in front of one terminal, without any modification of the hardware, did not result in significant differences in achievement on the posttest-pretest. Hence costs per student contact hour can be cut by a factor of three or four. Further, the increased efficiency was not achieved at the expense of poorer attitudes of the students toward the materials and the learning situation. (p. 84)

S. G. Larsen (1979) claimed that pairs of children on a microcomputer seemed to work best. He concluded that "for one child alone gets stuck too often; and three or more argue over who will type on the console" (p. 59).

D. Trowbridge and R. Durnin (1984) conducted a study to examine learning outcomes of individuals and groups in a computer environment. Individual interactivity as a function of group size was investigated by focussing on various modes of interaction available to students while they completed activities using a computer. The activities involve manipulation of pictures of batteries, bulbs, and wires on the computer screen so the student can perform simple experiments with simple direct current (DC) circuits. Achievement was measured by administering brief paper and pencil tests and an individual interview. In this study, fifty-eight seventh and eighth grade students were selected as a representative population. Groups ranged from individuals working alone to four students working together. The following conclusions were drawn from global assessments:

1. Students working in pairs or quads were more likely to cooperate with each other than students working in triads.
2. Students working in pairs were more likely to give or receive tutorial assistance than students in triads or quads.
3. Students working in pairs made fewer incorrect entries and formulated higher-quality responses to program questions than individuals, triads, or quads.
4. Whether working individually or in groups, students were uniformly attentive during instruction sessions and displayed little off-task behavior.

In addition, researchers observed that students working alone seemed to have a more difficult time answering questions correctly on their first attempt at the keyboard than those in groups of any size.

Cox and Berger (1985) conducted research about the importance of group size in the use of problem-solving skills on a microcomputer. Sixty-six seventh and eighth grade students were tested to evaluate the relationship between group size, microcomputer problem-solving success, and problem solving efficiency. Individuals in groups of two, three, or five students attempted to solve problems requiring indirect linking of twenty clues. The microcomputer was used as a data-presentation and recall device for students and a data-gathering device for the researchers.

The following conclusions were drawn from this study:

1. Students worked better in teams than alone.
2. Teams of two, three, and four solved more problems than groups of one and five.
3. While teams of five did not solve problems in significantly less time, social confrontations and friction occurred more often.
4. Teams of two to four would seem best suited to work together to solve problems similar to those in this study.

Guntermann and Tovar (1987) investigated individual productivity versus productivity in groups of two or three. In addition, he analyzed interaction processes underlying differences between groups of two and three and differences between male, female, or mixed groups learning LOGO on microcomputers. Thirty-six students, aged ten, learned LOGO individually or in groups of two or three for one session, had a practice session, then were required to produce a graphic in LOGO for the experimental session.

On the basis of the present data, individuals working on computers did not have an advantage with respect to problem-solving over groups of two or three on the product measures investigated. The investigators claimed that:

> The lack of difference found in the outcome measures between individuals and groups of two or three would

> lead one to conclude that computers may be used for instructional purposes as successfully with small groups of children as individuals. The dependent measures of final graphic scores, number of commands, and programming time may be associated with such cognitive objectives as logical programming, programming style, and efficiency and geometric representation of numerical commands. These objectives are particularly useful for problem solving in a laboratory environment where there may be no fixed goals per se. (p. 327)

Klinkefus (1988) reported for his research on "paired versus individual learning when using computer-assisted instruction". Ninety-nine seventh through ninth grade subjects were randomly assigned to work at computers alone or with a partner. All groups worked with the same computers and the same computer lessons which were designed to give practice on and reinforce concepts about basics of exponentiation and scientific notation. The experimenter concluded that no significant achievement differences were found between students working at the computer alone and those working in pairs.

Summary

1. The effectiveness of computer-assisted instruction upon classroom work

   Much research has been done to evaluate the effectiveness of implementing the microcomputer in classroom work. Some research results, like the investigations done by Thomas (1979), Taylor (1987), or Steinick (1987), showed that the microcomputer played an important role in students' studying processes. Those researchers discovered significant differences in student achievement when comparing computer-assisted instruction to conventional teaching methods. On the other hand, some researchers, like Kockler and Netusil (1974), Boettcher, Alderson and Saccucci (1981), and Bass, Ries, and Sharpe (1986) supported the view that there are no significant differences between computer-assisted instruction and conventional methods.

The results of studies regarding the comparison of computer-assisted instruction and traditional instruction were mixed and somewhat inconclusive. These different conclusions are somewhat related to the way in which the researchers designed their studies. The hardware, software, and trained personnel all contributed as variables in these results. Computer-assisted coursework which simply copied textbooks tended to have no significant positive conclusion for computer-assisted instruction. That means the content which appears on the computer screen should not be simply a textbook copy. However, results from the meta-analysis of previous studies by Burns and Bozeman (1981), Kulik and his colleagues (1980) and Roblyer (1985), demonstrated that computer-based instruction made small but significant contributions to the students' course achievement while also producing positive, but again small, effects on the students' attitudes toward instruction and toward the subject matter they were studying.

Regarding time and cost efficiency of computer-assisted instructions versus traditional instructions, more studies showed positive results for computer-assisted instruction than for traditional instruction. Kulik and his colleague (1983) based the result of their meta-analysis on fifty-one evaluations, discovering that students using CAI took substantially less time to learn the identified content. Roblyer (1985) also came to the similar conclusion that the use of CAI resulted in a significant reduction in instruction time.

Computer-assisted instruction in simulation attempts to replace empirical activities. Most studies demonstrated that computer-aided simulation has been more effective than traditional instruction, especially when studying technical courses. Some technical courses required expensive equipment or required the operation of equipment with certain risks of accident during the learning process, like aviation or machine operations. In these cases simulation has an important benefit in minimizing risks and costs, and increasing the opportunities for individualized instruction.

2. Comparisons of teaching methods in training CNC programmers

Relatively few studies have been conducted to investigate different teaching methods, including the area of microcomputer use in teaching students NC and CNC programming skills, even though the application of microcomputers in training is presently popular.

Pine (1973) and Olling (1974) separately conducted investigations concerning the effectiveness of microcomputer-training for NC programming instructions. They discovered that computer-assisted or simulator-aided instruction is effective in the development of students' attitudes and interests toward the study of numerical control. However, they did not note any significant differences in student achievement when studying "concepts" and "principles." These reports demonstrate that computer-assisted instruction in technical training does not significantly affect students' achievement. However, NC simulators do help students develop their attitudes and interests toward the study of NC programming.

3. Group size effect on the computer-assisted learning process

Okey and Majer (1976), Guntermann and Tovar (1987), and Klinkefus (1988) reported that there were no significant differences among groups of different sizes in either cognitive achievement or attitudes toward the content of CAI material. However, some of these researchers found that groups of three or four students used less time than students studying alone or in pairs.

Trowbridge and Durnin (1984) and Cox and Berger (1985) studied group size effect separately. Trowbridge and Durnin designed activities which involved experiments with simple direct current (DC), while Cox and Berger focused on problem-solving skills. Both studies have shown that small group use of highly interactive computer-based learning materials has certain advantages for students' achievement over individual usage.

By summarizing these previous studies, we can infer that a group size of two or three does not have any negative effect on levels of achievement in computer-assisted instruction. At the same time, this approach does save school districts considerable capital investment for such specialized equipment.

CHAPTER III. METHODOLOGY

This chapter provides a description of the methods of study, which includes hypotheses, sampling subjects, research design, variables of the study, data collection instruments, and method of statistical analysis of data.

Hypotheses of the Study

This study specifically tested the null hypotheses listed below:

Hypothesis 1

There was no significant effect of mathematics scores upon the achievement of CNC programming skills.

Hypothesis 2

There was no significant effect of drafting scores upon the achievement of CNC programming skills.

Hypothesis 3

There was no significant effect of computer concepts class upon the achievement of programming skills.

Hypothesis 4

There were no significant achievement differences among the three groups of students who used a computer with a partner, used a computer alone, and the control group which did not have access to computer simulators.

Hypothesis 5

There were no significant achievement differences between students verifying CNC programs by working at a microcomputer simulator with a partner and those working alone.

Hypothesis 6

There were no significant achievement differences between students verifying CNC programs by microcomputer simulators alone and those verifying CNC programs through an instructor.

Hypothesis 7

There were no significant achievement differences between students working at a microcomputer with a partner and those verifying CNC programs through an instructor.

Hypothesis 8

There were no significant differences in the numbers of questions asked per student, as measured during the practice period, among the three groups of students using a computer with a partner, using a computer alone, and those verifying CNC programs through an instructor.

Sampling Subjects

Subjects used in this study were the students enrolled at the National Yunlin Institute of Technology (YIT) in Taiwan during the 1988-1989 school year. These students were between nineteen and twenty years old. They were all majoring in the mechanical engineering and the mechanical design Associate Degree programs. Their educational backgrounds were equivalent to twelfth grade students or college freshmen in the United States. The YIT had approximately 1600 students located in the central part of Taiwan.

Five classes were selected. Each class had approximately 19 to 23 students. Students in each class were randomly divided into three groups.

Group I: An experimental group in which each student used a microcomputer to verify CNC programs during class sessions.

Group II: An experimental group in which every two students shared one microcomputer to verify CNC programs during class sessions.

Group III: A control group in which no microcomputer was provided. To verify CNC programs, one instructor was available for this group of students.

The number of subjects and computers assigned to each group in a class was designed as indicated in Table 1.

Table 1. The number of subjects and computers used for the research

	Number of computers	Subjects in a class	Total subjects
Group I	5	5	25
Group II	3	6	30
Group III	0	7	35
Total	8	18	90

There was only one female student in these five selected classes. This particular student was not included in the study. All of the subjects used in this study were male students.

A pretest was given to students at the very beginning of the study. The majority of students in this study did not have any previous experience in programming skills for computer numerical control machines. Only two out of a total of 107 students answered 5% of the pretest questions correctly. For the purpose of eliminating possible contamination from the study, these two students were also eliminated from the study.

A total of eight computers were used in the study. A total of ninety students were randomly selected from 104 students in the selected five classes.

Simulation Package

The simulation package is a Chinese package compatible with a personal computer. The major functions include:

1. Cataloguing
2. Editing
3. Simulation of CNC lathe programs
4. Simulation of CNC mill programs
5. Transferring files

Research Design

The investigation focused on the achievement of subjects who had been exposed to three different methods of CNC programming instructions.

The pretest-posttest control group design was used in this experiment. This design could be schematically presented as follows:

Group I	R	O1	X	O2	X	O3
Group II	R	O1	X	O2	X	O3
Group III	R	O1		O2		O3

where R stands for random selection of subjects, O stands for observations, O1 is the pretest, O2 and O3 are posttests. X is the treatment.

Variables of the Study

Independent variables

The following independent variables were studied:

1. Mechanical Drafting grades from the previous semester.
2. Computer concepts grades from the previous semester.
3. Mathematics grades from the previous semester.
4. The pretest scores.

Dependent variables

1. The subject's achievement of CNC programming skills.
2. The number of questions asked by each group of students during the experimental process.

Data Collection Instrument

The independent variables of grades in mechanical drafting class, computer concepts class, and mathematics were collected through school records.

Posttests were designed for this study in order to assess the levels of achievement of CNC programming skills at the end of each session.

The achievement instrument was designed to measure how well the subjects had learned the CNC programming skills. The skills included

1. understanding the basic function of commands

2. setting up the zero points
3. writing machining programs
4. debugging programs
5. selecting correct machining procedures

A primary concern for the test instrument developed by the researcher was validity and reliability. To develop the achievement instrument for this study, more than forty-five items were designed at the beginning. The instrument consisted of three sets of multiple-choice, mistake-correction type questions. An evaluation procedure to develop a high-reliability and high-validity instrument was followed. Finally, forty-five items were prepared.

Validity refers to the degree to which the test items reflect the content that the test is designed to measure. To determine the validity of the achievement instrument, a special jury of five CNC instructors was formed. The five CNC teachers were asked to evaluate each of the achievement test items. They were given a list of course objectives and asked to determine whether the test would measure the attainment of these objectives. They rated each item on a one through five scale, rating the appropriateness of the test. After adding up the scores for each item, the experimenter revised those items which scored lower than 3.0 according to the suggestions of the jury.

Reliability refers to the ability of an instrument to produce consistent results. Item analysis and the Kuder-Richardson 20 formula (KR-20) were used to determine reliability. After eliminating the lower point-biserial correlation coefficient items, the researcher constructed an instrument with KR-20 reliability of 0.86.

Table 2. Item analysis results for the instrument

Item Analysis Results				
Subtest summary				
subtest	no. items	mean	s.d.	KR#20
1	45	31.73	7.10	0.86

Procedure of the Experiment

The teaching process was completed in three weeks, each week comprising six hours of class time. There were a total of 18 contact hours of formal study.

The experimental process included the following activities:

1. Pretest

   The pretest was conducted during the first meeting before the teaching process began. The pretest and posttest used the same instrument. The pretest took thirty minutes.

2. Classroom lecture

   For each of the five classes, the classroom lecture was conducted by the experimenter in the same way. These lectures lasted for a total of five hours and thirty minutes. The experimenter covered the following subjects:

   (1) The computer numerical control concepts.

(2) The machine coordinate system.

(3) The preparatory functions. They are:

positioning (G00)

linear interpolation (G01)

circular interpolation (G02,G03)

dwell (G04)

plane selection (G17, G18, G19)

inch/metric conversion (G20, G21)

automatic reference point return (G28, G29)

reference point return check (G27)

cutter diameter compensation functions (G40, G41, G42)

absolute and incremental programming (G90,G91)

setting work coordinate system (G92)

feed per minute and feed per revolution (G94, G95)

A total of twenty G codes were lectured upon.

(4) Miscellaneous functions included the following:

program stop (M00)

optional stop (M01)

end of program (M02, M30)

spindle forward, backward, and spindle stop (M03,M04, M05)

cutting fluid on and off (M08, M09)

tool change (M06)

(5) The spindle function (S codes)

(6) The tool function (T codes)

(7) The feed function (F codes)

3. Demonstration

The CNC milling machine used for demonstration purposes was manufactured by a local company, Dahlih Machinery Company. The CNC milling machine (DAHLIH MCV-700) uses a FANUC 10M controller with twenty-four tool positions available in the tool magazine. It is a powerful industrial-type machine. The experimenter conducted the demonstration for each of the classes. Each demonstration took around thirty minutes.

4. CNC programming practice

Students in each class were randomly assigned to three groups in this step. In order to reduce possible contamination of the research results, subjects in these classes were not informed of the experimental plan until the end of the data collection process. Students in different groups were told to rotate in turn every three weeks, which means that, after the three-week experimental period, students would be switched from one group to another. This strategy eliminated the threat of the Hawthorne Effect and the John Henry Effect.

In this step the experimenter was in charge of answering questions for students, in groups one and two, who were learning programming with computers. The third group of students were under the control of the experimenter's colleague. The number of questions asked by students during the programming practice period was calculated.

5. Posttest one

The first posttest was conducted at the end of the second week. The test included fifteen multiple choice questions. The students completed the test within thirty minutes. The test questions are listed in Appendix C.

6. Posttest two

The second posttest was conducted at the end of the third week. The test included three machine-part drawings and three incomplete-part programs. The students were asked to fill-in blanks with correct commands. There were thirty blocks of CNC program to be filled. Students completed the test in about an hour. The test questions are listed in Appendix D.

Methods of Statistical Analysis of Data

This section presents statistical techniques that were employed to analyze data for the research hypotheses of this experiment.

To control error and increase precision, multiple covariance analysis was used to test the equality of achievement among three groups of students. The analysis of covariance is concerned with two or more measured variables where any measurable independent variable is not at a predetermined level as is the case in a factorial experiment, as the variance of a treatment mean is $\sigma^2 = S^2/n$. Hence, to decrease this variance, the only two approaches would be to increase the sample size or to control the variance in the sampled population.

The following procedure was used to analyze the data collected in this study:

1. A multiple covariance analysis using the GLM procedure with the aid of a SAS package was used to evaluate the effects of previous mathematics, drafting, and computer concepts scores upon the achievement of programming skills. Before the covariance analysis was employed, a series of tests were conducted to match the assumptions for valid use of covariance. These tests included:

(1) Testing to see whether the variances of the three groups were statistically equal in mathematics, mechanical drafting, and computer concepts classes.

Hoa: A1m=A2m=A3m=Am

Hob: A1d=A2d=A3d=Ad

Hoc: A1c=A2c=A3c=Ac

(2) Testing to see whether the means of the three groups were equal in mathematics, mechanical drafting, and computer concepts classes.

Hod: $u_{1m}=u_{2m}=u_{3m}$ (for mathematics scores)

Hoe: $u_{1d}=u_{2d}=u_{3d}$ (for mechanical drafting scores)

Hof: $u_{1c}=u_{2c}=u_{3c}$ (for computer concepts scores)

(3) Testing the hypothesis that the within groups' regression coefficients were equal. That means testing to determine that the slopes of the three groups were identical.

Hog: $B_{1m}=B_{2m}=B_{3m}=B_m$ (for mathematics scores)

Hoh: $B_{1d}=B_{2d}=B_{3d}=B_d$ (for drafting scores)

Hoi: $B_{1c}=B_{2c}=B_{3c}=B_c$ (for computer concepts scores)

2. The hypotheses that no significant effect of mathematics scores, mechanical drafting scores, and computer concepts scores was found in reference to the achievement of learning CNC programming skills were tested.
(Hypotheses 1, 2, and 3)
3. After taking out insignificant factors, the GLM procedure was used again to determine any significant achievement differences among the three groups of students.
(Hypothesis 4)
4. A t-test was used to test the significance of Group I and Group II by the adjusted group means. (Hypothesis 5)

5. A t-test was used to test the significance of Group III versus Group I by the adjusted group means. (Hypothesis 6)
6. A t-test was used to test the significance of group III versus Group II by the adjusted group means. (Hypothesis 7)
7. Analysis of variance was used to analyze questions asked by students in each group. (Hypothesis 8)

   The Tukey test and Student-Newman-Keuls test were employed for pairwise comparisons following a significant F ratio in the ANOVA.

CHAPTER IV. FINDINGS

The results of the data analysis will be presented in this chapter. The primary goal of this experiment was to compare the mean of posttest scores across the levels of the categorical variable (the groups). If the interval variables of background experiences were ignored, a one-way analysis of variance would be a suitable way to analyze the data. In this study, the students' backgrounds in mathematics, mechanical drafting, and computer concepts were treated as control variables (covariates). The analysis of covariance using a general linear model was utilized in analyzing these data.

The analysis involves adjusting the sample means posttest scores by controlling students' experience so that the posttest scores reflect the expected differences if the students in different groups had the same average background experience. Controlling for experience corresponds to making an adjustment in the observed mean posttest scores so that the true values reflect what the experimenter expected if all groups of subjects were equal, on the average, in experience.

Since the multiple covariance analysis was used to control error and increase precision, several assumptions had to be tested first. After these assumptions were confirmed, the posttest scores of the three groups were adjusted by the covariates and the adjusted means were then statistically compared.

The assumptions necessary for the valid use of covariances are that:

1. The covariances are fixed and independent of treatments.
2. The regression of achievement on covariances after removal of treatment differences are linear and independent of treatment.
3. The residuals are normally and independently distributed with zero mean and a common variance.

Testing Assumptions for Multiple Covariance Analysis

To satisfy the assumptions underlying analysis of covariance, the following three steps were followed:

Step one: Testing for group variances

The first step was to determine if the group variances of three different groups in mathematics, mechanical drafting, and computer concepts classes were statistically equal.

1. Null hypothesis for mathematics scores

   There was no significant difference in the true group variances of mathematics scores among the three groups.

   Hoa: A1m = A2m = A3m = Am

   As shown in Table 3, the sum of squared errors in group 1 is

1403.82 with 23 degrees of freedom, in group 2 is 1398.61 with 28 degrees of freedom, and in group 3 is 1323.72 with 33 degrees of freedom. The average number of degrees of freedom is 28.

Table 3. The group variance of mathematics scores

Group	Sum of Squared Errors	DF	Mean Squared Errors
1	1403.82	23	61.04
2	1398.61	28	49.95
3	1323.72	33	40.11
Average		28	

The Hartley's Maximum F is:

F=(the largest group mean square)/(the smallest group mean square)

F=61.04 / 40.11 =1.522

The table value of F(df=30) equals 2.40 for three groups at the 0.05 level of significance. Since 1.522 is less then 2.40, the null hypothesis was not rejected at 0.05 level of type I error. It was thus concluded that there was no significant difference in the true group variances of mathematics scores among the three groups.

2. Null hypothesis for mechanical drafting scores

There is no significant difference in the true group variances of mechanical Drafting scores among the three groups.

Hob: A1d=A2d=A3d

The sum of squared errors in group 1 is 1497.62 with 23 degrees of freedom, in group 2 is 1425.68 with 28 degrees of freedom, and in group 3 is 1568.91 with 33 degrees of freedom. The average number of degrees of freedom is 28.

Table 4. The group variance of mechanical drafting scores

Group	Sum of Squared Errors	DF	Mean Squared Errors
1	1497.62	23	65.11
2	1425.68	28	50.92
3	1568.91	33	47.54
Average		28	

The Hartley's Maximum F is:

F=(the largest group mean square)/(the smallest group mean square)

F=65.11 / 47.54 =1.37

The table value of F(df=30) equals 2.40 for three groups at the 0.05 level of significance. Since 1.37 is less then 2.40, the null hypothesis was not rejected. It was thus concluded that there was no significant difference in the true group variances of mechanical drafting scores among the three groups.

3. Null hypothesis for computer concepts scores

   There was no significant difference in the true group variances of computer scores among the three groups.

   Hoc: A1c=A2c=A3c

   As stated in Table 5, the sum of squared errors in group 1 is 1313.40 with 23 degrees of freedom, in group 2 is 1415.43 with 28 degrees of freedom, and in group 3 is 1298.16 with 33 degrees of freedom. The average number of degrees of freedom is 28.

Table 5. The group variance of computer scores

Group	Sum of Squared Errors	DF	Mean Squared Errors
1	1313.40	23	57.10
2	1415.43	28	50.55
3	1298.16	33	39.34
Average		28	

The Hartley's Maximum F is:

F=(the largest group mean square)/(the smallest group mean square)

F=57.10 / 39.34 =1.45

The table value of F(df=30) equals 2.40 for the three groups at the 0.05 level of significance. Since 1.45 is also less then 2.40, the null hypothesis was not rejected. It was concluded that there was no significant difference in the true group variances in computer scores among the three groups.

From the above three tests of hypotheses, it was confirmed that the true group variances of the posttest scores in mathematics, mechanical drafting, and computer classes did not have significant differences.

Step two: Testing for true group means

The following hypotheses were to determine if the true group means for mathematics, mechanical drafting, and computer classes are equal. In other words, this was to test if all groups had the same mean for the control variables. If there was no significant difference among the groups in their distribution of the control variables, then the results of this control would be accepted for use in the covariance analysis.

On the other hand, if the group means for these covariates were not equal, rerandomization might be necessary before analysis of the experiment could be performed.

1. Null hypothesis for mathematics scores

There was no significant difference of the true group means for mathematics scores among the three groups.

Hod: u1m=u2m=u3m (for mathematics scores)

The result of running the GLM procedure is contained in Table 4, where the reported F value is 0.37. The PR value is 0.689, which is much larger than 0.05. Therefore, the null hypothesis was not rejected. This means there was no significant difference in the true group means for mathematics scores of the three groups at the 0.05 level significance.

Table 6. General linear models procedure for the dependent variable of mathematics scores

Dependent Variable: Mathematics

Source	DF	Sum of Squares	Mean Squares	F Value	PR > F
Model	2	106.16	53.08	0.37	0.689
Error	87	12344.16	141.89		
Total	89	12450.32			

2. Null hypothesis for mechanical drafting scores

There was no significant difference in the true group means for mechanical drafting scores among the three groups.

Hoe: u1d=u2d=u3d (for mechanical drafting scores)

The result of running the GLM procedure is contained in Table 7, where the F value is 1.36. The PR value is 0.261, which is much larger than 0.05. Therefore, the null hypothesis is not rejected. This means there was no significant difference in the true group means for mechanical drafting scores among the three groups at the 0.05 level of significance.

Table 7. General linear models procedure for dependent variable of mechanical drafting scores

Dependent Variable: Mechanical drafting

Source	DF	Sum of Squares	Mean Squares	F Value	PR > F
Model	2	201.90	100.95	1.36	0.261
Error	87	6436.50	73.98		
Total	89	6638.40			

3. Null hypothesis for computer concepts scores

There was no significant difference in the true group means for computer scores among the three groups.

Hof: u1c=u2c=u3c (for computer scores)

The result of running the GLM procedure is contained in Table 8, where the F value is 0.10. The PR value is 0.903, which is much larger than 0.05. Therefore the null hypothesis was not rejected. That means there was no significant difference in the true group means for computer scores among the three groups at the 0.05 level of significance.

Table 8. General linear models procedure for dependent variable of computer scores

Dependent Variable: Computer Scores

Source	DF	Sum of Squares	Mean Squares	F Value	PR > F
Model	2	40.00	20.00	0.10	0.903
Error	87	17020.10	195.63		
Total	89	17060.10			

Step three: Testing the within groups' regression coefficients

The third step was to test the hypothesis stating that the within groups' regression coefficients were equal. This test involved checking for interaction by determining whether the best-fitting straight lines for the observations within each group had different slopes. If the evidence were sufficient to fail to reject the null hypothesis of no interaction, then a collection of lines could be expressed with identical slopes.

1. Null hypothesis for mathematics, mechanical drafting, and computer concepts classes
   There was no significant difference in the interaction between posttest group means and mathematics, mechanical drafting, and computer scores.

   Hog: $B1m=B2m=B3m=Bm$

   Hoh: $B1d=B2d=B3d=Bd$

   Hoi: $B1c=B2c=B3c=Bc$

Table 9. The GLM analysis of the interaction of covariances with group means

Dependent Variable: Posttest

Source	DF	Type I SS	Mean Squares	F Value	PR > F
GRP	2	31.73	15.87	0.32	0.724
MATH	1	367.34	367.34	7.52	0.008
DRAFTING	1	8.47	8.47	0.17	0.678
COMPUTER	1	195.32	195.32	4.00	0.049
MATH*GRP	2	25.96	12.98	0.27	0.767
DRAFTING*GRP	2	63.15	31.57	0.65	0.527
COMPUTER*GRP	2	46.21	23.10	0.47	0.625

After running the GLM analysis, results were printed in Table 9. From the type I sum of squares, the mathematics and group interaction had the mean square value of 12.98, the interaction of drafting and GRP had the means square value of 31.57, and the interaction of computer and GRP had the mean square value of 23.10.

The F values to test the significance of these interactions were calculated by using the following formula:

F=(type I mean square of interaction) / (pooled mean square of error)

The pooled GLM analysis of these three groups is shown in Table 10. The mean squared of error value was 46.95, with 84 degrees of freedom.

Table 10. The GLM analysis of covariance

Dependent Variable: Posttest

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	5	602.85	120.57	2.57	0.033
Error	84	3943.55	46.95		
Total	89	4546.40			

Fm=(12.98) / (46.95) =0.276

$Fd=(31.57) / (46.95) =0.672$

$Fc=(23.10) / (46.95) =0.492$

The interactions in Table 9 have two degrees of freedom, and the pooled mean squared error in Table 10 has 84 degrees of freedom. The table value for F is 3.1. The obvious conclusion was that the null hypotheses could not be rejected. That means the three groups have statistically identical slope in mathematics, mechanical drafting and computer scores. The regression lines between posttest scores and mathematics scores, drafting scores, and computer scores for subjects in group 1, 2, and 3 paralleled each other. In this case, the difference between mean posttest scores for students in group 1, 2 and 3 was identical for all fixed values of each covariate. Therefore, the difference in the means, controlling for mathematics drafting, and computer scores, could be summarized by one number.

Results of Hypothesis Testing

Hypotheses 1, 2, and 3

This step was to test the null hypothesis that the pooled regression coefficient was zero, in order to determine if mathematics scores, mechanical drafting scores, and computer concepts scores had a significant effect upon the achievement of CNC programming skills.

The null hypotheses for testing the effect of mathematics, mechanical drafting, and computer concepts scores were:

The pooled regression coefficients of mathematics, drafting, and computer concepts scores did not differ significantly from zero.

Ho1: $B_{Mpool} = 0$

Ho2: $B_{Dpool} = 0$

Ho3: $B_{Cpool} = 0$

In this step, the variables of students' previous experiences in mathematics, mechanical drafting, and computer scores were treated as the control variables.

The B_{pools} were the slopes of these variables. If a Bpool is equal to zero that means this particular variable has no significant relation to the posttest scores. Then that variable must be taken out from the multiple covariance analysis. On the other hand, if the null hypothesis is rejected, that particular variable will be considered as a covariate which increases test precision.

After running the GLM procedure, the results were summarized in Table 11. The type III sum of squares for mathematics, mechanical drafting, and computer concepts are 135.78, 12.37, and 195.37 respectively. Comparing the PR values, it is obvious that mathematics and mechanical drafting classes did not have a significant effect upon the posttest scores. These two variables were then eliminated from the analysis. The only significant variable was the previous scores of computer concepts class, where the PR value was 0.033 as compared with the alpha level of 0.05.

Table 11. The GLM analysis of posttest on mathematics, mechanical drafting, and computer classes

Dependent Variable: Posttest

Source	DF	Type III SS	Mean Square	F Value	PR > F
GRP	2	42.80	21.40	0.46	0.636
MATH	1	135.78	135.78	2.89	0.093
DRAFTING	1	12.37	12.37	0.26	0.609
COMPUTER	1	195.32	195.32	4.16	0.045

This result shows that only computer concepts experience has a significant effect upon the achievement of learning CNC programming. The scatter plot of computer concepts scores by posttest scores is shown on Appendix G. To clarify if the computer scores and the posttest scores are positively or negatively correlated, the researcher used the Pearson correlation method in the SAS package. The results are contained in Table 12. The Pearson correlation coefficient between computer scores and posttest scores is 0.30873. The PR value for testing null hypothesis RHO=0 is 0.0031. This value is less than 0.05. Therefore the null hypothesis was rejected. That means the computer scores are positively correlated with posttest scores. The correlation coefficient is significant at the 0.05 level.

In order to measure precisely the effectiveness of computer simulation in training programmers for CNC machining, the computer scores were considered as a covariate.

Table 12. Pearson correlation coefficients of computer scores and the posttest scores

PROB > |R| UNDER HO: RHO=0 / N = 90	COMPUTER	POSTTEST
COMPUTER	1.00000 0.0000	0.30873 0.0031
POSTTEST	0.30873 0.0031	1.00000 0.0000

Hypotheses 4, 5, 6, and 7

This step was carried out to test the hypothesis that the true adjusted group means for posttest scores did not contain any significant differences by using the reduced model. The reduced model used only the computer concepts scores as a covariate.

1. Hypothesis 4

   There was no significant achievement difference among the three groups of students which used a computer with a partner or used a computer alone, and the control group which did not have access to computer simulators.

   H_o4: u1=u2=u3 (adjusted for computer experience)

After running the GLM procedure using computer concepts scores as a covariate, the result was printed in Table 13. The type III sum square of the groups is 22.69, and the F value is 0.24 with two degrees of freedom. The PR value is 0.788. This value is not significant at the 0.05 level. Thus, the null hypothesis was not rejected. It was then concluded that there was no significant achievement difference among the three groups of students which used a computer with a partner or used a computer alone and those in the control group.

Table 13. The general linear model procedure using computer experience as a covariate

Dependent Variable: Posttest

Source	DF	Type I SS	Mean Square	F value	PR > F
GRP	2	31.37	15.87	0.33	0.7169
Computer	1	430.32	430.32	9.06	0.0034

Source	DF	Type III SS	Mean Square	F value	PR > F
GRP	2	22.69	11.35	0.24	0.7880
Computer	1	430.32	430.32	9.06	0.0034

The next step involved computing the adjusted group means. The adjusted means on the posttest scores for a particular group is its conditional mean on the posttest scores, where the covariate is equal to the mean score of the combined population among the three groups. In this case, the only effective covariate is the computer concepts scores. The regression function for a particular group evaluated at the overall mean of computer concepts scores gives the adjusted mean for that group.

The adjusted group means are listed in Table 14.

Table 14. The adjusted group means of posttest scores

GRP	POSTTEST LSMEAN	STD ERR LSMEAN	PROB > |T| Ho: LSMEAN=0	LSMEAN NUMBER
1	31.209	1.379	0.0001	1
2	31.591	1.258	0.0001	2
3	32.402	1.165	0.0001	3

It is obvious that the least square means of the posttest were significantly larger than zero.

The next procedure required computation of the approximate variance of the difference between any two adjusted means and also testing the following null hypotheses.

2. Hypothesis 5

There were no significant achievement differences between students verifying CNC programs by working at a microcomputer simulator with a partner and those working alone.

Ho5: LEMEAN (1) - LSMEAN (2) =0

3. Hypothesis 6

There were no significant achievement differences between students verifying CNC programs by working at a microcomputer simulator alone and those verifying CNC programs through an instructor.

Ho6: LSMEAN (1) - LSMEAN (3) = 0

4. Hypothesis 7

There were no significant achievement differences between students working at a microcomputer with a partner and those verifying CNC programs through an instructor.

Ho7: LSMEAN (2) -LSMEAN (3) =0

The t-test results of the least square means was listed in Table 15.

From Table 15, the t-test results show that no significant difference at 0.05 level was found between any two of the three groups. That means hypotheses 5, 6, and 7 cannot be rejected. It is reasonable to conclude that there were no significant achievement differences between any two among the three groups.

Table 15. The t-test of the least square means of group 1, group 2 and group 3

PROB > |t| Ho: LSMEAN (i) = LSMEAN (j)			
i/j	1	2	3
1	.	0.8382	0.5107
2	0.8382	.	0.6375
3	0.5107	0.6375	.

Hypothesis 8

There were no significant differences regarding the numbers of questions asked per student, as measured during the practicing period, among students studying CNC programming by working at a microcomputer cutter-route simulator with a partner, by those working at a microcomputer simulator alone, and by those verifying CNC programs through an instructor.

H_o8: u1=u2=u3

The questioning frequencies of students from the three groups were recorded during the process of the experiment. Table 16 illustrates the questioning frequencies of three groups of students from the five classes which were in the study.

Table 17 summarizes the analysis of variance performed on the means for the rate of student questioning. The F value is 11.49 with 2 and 12 degrees of freedom; the PR value is 0.0016. It is reasonable to conclude that there is sufficient evidence to reject the null hypothesis. That means the questioning rates of the three groups were significantly different, and at least one pair among the three groups was significantly different from the others.

Table 16. Questioning frequencies of students during the experiment

Group	Class	Number of Students	Number of Questions asked	Questions per Student
1	A1	5	15	3
1	A2	5	13	2.6
1	A3	5	10	2
1	A4	5	18	3.6
1	A5	5	16	3.2
2	A1	6	9	1.5
2	A2	6	12	2.
2	A3	6	10	1.67
2	A4	6	15	2.5
2	A5	6	8	1.33
3	A1	12	18	1.5
3	A2	12	19	1.58
3	A3	12	17	1.417
3	A4	8	10	1.25
3	A5	8	17	2.13

In order to investigate which pairs or combinations of means were not equal, the Student-Newman-Keuls test and the Tukey test for the variable AVEQUES were used to generate multiple comparisons. The null hypothesis tested for each pairwise comparison was

Ho: $u_i=u_k$ for i not equal to k

Table 17. The analysis of variance performed on the means for students' questioning rate

Dependent Variable: AVEQUES

Source	DF	Sum of Square	Mean Square	F	PR > F
Model	2	5.188	2.594	11.49	0.0016
Error	12	2.710	0.226		
Total	14	7.898			

The result of the Student-Newman-Keuls test is summarized in Table 18, while the Tukey test is summarized in Table 19.

The Tukey and Student-Newman-Keuls tests are both appropriate for pairwise comparisons following a significant F ratio in the ANOVA when the group sizes are equal. Sometimes, more statistically significant differences are found by using the Student-Newmen-Keuls method as it is the more powerful test statistically.

In this study, both the Student-Newman-Keuls method and the Tukey method produced the same results. In Table 18 and Table 19, it was noted that the means with the same letter are not significantly different. In other words, group one was significantly different from group two and group three; however, group two and group three were not

Table 18. The Student-Newman-Keuls multiple comparison for the variable AVEQUES

Student-Newmann-Keuls test for variable: AVEQUES

ALPHA=0.05 DF=12 MSE=0.225839

SNK GROUPING	MEAN	N	GRP
A	2.9200	5	1
B	1.8000	5	2
B	1.5754	5	3

Means with the same letter are not significantly different.

Table 19. The Tukey studentized range test for variable AVEQUES

Tukey's student range test for variable of AVEQUES

ALPHA=0.05 DF=12 MSE=0.225839

Critical value of studentized range=3.773

Minimum significant difference=0.80186

TUKEY GROUPING	MEAN	N	GRP
A	2.9200	5	1
B	1.8000	5	2
B	1.5754	5	3

Means with the same letter are not significantly different.

significantly different. Thus the following conclusions were made:

1. There were no significant differences in the frequency of questions generated between students verifying CNC programs by working at a microcomputer simulator with a partner and those verifying CNC programs through an instructor.
2. There was a significant difference in the frequency of questions generated between students verifying CNC programs by working at a microcomputer simulator with a partner and those working alone.
3. There was a significant difference in the frequency of questions generated between students verifying CNC program by working at a microcomputer simulator alone and those verifying CNC programs through an instructor.

CHAPTER V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

As stated in the first chapter, the development and application of advanced manufacturing technology is often referred to as the second industrial revolution, and is perceived as being critical to the survival of the manufacturing industry. To prepare young students for a career in modern industry, it is necessary to include both theory and practice of computer numerical control technology as part of their educational program.

Since CNC program simulators can check a CNC machining program on the microcomputer screen before the program runs on a real CNC machine, teachers and students can be sure the program is error-free. This can reduce possible damage to the CNC machine tool. Microcomputer simulators have become an important tool in teaching CNC programming, especially now that the price of microcomputers is becoming more reasonable for training schools.

This chapter presents a summary including the purpose of this study, a brief outline of the research design features, a list of major findings, and an outline of the conclusions relative to these findings. Finally, included in this chapter are recommendations concerning the study's implications for educators and researchers.

Restatement of the problem

Computer numerical control has been depicted as a manufacturing process highly representative of the concept of automation. However, technical education research in this field is relatively rare. This study focused upon an investigation of the effectiveness of instruction methods, including computer simulations, in teaching programming skills for computer numerical control machine programmers in a metal-working laboratory.

The problems posed by this study were:

1. Achievement differences of CNC programming skills between students who used microcomputers alone to simulate CNC programs and those who did not use the microcomputer simulation package.
2. Achievement differences of programming skills between students who used a microcomputer simulator with a partner and those who used a microcomputer simulator individually.
3. Possible effects of students' previous experience in computer concepts, mathematics, and mechanical drafting upon the achievement of CNC programming skills.
4. Differences in the amount of assistance required by students learning CNC programming skills between students who used a microcomputer simulator with a partner, used a microcomputer

alone, and those who did not use a microcomputer simulator at all.

Review of related literature

The Experimenter reviewed three topics from related literature sources:

1. The effectiveness of computer-assisted instruction in the classroom.
2. Comparisons of CNC teaching methods, including microcomputer simulations.
3. The effect of group size on the computer-assisted learning process.

In reference to the success of computer-assisted instruction in the classroom, Roblyer (1985) stated in his meta-analysis that:

1. Supplemental computer-based instruction has greater learning effects than replacing traditional teaching methods completely.
2. The use of computer-assisted instruction significantly reduces instruction time and creates an environment in which attitudes are favorable to computers.

Previous studies related to simulations used in training CNC programmers are relatively rare. Pine (1973) and Olling (1974) conducted separate investigations on the effectiveness of NC programming instructions. Their findings demonstrated that computer-assisted or simulator-aided instruction is effective in developing students' attitudes and interest toward the study of numerical control, but did not demonstrate any significant differences in student achievement while studying "concepts" and "principles".

The effect of group size on computer-assisted instruction has interested many researchers; however, none of the research was related to CNC programming. The results of these studies were somewhat mixed, but showed a group size of two or three does not have any negative effect upon the level of achievement in computer-assisted instruction. On the other hand, group learning does save school districts expensive investments in equipment.

Research method

The research methodology is briefly summarized as follows:

1. Sampling subjects

   The sample consisted of ninety students enrolled at the National Yunlin Institute of Technology in Taiwan during the 1988-1989 school year. These students were all majoring in the mechanical engineering and the mechanical design Associate Degree programs. Their educational backgrounds were equivalent to twelfth grade students or college freshmen in the United States.

   Five classes were selected. Students in each of the five classes were randomly assigned to three groups. For each class, five students were assigned to group one, six students to group two, and seven students to group three. A total of eighteen subjects were selected from each class. The rest of the students in the original class studied with group three.

2. Research design

A pretest-posttest control group design was used in this study. In order to eliminate possible contamination in the experiment, students were not informed of the experimental plan until the end of the data gathering process. All subjects were given a pretest to determine whether they already possessed the information to be learned in the study.

3. Simulation package

A Chinese simulation package was developed by the Multitech Company in Taiwan. The package was built to accommodate personal computers. The major functions of this package included: cataloguing, editing, simulating a CNC lathe program, simulating a CNC mill program, and sending programs to a tape puncher or a CNC machine tool through an RS 232C interface.

4. Instrumentation

Student achievement was measured by two posttest evaluations. The first posttest included fifteen multiple choice problems regarding codes and commands used in CNC programming. Both English and Chinese versions were presented in the evaluation. The second posttest was constructed of thirty mistake/correction type questions from three CNC programs. Students were asked to pick out mistake commands in the program and correct them.

The instrument was evaluated, and revised. The Kuder-Richardson 20 reliability was 0.86.

5. Process of the teaching experiment

The experimental process was completed in three weeks. Each week provided six contact hours of instruction. There were a total of eighteen hours of instruction. The major activities of this study were:

(1) A pretest

(2) Classroom lectures

(3) Demonstrations of a CNC machine tool

(4) Practice of CNC programming by the three groups

(5) Posttest one

(6) Posttest two

Data analysis and findings

Based upon pretest scores, the subjects in this study were considered equally knowledgeable of CNC machine programming prior to the study.

A multiple covariance analysis, using General Linear Model procedures, was used to control error and increase the precision of the analysis. Students' previous experiences in mathematics, mechanical drafting, and computer concepts were used as control variables. Several assumptions have been tested for the valid use of covariance. These tests included:

1. Testing the null hypotheses that the group variances of three different groups in mathematics, mechanical drafting, and computer concept scores are statistically equal.
2. Testing the null hypotheses that the true group means for mathematics, mechanical drafting, and computer concept scores are equal.
3. Testing the hypotheses that the within groups' regression coefficients are equal.

After these assumptions had been confirmed, the pooled regression coefficients of the control variables were tested. Then the posttest scores of the three groups were adjusted by the covariates, and the adjusted means were compared statistically.

The pooled regression coefficients of mathematics, mechanical drafting, and computer concepts were tested to see if these variables were significantly different from zero.

After running the GLM procedure, it was found that the mathematics and mechanical drafting scores did not have a significant effect on the posttest scores. These two variables were then eliminated from further analysis. The only variable significant at the 0.05 level was the previous scores of computer concepts class.

A covariance analysis, using the computer concepts scores as a control variable, was performed. The results are presented in Table

20. The type III sum square of the groups is 22.69, and the PR value is 0.788. It can be concluded that there is no significant difference in achievement among the three groups of students which used computers with a partner, used computers alone, and did not use computers at all.

Table 20. Type III sum squares of the covariance analysis using computer concept scores as a covariate

Source	DF	Type III SS	Mean square	F value	PR > F
GRP	2	22.69	11.35	0.24	0.7880
Computer	1	430.32	430.32	9.06	0.0034

The group means were adjusted for the computer concepts scores. The adjusted means of the three groups were then compared to each other and are reported in Table 15. The results demonstrate that no significant difference in achievement at the 0.05 level was found between any two of the three groups.

The number of questions raised by students during the practice period of programming were recorded. A comparative study was done to evaluate any differences in the number of questions posed by each group.

The results of the analysis of variance (ANOVA) show significant differences at the 0.05 level. The Tukey method and the Student-Neuman-Keuls method were used to examine the pairwise comparisons.

Both methods of analysis produced similar results. The students verifying CNC programs by working at a microcomputer simulator alone had significantly more questions than those working at a microcomputer simulator in teams and those verifying CNC programs through an instructor. The students verifying CNC programs by working at a microcomputer alone did not significantly differ in the rate of questioning from those verifying CNC programs through an instructor.

Conclusions

The conclusions of this study will be presented in terms of the stated hypotheses. Each hypothesis will be restated and followed by a conclusion based upon the statistical analysis of data in this study.

Hypotheses 1 through 3

1. There was no significant effect of mathematics scores upon the achievement of CNC programming skills.
2. There was no significant effect of mechanical drafting scores upon the achievement of CNC programming skills.
3. There was no significant effect of computer concepts scores upon the achievement of programming skills.

Conclusions of hypotheses 1 through 3

The possible effect of previous experiences in computer concepts, mathematics, and mechanical drafting classes upon mastery of CNC programming skills was studied. Only background in a computer concepts class significantly affected student performance in the CNC programming class, while background in mathematics and mechanical drafting did not.

Hypotheses 4 through 7

4. There were no significant achievement differences among the three groups of students which used a computer with a partner, used a computer alone, and the control group which did not have access to computer simulators.
5. There were no significant achievement differences between students working at a microcomputer with a partner and those working alone.
6. There were no significant achievement differences between students verifying CNC programs by microcomputer-simulators individually and those verifying CNC programs through an instructor.
7. There were no significant achievement differences between students working at a microcomputer with a partner and those verifying CNC programs through an instructor.

Conclusions of hypotheses 4 through 7

Based upon the findings presented in Tables 13, 14, and 15, these three different approaches are equally effective for students attempting to obtain knowledge and skills of computer numerical control machine programming. There are no significant difference in achievement regarding the CNC programming skills among the students in the three different treatment groups.

Hypothesis 8

8. There were no significant differences among the three groups of students using a computer with a partner, using a computer alone, and the control group, regarding the numbers of questions asked per student.

Conclusions of hypothesis 8

Based upon the findings presented in Tables 17, 18 and 19, the numbers of questions raised per student in each group were significantly different for the three different teaching approaches. Group one students, those who used program simulation packages individually, had significantly more questions per student than those who used program simulation packages with a partner and those who did not use a microcomputer program simulator at all.

Students who did not use a microcomputer program simulator were allowed to discuss the CNC programs with their classmates during the class session. The students who used a program simulation package with a partner were also allowed to discuss the programs with their teammate. However, the students in group one, who used the microcomputer alone, did not have a partner with whom to discuss their findings. This was considered the main reason for the differences in student performance.

Discussions

Results reveal that course grade in a computer concepts class significantly affected students' performance in a subsequent CNC programming class. However, computer anxiety may be a confounding factor in these results. Computer anxiety usually appears in the form of a negative attitude toward computer technology. The negative attitude includes resistance to talking or even thinking about computers (Chuang, 1988). Many studies have been conducted in the field of computer anxiety. A conclusion was drawn by Cambre and Cook (1985) that there were relationships between exposure to computer terminal use and changes in basic physiological activity regardless of prior computer exposure. Moreover, a significant decrease was found in anxiety as a function of utilization of the computer terminal.

The computer concepts class had a significant effect on students' performance in CNC programming classes. Perhaps those students who had higher scores in the computer concepts class and got higher scores in CNC programming might have a lower level of computer anxiety.

This study found that three different approaches are equally effective for students attempting to obtain knowledge and skills of computer numerical control machine programming. However, it was noticed that during the experimental period students in the groups using computers were more motivated in learning CNC programming skills. Students in the group which did not use computers appeared more passive in the learning activity.

The results of this study also implied that the lack of sufficient expensive CNC machine tools should not reduce the opportunity for students to learn CNC programming and operations. Since microcomputers are very popular in technical institutes and colleges in Taiwan, computer simulation on a microcomputer is a very feasible way of teaching CNC programming.

Since computer simulation is as effective as the traditional method, if computer simulation was used properly, the instructor could spend more time monitoring CNC machine tool operations as opposed to assisting students in programming. The results concerning the number of questions raised per student in the CNC programming class showed that a group of two students who shared a computer had significantly fewer questions per student than those students who used a microcomputer alone. The results support the conclusion that the teacher in a CNC laboratory could spend less time on students when they are working on a computer in pairs. The teacher then could spend more time helping students who are running programs on a CNC machine tool.

The results regarding the optimum group size of teams is consistent with previous suggestions by Larsen (1979) and the previous findings of Trowbridge and Durnin (1984).

Recommendations

Based upon the results of this study, the following recommendations were suggested:

Recommendations for CNC instructors

1. Inexpensive microcomputer simulation package is equally effective and does not have negative effect upon students' learning of CNC programming skills. On the other hand, microcomputer simulation package can help teachers to diagnose and discover possible defects in CNC programs before they are run on a CNC machine tool.
2. It is recommended that a group of two students can better use a microcomputer simulation package; these students need less assistance from an instructor. This arrangement does not have any negative effect upon student achievement, but gives students a chance to discuss findings with their classmates. It is obvious that peer discussions are very helpful in the study of CNC programming skills.
3. Background in computer concepts does provide a slight advantage when learning CNC programming skills. It is thus suggested that computer concepts should be taught in advance of the CNC programming class.

Recommendations for further research

1. Replication of this research at other institutions to measure the possible effects of computer simulation in teaching CNC programming skills is recommended.
2. Other simulation packages are recommended for further similar research, to detect possible differences in students' learning outcome in different simulation packages.
3. Further studies using additional variables, such as computer anxiety, interest, and aptitude, are also recommended.
4. A study should also be conducted to determine whether more exposure to a computer simulator-aided CNC programming class will make any significant difference in student achievement among experimental and control groups. Perhaps doubling the time to 36 hours of instruction could be tested for its potential affects on achievement.

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APPENDIX A.

THE ROUGH SCORES OF THE SUBJECTS

THE ROUGH SCORES OF THE SUBJECTS

OBS	BLK	GRP	MATH	DRAFT	COMPUTER	POSTTEST
1	A1	3	77	84	72	23
2	A1	3	81	87	81	36
3	A1	1	67	85	80	30
4	A1	2	72	85	72	28
5	A1	1	90	88	74	26
6	A1	3	74	74	66	28
7	A1	1	79	84	63	23
8	A1	3	44	74	29	32
9	A1	3	36	78	64	22
10	A1	2	83	80	88	38
11	A1	2	68	84	67	34
12	A1	2	67	73	67	23
13	A1	1	77	80	62	16
14	A1	2	60	75	45	18
15	A1	3	73	80	76	26
16	A1	3	73	86	80	39
17	A1	2	60	78	72	27
18	A1	1	60	78	60	33
19	A2	1	67	62	62	19
20	A2	1	76	60	78	42
21	A2	2	84	61	87	40
22	A2	1	60	74	64	37
23	A2	1	70	49	60	38
24	A2	3	71	81	69	31
25	A2	2	94	84	77	23
26	A2	3	73	67	67	32
27	A2	2	67	72	60	41
28	A2	2	95	74	67	44
29	A2	1	85	67	66	37
30	A2	3	61	69	67	41
31	A2	3	72	78	66	40
32	A2	3	94	72	81	37
33	A2	2	67	75	60	32
34	A2	3	71	65	65	33
35	A2	2	68	60	68	33
36	A2	3	60	81	61	41
37	A3	2	71	73	87	26
38	A3	2	69	70	76	36
39	A3	1	53	63	71	29
40	A3	2	78	63	87	30
41	A3	3	72	67	78	30
42	A3	3	72	82	82	34

43	A3	1	67	73	70	36
44	A3	3	80	80	98	38
45	A3	3	44	61	51	27
46	A3	1	50	61	70	19
47	A3	1	80	69	89	36
48	A3	2	79	65	84	31
49	A3	1	60	63	60	20
50	A3	2	60	63	55	39
51	A3	3	63	68	84	26
52	A3	3	83	71	90	36
53	A3	2	62	66	69	19
54	A3	3	50	68	31	16
55	A4	2	86	65	63	36
56	A4	2	67	78	60	40
57	A4	1	74	83	69	37
58	A4	3	60	76	66	33
59	A4	1	82	60	70	30
60	A4	2	68	50	70	25
61	A4	3	68	60	64	37
62	A4	2	61	77	66	40
63	A4	2	71	91	62	36
64	A4	3	64	79	81	34
65	A4	3	87	70	78	43
66	A4	1	77	75	69	42
67	A4	3	90	73	70	40
68	A4	1	76	62	75	32
69	A4	2	62	60	60	31
70	A4	3	70	70	47	38
71	A4	1	86	60	64	38
72	A4	3	74	73	74	38
73	A5	1	83	73	84	35
74	A5	2	86	75	77	30
75	A5	1	62	81	72	37
76	A5	3	73	82	68	30
77	A5	2	60	76	33	32
78	A5	1	92	81	84	31
79	A5	2	82	67	45	18
80	A5	2	77	69	78	29
81	A5	3	69	82	60	25
82	A5	3	73	81	76	34
83	A5	3	83	79	65	28
84	A5	2	89	75	72	36
85	A5	3	90	68	83	43
86	A5	2	89	77	77	34
87	A5	3	81	67	45	25
88	A5	3	79	79	65	21
89	A5	1	83	77	40	36
90	A5	1	68	71	20	17

APPENDIX B.

ITEM CHARACTERISTICS SUMMARY

ITEM CHARACTERISTICS SUMMARY

item	scale	mean	var.	pt.bis. correlations 1
1	1	0.70	0.21	0.25
2	1	0.91	0.08	0.13
3	1	0.81	0.15	0.25
4	1	0.94	0.05	0.18
5	1	0.84	0.13	0.47
6	1	0.93	0.06	0.33
7	1	0.81	0.15	0.13
8	1	0.74	0.19	0.33
9	1	0.83	0.14	0.02
10	1	0.83	0.14	0.09
11	1	0.74	0.19	0.26
12	1	0.63	0.23	0.35
13	1	0.69	0.21	0.36
14	1	0.92	0.07	0.29
15	1	0.93	0.06	0.32
16	1	0.91	0.08	0.49
17	1	0.44	0.25	0.33
18	1	0.86	0.12	0.26
19	1	0.76	0.18	0.44
20	1	0.64	0.23	0.61
21	1	0.66	0.23	0.40
22	1	0.62	0.24	0.36
23	1	0.67	0.22	0.41
24	1	0.69	0.21	0.59
25	1	0.32	0.22	0.09
26	1	0.81	0.15	0.49
27	1	0.88	0.11	0.51
28	1	0.47	0.25	0.43
29	1	0.91	0.08	0.18
30	1	0.84	0.13	0.05
31	1	0.47	0.25	0.54
32	1	0.59	0.24	0.54
33	1	0.46	0.25	0.49
34	1	0.87	0.12	0.23
35	1	0.73	0.20	0.41
36	1	0.93	0.06	0.14
37	1	0.74	0.19	0.56
38	1	0.60	0.24	0.56
39	1	0.48	0.25	0.44
40	1	0.59	0.24	0.46

41	1	0.52	0.25	0.64
42	1	0.42	0.24	0.57
43	1	0.67	0.22	0.58
44	1	0.54	0.25	0.42
45	1	0.36	0.23	0.42

APPENDIX C.

POSTTEST ONE QUESTIONS

Multiple choice. Select correct codes to their modes of operation.
請把正確的指令或位址圈起來

1. Dwell
   進給暫停
   a. G01
   b. G03
   c. G04
   d. G99

2. Automatic Zero return (automatic home)
   刀具自動回機械原點
   a. G00
   b. G28
   c. G27
   d. G98

3. Cutter radius compensation right
   刀具向右側偏一半徑值
   a. G40
   b. G41
   c. G42
   d. G76

4. Specifies incremental command
   設定增量值座標
   a. G92
   b. G72
   c. G90
   d. G91

5. Return to reference point
   刀具自動由機械原點回到指定的位置
   a. G28
   b. G29
   c. G30
   d. G92

6. Spindle on forward (cw)
   主軸正轉(順時針方向)
   a. M00
   b. M03
   c. M05
   d. M05

7. Program end- rewind stop
   程式終了,紙帶回捲
   a. M00
   b. M01
   c. M02
   d. M30

8. Indicates offset selection
   設定補正編號之位址
   a. N
   b. F
   c. D
   d. P

9. Indicates radius length of arc
   設定圓弧半徑長度之位址
   a. I
   b. K
   c. D
   d. R

10. Indicates tool selection
    選擇刀具
    a. I
    b. K
    c. T
    d. S

11. Indicates miscellaneous functions
    選擇輔助機能
    a. N
    b. P
    c. M
    d. Q

12. Indicates time dwell
    設定暫停時間
    a. P
    b. Q
    c. R
    d. T

13. Sets the mode of operation for preparatory functions
    設定準備機能
    a. G
    b. M
    c. F
    d. P

14. Indicates spindle speed selection
    設定主軸轉速
    a. S
    b. M
    c. N
    d. V

15. Indicates feed rate selection
    設定進給速率
    a. V
    b. S
    c. F
    d. M

APPENDIX D.

POSTTEST TWO QUESTIONS

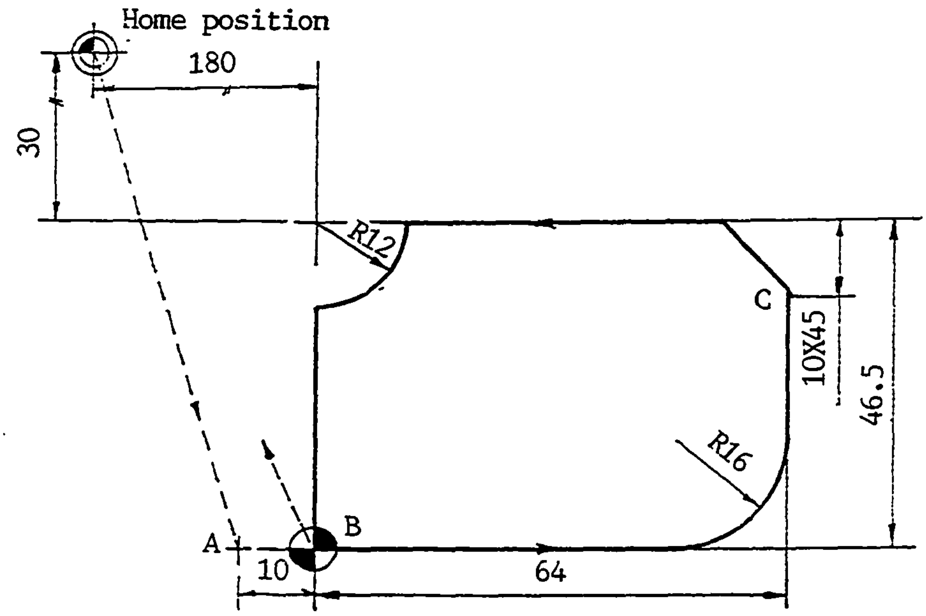
Directions:

Debug the following finish cut part programs.

Read the following programs. Each program may have mistakes in it. For each line of a program indicate any code that may be incorrect by placing an "X" in the appropriate categories to the left. If there is no error mark "X" in the no error column.

PROGRAM 1

	G	X	Y	Z	I	J	M	No Error
N01 G92 X-180.0 Y30.0 Z140.0;	___	___	___	___	___	___	___	___
N02 G90 G00 G18 X-10. Y0 Z-3. S400 M03; (Point A)	___	___	___	___	___	___	___	___
N03 G01 X-48.0 F120;	___	___	___	___	___	___	___	___
N04 G03 X64.0 Y16. I0 J-16.0;	___	___	___	___	___	___	___	___
N05 G91;								
N06 G01 X0 Y36.5 ;	___	___	___	___	___	___	___	___
N07 X48. Y10.;	___	___	___	___	___	___	___	___
N08 X12. Y0;	___	___	___	___	___	___	___	___
N09 G03 X-12. Y-12. I-12. J0;	___	___	___	___	___	___	___	___
N10 G01 X0 Y0; (Point B)	___	___	___	___	___	___	___	___
N11 G00 X-180.0 Y30.0 Z140.0 M05; (Spindle Off)	___	___	___	___	___	___	___	___
N12 M99; (Program Ended)	___	___	___	___	___	___	___	___

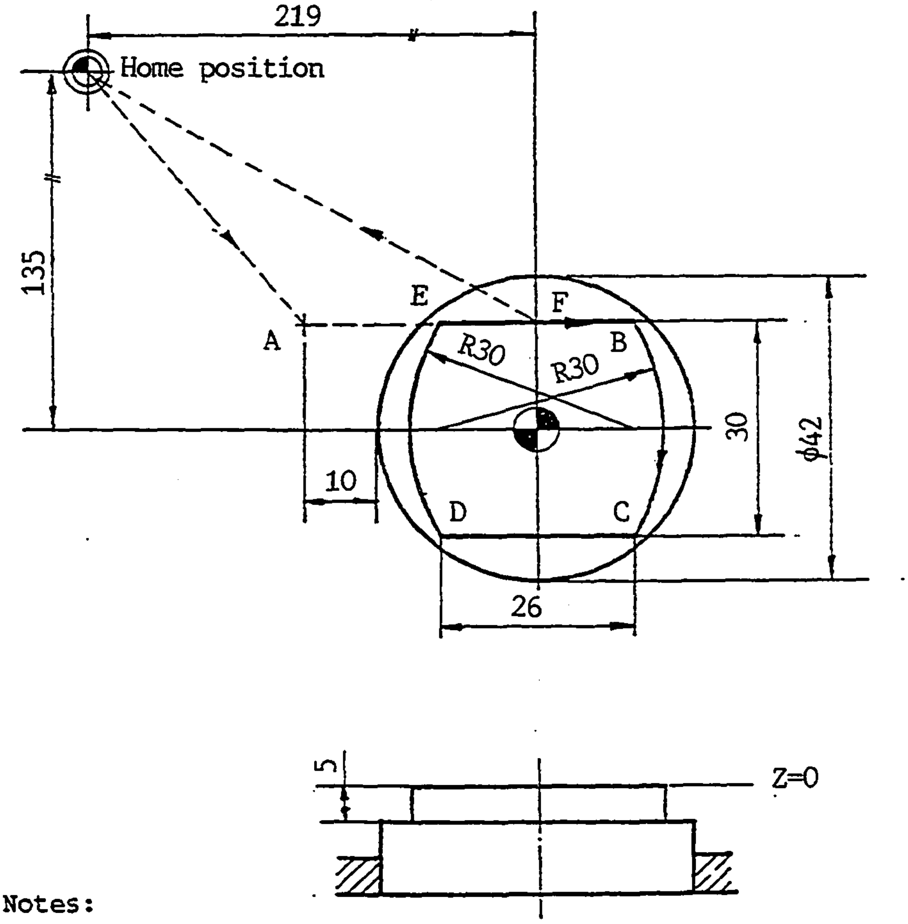


Notes:

1. Please complete the program for milling the perimeter of the part shown on the blue print.
2. The cutter diameter is 20 mm.
3. At the home position, the tool is 85 mm above workpiece surface.
4. The cutting depth is 3 mm.
5. The center of the cutter starts at the home position, moves along the path as indicated in a counter-clockwise direction, then returns to the home position.

PROGRAM 2

	G	X	Y	Z	I	J	M	No Error
N01 G21;								
N02 G92 X219.0 Y135.0 Z35.;	___	___	___	___	___	___	___	___
N03 G90 G00 S300 M03;								
N04 G42 X-31. Y15. D01; (Point A)	___	___	___	___	___	___	___	___
N05 G01 Z-5.0 F80;	___	___	___	___	___	___	___	___
N06 G01 X13.0; (Point B)	___	___	___	___	___	___	___	___
N07 G02 X13. Y-15. I-13. J-15.;	___	___	___	___	___	___	___	___
N08 X-13. Y-15.; (Point D)	___	___	___	___	___	___	___	___
N09 G02 X-13. Y15. I17.2 J15.;	___	___	___	___	___	___	___	___
N10 G01 X0 Y15.0; (Point F)	___	___	___	___	___	___	___	___
N11 G00 G40 X219. Y135. Z35. M05;	___	___	___	___	___	___	___	___
N12 M30;								

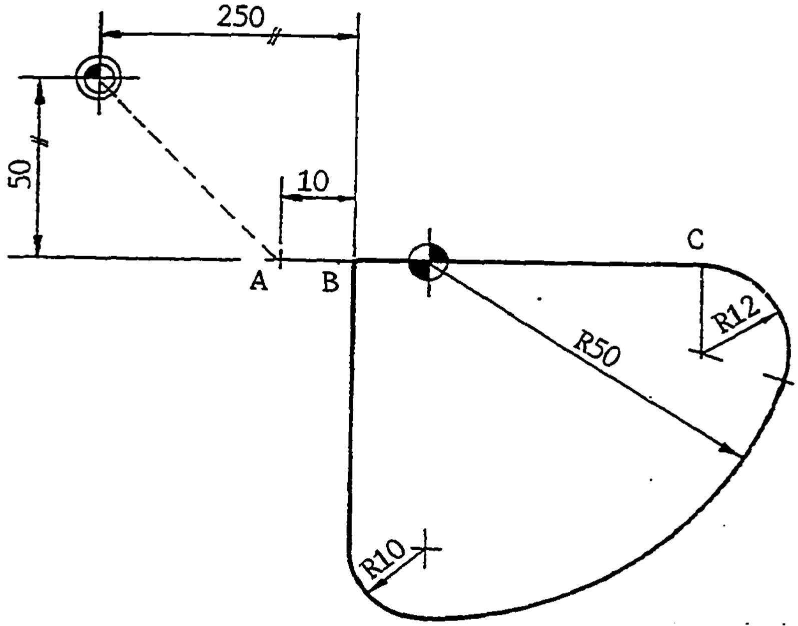


Notes:

1. Please complete the program for milling the perimeter of the part shown on the blue print.
2. The cutter diameter is 16 mm.
3. At the home position, the tool is 35 mm above workpiece surface.
4. The cutting depth is 5 mm.
5. The cutter starts from the home position, and returns to the home position after moving around the part in clockwise direction.
6. The tool diameter compensation has already been taken into account.

PROGRAM 3

	G	X	Y	Z	I	J	M	No Error
N01 G21;	___	___	___	___	___	___	___	___
N02 G92 X250.0 Y50.0 Z85.;	___	___	___	___	___	___	___	___
N03 S800 M03;								
N04 G90 G00 X-20. Y0 Z5.; (Point A)	___	___	___	___	___	___	___	___
N05 G42 G01 X-10. Y0 D02 F80; (Point B)	___	___	___	___	___	___	___	___
N06 X38.0 Y0; (Point C)	___	___	___	___	___	___	___	___
N07 G02 X48.31 Y-15.79 I0 J-12.;	___	___	___	___	___	___	___	___
N08 G02 X0 Y-50.0 I0 J15.789;	___	___	___	___	___	___	___	___
N09 G02 X-10. Y-40. I-10. J10;	___	___	___	___	___	___	___	___
N10 X-10.0 Y0;	___	___	___	___	___	___	___	___
N11 G40 G00 X250. Y50. Z85. M05;	___	___	___	___	___	___	___	___
N12 M30;								



Notes:

1. Please complete the program for milling the perimeter of the part shown on the blue print.
2. The cutter to be used has a diameter of 16 mm.
3. At the fixed zero point, the tool end is 85 mm above workpiece surface.
4. The cutting depth is 5 mm.
5. The cutter starts at the home position and returns to the home position after moving around the part in clockwise direction.
6. The tool diameter compensation has already been taken into account.

APPENDIX E.

OBJECTIVES OF THE COMPUTER NUMERICAL CONTROL CLASS

OBJECTIVES OF THE COMPUTER NUMERICAL CONTROL CLASS

As a result of their learning experiences, the students should be able to:

1. identify the basic steps to be followed in producing machine parts by CNC machines,
2. identify the major advantages and disadvantages of CNC machines,
3. understand the Cartesian coordinate system,
4. identify the major features of the absolute dimensioning system,
5. identify the major features of the incremental dimensioning system,
6. understand the word addresses and their programming formats,
7. select properly preparatory functions including interpolation functions, feed functions, reference point functions, coordinate system and coordinate value functions, and tool diameter compensation functions,
8. select properly miscellaneous functions,
9. write a complete part program for CNC machining,
10. debug existing CNC part programs.

APPENDIX F.

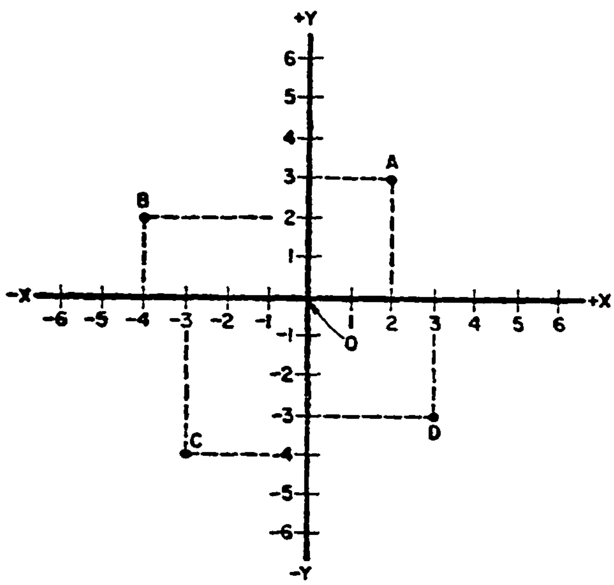
LABORATORY PROBLEMS

Laboratory Problem 1

Coordinate system and coordinate values

Directions:

1. Fill in the blanks below the drawing with appropriate coordinate values.
2. Complete part A in absolute dimensioning system; complete part B in incremental dimensioning system.
3. Cutter starts from point O. It moves in the sequence A, B, C, D, and then returns to O.
4. Each division on the scale is 10 mm.



Part A: Use absolute dimensioning system

```
G90  X20.0  Y30.0;   (O -> A)
     X-40.0  Y____;   (A -> B)
     X-30.0  Y____;   (B -> C)
     X____  Y-30.0;   (C -> D)
     X____  Y____;   (D -> O)
```

Part B: Use incremental dimensioning system.

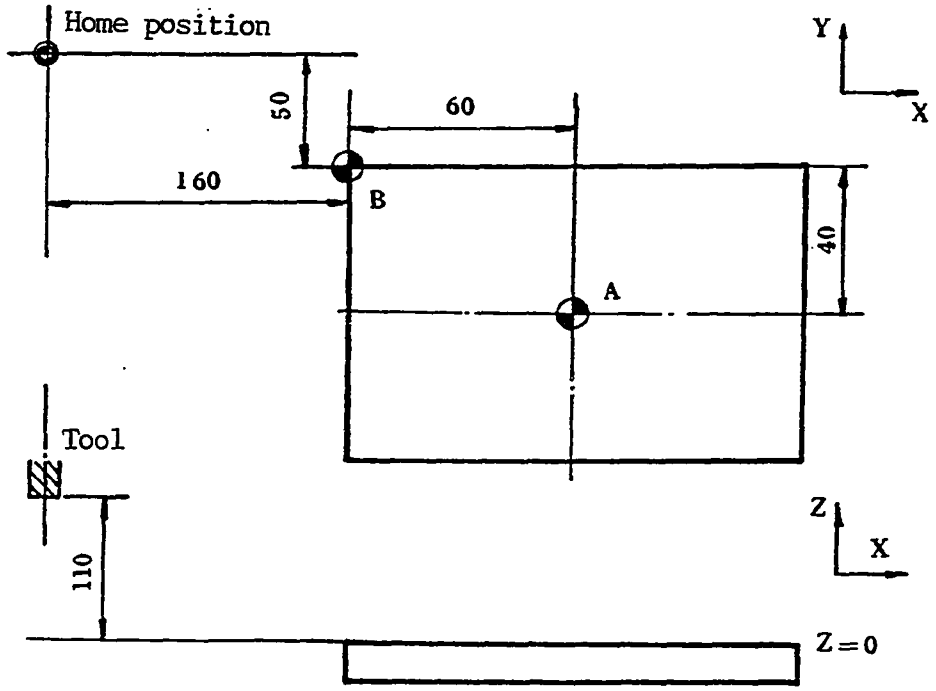
```
G91  X20.0  Y30.0;  (O -> A)
     X____  Y-10.0;  (A -> B)
     X10.0  Y____;  (B -> C)
     X____  Y10.0;   (C -> D)
     X-30.0  Y____;   (D -> O)
```

LABORATORY PROBLEM 2

Setting work coordinate system

Directions:

1. In the blanks below the drawing, fill in the correct coordinate values to set up the work coordinate system.
2. The cutter is at the home position (M). The cutter is 110 mm above the surface of the workpiece.
3. Please choose point A as your coordinate system origin for the first question; choose point B for the second question.



1. Setting point A as the origin of work coordinate system

   G92 X______ Y______ Z______;

2. Setting point B as the origin of work coordinate system.

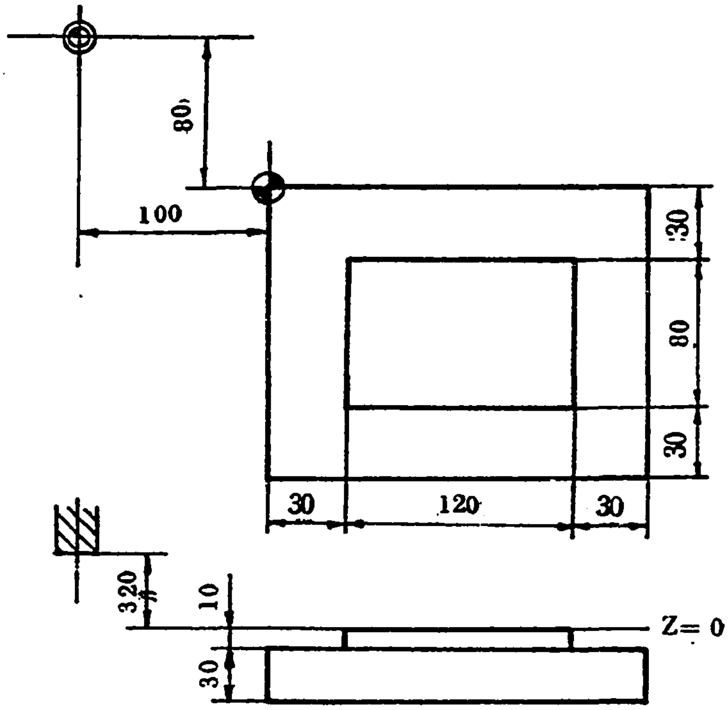
   G92 X______ Y______ Z______;

LABORATORY PROBLEM 3

Positioning and linear interpolation (1)

Directions:

1. Prepare a program for milling the part shown on the blue print.
2. The cutter starts at the home position and then returns to the home position after milling the part in counter clockwise direction.
3. The workpiece is held by a vise on a machine table.
4. The cutter is 320 mm above workpiece surface when at the home position.
5. The cutter to be used is a 20 mm diameter HSS end mill.
6. The material used is aluminum 6061-T6.
7. The surfaces of the aluminum block have already been machined.
8. The dimensions of the aluminum block are 180 mm X 140 mm X 40 mm.

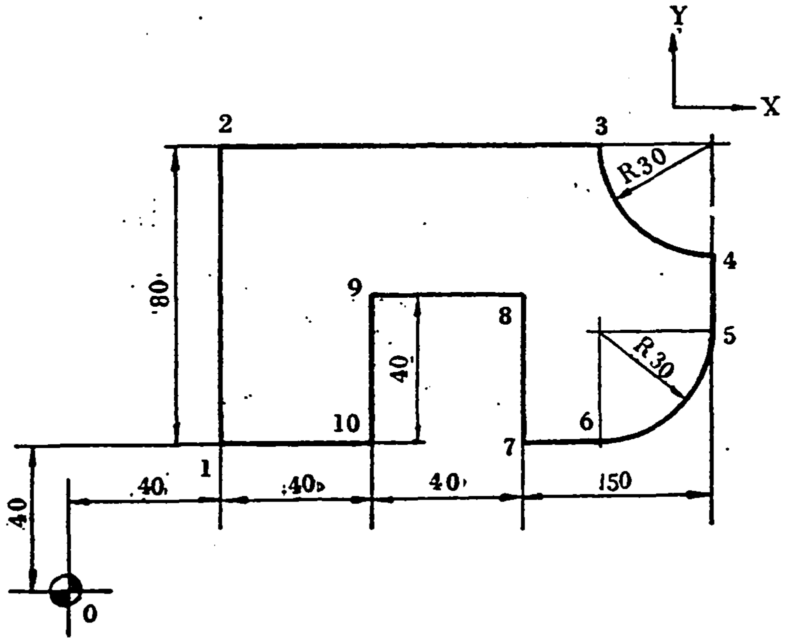

80
100
30
80
30
30
120
30
320
10
Z= 0
30

LABORATORY PROBLEM 4

Circular interpolation (1)

Directions:

1. Prepare a part program for milling the perimeter of the part.
2. The cutter to be used is a 6 mm diameter HSS end mill.
3. The cutter starts from the point O, and returns to point O after cutting the perimeter of the part.
4. The cutter is 30 mm above workpiece surface (Z=0 plane).
5. The cutting depth is 3 mm.
6. Material is aluminum 6061-T6.
7. The programmed path should offset an amount of the end mill radius from the drawing to obtain exact size of the part.

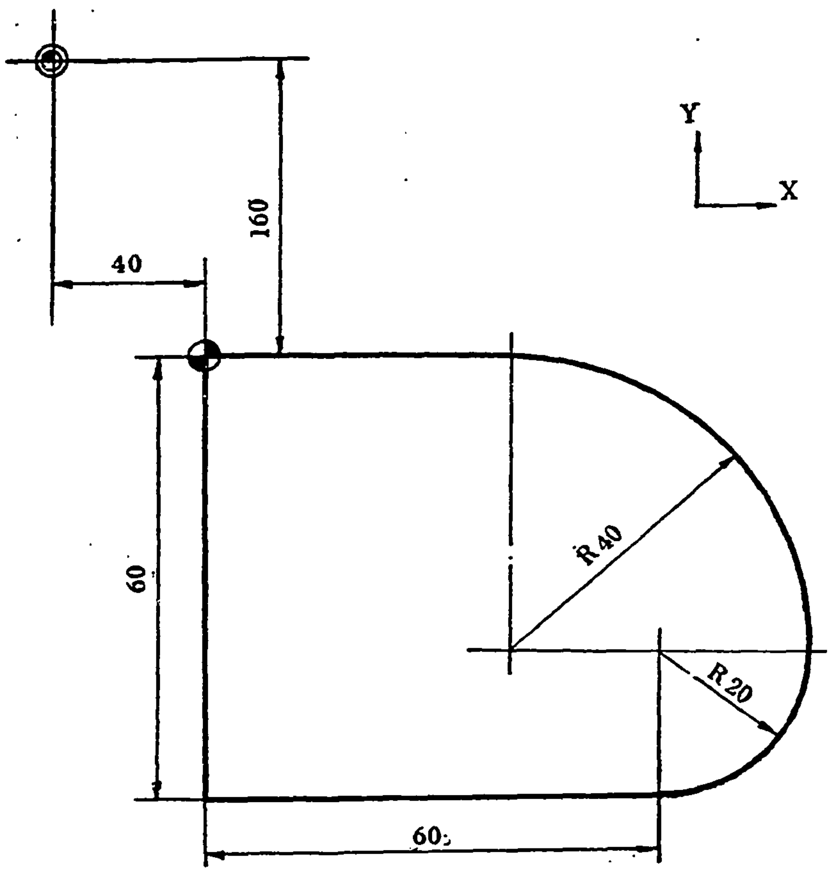

Y
X
2
3
R30
4
80
9
8
5
R30
40
10
6
7
1
40
40
40
150
40
0

LABORATORY PROBLEM 5

Circular interpolation (2)

Directions:

1. Prepare a part program for milling the perimeter of the part.
2. The cutter to be used in an HSS end mill and has a diameter of 20 mm.
3. The cutter starts from the home position and returns to the home position after cutting the perimeter of the part.
4. The exact size of the part as shown on the drawing is required. The tool should travel along the perimeter with suitable offseting.
5. The spindle height is 500 mm, cutter length is 64 mm, and the surface of the workpiece (Z=0 plane) is 10 mm above the machine table.
6. The cutting depth is 8 mm.
7. Material is aluminum 6061-T6.



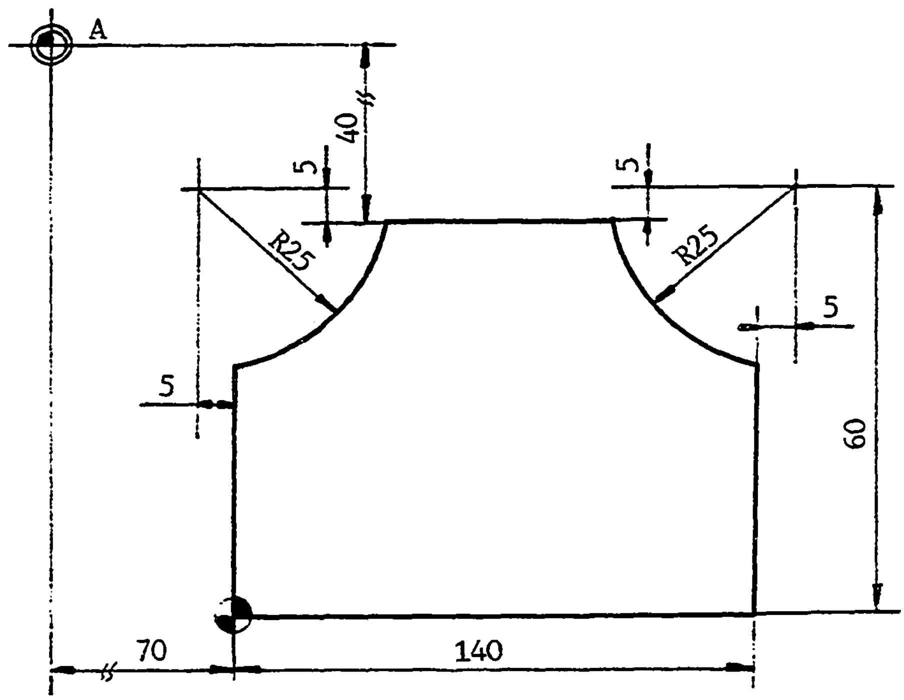
Y
X
40
160
60
R 40
R 20
60

LABORATORY PROBLEM 6

Tool diameter compensation (1)

Directions:

1. Prepare a part program for milling the perimeter of the part.
2. The cutter to be used in a HSS end mill and has a diameter of 20 mm.
3. The cutter starts from point A and returns to point A after cutting the perimeter of the part.
4. The cutter is 35 mm above workpiece at point A.
5. The cutting depth is 8 mm.
6. Material is aluminum 6061-T6.
7. The tool diameter compensation using G40, G41, and G42 must be taken into account.

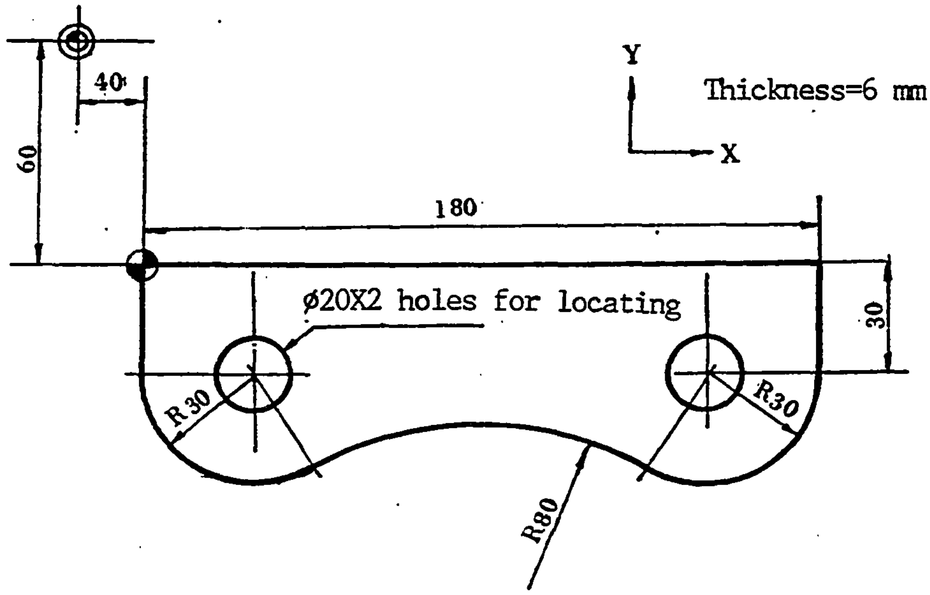

A
40
5
5
R25
R25
5
5
60
70
140

LABORATORY PROBLEM 7

Tool diameter compensation (2)

Directions:

1. Prepare a part program for milling the perimeter of the part.
2. The cutter to be used in a HSS end mill and has a diameter of 20 mm.
3. The cutter starts from the home position and returns to the home position after cutting the perimeter of the part.
4. The spindle height is 500 mm, cutter length is 64 mm, and the surface of the workpiece (Z=0 plane) is 10 mm above the machine table.
5. The cutting depth is 6 mm.
6. Material is aluminum 6061-T6.
7. The tool diameter compensation using G40, G41, and G42 must be taken into account.



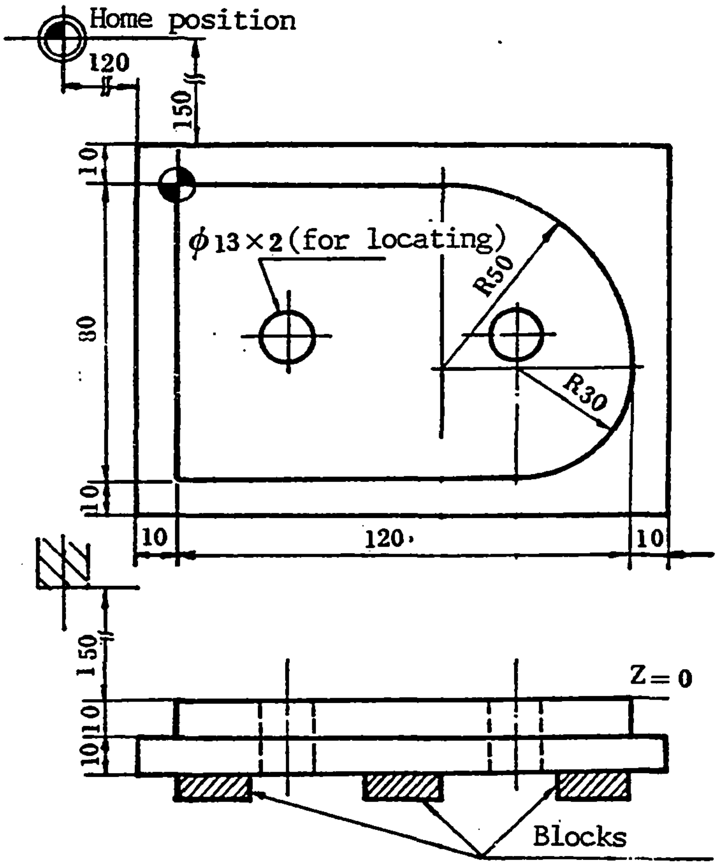
Y
X
Thickness=6 mm
40
60
180
30
ø20X2 holes for locating
R30
R30
R80

LABORATORY PROBLEM 8

Tool diameter compensation (3)

Directions:

1. Prepare a part program for milling the perimeter of the part.
2. The cutter to be used in a HSS end mill and has a diameter of 20 mm.
3. The cutter starts from the home position, and returns to the home position after cutting the part.
4. The spindle height is 500 mm, cutter length is 64 mm, and the surface of the workpiece (Z=0 plane) is 10 mm above the machine table.
5. The cutting depth is 10 mm.
6. Material is aluminum 6061-T6.
7. The surfaces of the aluminum blocks have already been machined.
8. The dimensions of the aluminum block are 140 mm X 100 mm X 20 mm.
9. The tool diameter compensation using G40, G41, and G42 should be taken into account.



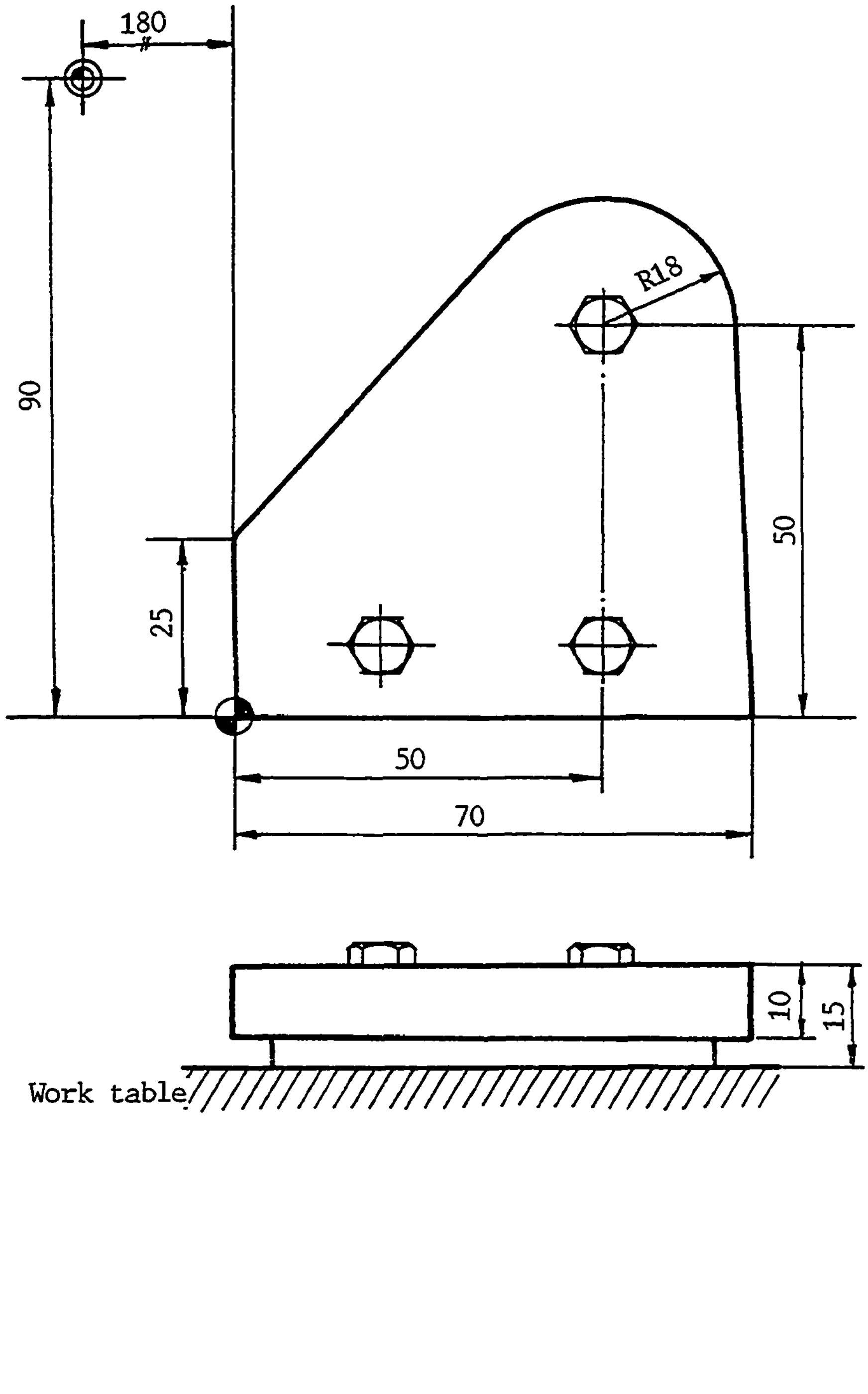
Home position
120
150
10
80
10
ϕ13×2(for locating)
R50
R30
10
120
10
150
Z=0
10
10
Blocks

LABORATORY PROBLEM 9

Tool diameter compensation (4)

Directions:

1. Prepare a part program for milling the perimeter of the part shown on the blue print.
2. The cutter starts from the home position and returns to the home position after moving around the part in counter clockwise direction.
3. The spindle height is 500 mm. The cutter length is 65 mm.
4. The workpiece is held on a machine table by bolts and nuts through the three holes on the top. The workpiece surface is 25 mm above the work table surface.
5. The cutter to be used is a HSS end mill and has a diameter of 20 mm.
6. The tool diameter compensation using G40, G41, and G42 must be taken into account.


180
90
R18
25
50
50
70
10
15
Work table

APPENDIX G.

PLOT OF COMPUTER CONCEPTS SCORES BY POSTTEST SCORES

PLOT OF POSTTEST*COMPUTER

LEGEND: A = 1 OBS, B = 2 OBS, ETC.

```
POSTTEST |                                  A
         |                                   A   B  A
         |                              AA  A
40       +                              A  B A        A
         |                            A           A
         |                        A     A CA AAA   A  A    A
         |                    A          AA  AA A  A   B
35       +                                          A
         |                                  A   AA B
         |               A A            B  BB   A
         |                              A    A      B
30       +                                  AA   BA   A
         |                                    A  A
         |                          A      B  B
         |                                     AA   A A
25       +                       A      A    A
         |
         |                                B A A  A
         |                                 A
20       +                              A
         |                               A   B
         |          A           B
         |                A              A
15       +
         |
         |
         |
10       +
         -+----+----+----+----+----+----+----+----+----+----+----+----+----
          0   10   20   30   40   50   60   70   80   90   100  110

                                   COMPUTER
```