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Curriculum Development for Computer Numerical Control Course

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CURRICULUM DEVELOPMENT FOR
COMPUTER NUMERICAL
CONTROL COURSE

BY

Brad Curry

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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ABSTRACT

This study analyzed the past Machine Tool Advanced Skills Technology (MAST), and the National Institute for Metalworking Skills, Inc (NIMS) standards of workforce competency to be used to develop a curriculum, learning objectives and skill sets need by industry for a course on CNC machining. Instructional methods and strategies for delivery were determined for best practices. The coursework was designed and delivered, with an analysis of student learning based on learning objectives performed. Students were surveyed in regard to their understanding of the material covered in the course.

Categories of knowledge needed include machining knowledge about tooling and tool selection, CNC machine utilization, operational procedures, programming g-codes, programming coordinate positions, programming correct g-code syntax and acquisition of skills related to set-up, operate and program a CNC machine.

The research and subsequent delivery of training tried to define and achieve a fully competent individual in CNC machining within the context of a 15 week college course. The research yielded students capable of programming and setting up a CNC machine but found students lacking in basic machining theory and application indicating that students were not prepared to be fully competent for industry after taking the course.

ACKNOWLEDGEMENT

This work is the accumulation of the past 20 years of work experience consistently looking for a better way. My journey in the machine tool trades started out in a saw room pushing a broom and brought me here. As a result, there are many people that I have to thank for helping me to get to where I am today.

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CHAPTER 1

INTRODUCTION

CNC machining has been a dominant manufacturing practice in industry for machining of parts for over 40 years. CNC stands for computer numerical control and is a machining process whereby a computer controller automatically operates a variety of machine-tool movements to form and shape precision parts. The advent of CNC machining originally started after World War II as a way to increase production and efficiency in industry. Since that time the trend in the precision machining industry has been away from traditional manual machining methods and towards more and more CNC machinery that are now available and capable of running in three, four or five axes of movement. CNC machines offer the following advantages to traditional machining methods:

- Better control and accuracy
- Improved part quality and repeatability
- Reduced tooling expenses, tooling costs and job set up times
- Reduced production times
- Scrap reduction
- Better production and job planning

All of these advantages together can provide a great financial reward to companies that invest in CNC equipment (Valentino, 2003). A modern machine shop environment is primarily composed of CNC machines today. While some companies may still have a few manual machines around, these are typically utilized for one or two piece production runs or in company tool rooms and generally are not used for high quantity production.

The Society of Manufacturing Engineers (SME) in a recent report has recommended that educators and industry come together to "improve the consistency and qualities of manufacturing curricula to better prepare students for manufacturing employment. (Engineers, 2012) With industry and technology continuing to utilize CNC as the main method of part production it is imperative that a student who is majoring in industrial technology or other related disciplines in manufacturing or engineering be informed about the applications and use of CNC in the workplace. CNC machining and programming can be a very complex task for individuals to master. It is imperative that a student studying manufacturing technology get a firm grasp in the use and application of CNC machine tools.

Purpose of the Study

Eastern Illinois University has offered a course in computer numerical control programming to students for many years. The course was taught as mostly lecture with some application exercises performed on an older retrofitted Clausing/Kondia knee mill (Figure 1) with a controller that utilized conversational language that was proprietary to the machine. The department was the grant recipient of a new Bridgeport VMC (Figure 2) with Fanuc Controller to use in updating the CIM lab with more modern equipment.

The purpose of this study is to develop the curriculum for a college level course on Computer Numerical Control machining processes that can be utilized in a college course and in an industry training program to teach individuals to be able to operate and program CNC equipment. The goal of the research is not to merely have the course be steeped in the theory of CNC, but to align the curriculum with industry standards and to provide a competency based curriculum that will enable technology students participating in the course to go beyond just general knowledge about CNC terminology and programming language but to be able to actively write and create part programs that will enhance a student's career readiness for entry into a manufacturing or manufacturing management position.

Figure 1. Clausing/Kondia Knee Mill

Figure 2. Bridgeport VMC with Fanuc Controller

Statement of the Problem

There are a variety of questions that need to be looked at when designing curriculum for a course. The first problem that exists in regard to a course on CNC is whether an individual can become proficient in the use and application of CNC in the timespan of a fifteen week college class that would typically provide roughly 40-45 hours' worth of instruction? Are individuals capable of handling and processing all of the required information in the cognitive, affective, and psychomotor learning domains for retention and application in such a short amount of time? What knowledge does an individual need to possess before taking a class on CNC? What needs to be taught in that time period to insure proficiency of skills and mastery of subject? What are the most important aspects that should be taught? What should a student know and be able to do upon completion of the course?

These are all questions that both education and industry need to be looking at for all types of manufacturing jobs. This paper will look exclusively at these questions in terms of learning computer numeric control in a traditional university setting for students majoring in Industrial Technology.

The major program is intended to prepare individuals for technical or management positions in business, industry, education or government. The CNC class consists of a fifteen week program that incorporates three hours of lecture and three hours of lab each week. The goal of the paper is to determine a best practice for designing a CNC curriculum for the course that will be both effective and relevant in teaching industrial technology students so that they will be able to enter the manufacturing world and have a thorough understanding of how to utilize CNC equipment in their job setting.

The paper will address what knowledge and skills are needed to perform CNC operations and then address appropriate teaching methods and strategies to use in the design of the course. Curriculum and coursework will be written and taught to a group of students to test the appropriateness of the material to determine if it matches student's current level of knowledge and skills and sufficiently challenges students to achieve and learn the next higher level of knowledge, understanding and skills needed.

Principle Research Questions

What should be covered in a modern CNC course to ensure that students are taught the required knowledge and skills needed by industry to prepare students for technical positions in the manufacturing industry?

Additional feedback will be gained from students participating in a CNC course utilizing curriculum developed from the research to try to determine the impact the curriculum had on learning the subject material.

Justification

Look at any trade publication on machining and there will be some mention of the skills gap in manufacturing that exists. (Zelinski, 2013) Skilled trade workers continue to be among the most in demand jobs and the hardest to fill according to Manpower Groups 2012 Talent Shortage Survey. (Heckel, 2013) This echoes multiple pronouncements in industry that continue to cry out for more qualified workers. Technology changes rapidly and universities must continue to teach and prepare degreed individuals with classwork that will challenge them academically and provide students with the knowledge and skills they will need to have to be successful and meet employers expectations when they enter the workforce.

Past coursework taught at EIU did not fully meet industry standards in regard to current CNC machining application and g-code programming and needs to be reviewed to make better use of the Bridgeport VMC equipment in the Technology Departments CIM laboratory. A course curriculum that is more aligned with industry standards and competency based will generate a better understanding of the role CNC equipment plays in manufacturing. Hands on skills learned in a lab setting will also provide students with more relevant learning that will help prepare them for entry into a career in manufacturing.

Limitations

This study was limited by the researcher to one semester of course work done by a class at Eastern Illinois University in the spring semester of 2009. The course was catalogued as INT 3203 for Computer Numeric Control Programming and is a 3 credit course with a prerequisite of INT 3113 for Manufacturing Machine Processes. This course is now AET 3203. Student population consisted of 13 students from the School of Technology all majoring in Production Management or Career and Technical Education within the Industrial Technology major. CNC coursework was limited to the topic of CNC machining related to milling machine processes and did not cover CNC usage on Lathes or other machines that take advantage of the CNC application.

Significance of the Study

This study will provide an up to date curriculum and course materials related to state of the art CNC milling equipment used in industry. An instructor that has a better understanding of what needs to be taught is better prepared to provide relevant instruction for students that need to learn the material required for eventual job performance. The study will also address key points for academia recommended by SME in their report *Workforce Imperative: A Manufacturing Education Strategy.* (Engineers, 2012)

Definition of Terms

There are several terms used in the paper that have specific meaning in the context of machining language that also hold different meaning when used in everyday conversation. For sake of clarity and to enable the reader to be sure of the meaning intended, this definition of terms is included.

CAD/CAM: Computer Aided Design/Computer Aided Manufacturing (Valentino, 2003).

Cartesian Coordinates: A system for defining a point in space relative to a zero position. The point is located by specifying its distance along three mutually perpendicular axes (X,Y, Z) that intersect at a zero point of origin (Valentino, 2003).

CNC: Stands for computer numerical control. CNC is a system of manufacturing parts by using an on-board computer or machine control unit (MCU) to control an NC machine (Valentino, 2003).

G Code: A code in word address format that signals for a preparatory function to follow. G codes initiate such operations as drilling, milling, and canned cycle execution (Valentino, 2003).

Machining Center: A CNC machine that, at one setup, is capable of executing such operations as milling, drilling, boring, tapping, and reaming on one or more faces of a part (Valentino, 2003).

Manual data input (MDI): a feature of a control system that allows the operator to manually key in a program or alter the commands of an inputted program (Valentino, 2003).

Manual part programming: The preparation of a manuscript in machine control language and format to define a sequence of commands for use on a CNC machine (Valentino, 2003).

Part programmer: A person who prepares the planned sequence of events for the operation of a CNC machine (Valentino, 2003).

Part programs: A complete set of instructions written by a part programmer in a programming language (word address, etc.). The MCU follows the part program's instructions in manufacturing the part (Valentino, 2003).

Shop traveler: A sequenced list of steps used by a machine shop to indicate what needs to be done to a part and where to move a part from one machining operation or process to another to manufacture a part complete.

Tooling: the tool holders and cutting tools used in the machining processes to make a part i.e. center drills, drills, taps, endmills, collets, reamers, collet nuts, and adaptors.

Tooling Sheet: A list of cutting tools, their tool lengths, cutting application and their corresponding tool number in a program to help an operator set up and run a CNC machine.

Word: An ordered set of characters used to execute a specific action of a machine tool (Valentino, 2003).

Word address format: A system of coding instructions whereby each word in a block is addressed by using one or more alphabetic characters identifying the meaning of the word (Valentino, 2003).

Workholding: the methods used to hold a part while machining operations are performed.

Summary

Manufacturing, engineering, government and other professional organizations have all been stating the existence of a skills gap in workforce preparation for many years. Since Higher Education facilities are a part of the supply line to prepare workers for entry into these fields it is critical for coursework to be relevant, up to date and meet competency objectives needed by industry for individuals to start working and contributing to a company's bottom line as quickly and efficiently as possible. This study will try to provide the answers to what needs to be taught in a CNC course through an in depth review of industry competencies and standards.

CHAPTER 2

LITERATURE REVIEW

A current issue that exists for CNC machining and industry is how to recruit new individuals to industry and then effectively train them. (Free, 2013)Industry as a whole has seen a reduction in the workforce but there remains a demand for qualified, highly skilled CNC programmers and machinists. In fact, according to the U.S. Occupational Outlook Handbook, "Computer control programmers and operators should have excellent job opportunities despite the projected slow decline in employment. Due to the limited number of people entering training programs, employers are expected to continue to have difficulty finding workers with the necessary skills and knowledge"(Bureau of Labor Statistics, 2008). While the modern manufacturing environment has utilized technological advances to increase production and efficiency by utilizing better and faster machinery and equipment, there will remain the demand for highly skilled workers to program, run and operate this equipment.

Another reason for an increased demand for highly skilled workers is largely due to the loss of manufacturing employees as they become old enough to retire. These retirements are causing a loss of collective knowledge from years of machine experience that will no longer be available as these workers leave. Many in the industry are already feeling the pinch. There's an industry wide call for a more educated manufacturing workforce and new programs and university/industrial alliances have been formed recently (Katz 2008).

The focus of these programs will, of course, be on training and development of a newer and younger workforce. This training will require a different focus and methods then the training that occurred before. Traditionally the training for these types of jobs was done through high school and community college technology classes. According to Field (2004) however, "For the past 10 years or so, high schools and community colleges—primary sources for skill training for the machine shop industry—have been decreasing the number of classes being taught (p. 115). Industry and trade groups did not help the matter either as there were no demands made upon the traditional training and education channels to maintain and keep current on shop courses. By 2004, the needs of industry finally spoke out and the Student Summit at the International Manufacturing Technology Show (IMTS) began a movement to bring machining back to high schools and community colleges. (Field, 2004)

Industry must lead the way to train a newer work force. Training will continue to be very important for industry because according to Peter Zelinski, "Shops across the country speak of their growing difficulty in filling the sorts of positions that once would have been filled by machinists who arrive already having the skills needed for the job." (Ask the Teacher section, para. 3) Another result of the lack of skilled workers is to outsource jobs. According to Jerry Field, one of the problems pointed out during IMTS 2004 was that "Jobs had to be outsourced because highly skilled employees required to run the new equipment were not coming through the traditional training and education channels." (2004) Industry must act fast if so many manufacturing companies across the nation are experiencing shortages and having to outsource work due to a lack of individuals available to do the work.

Traditional training for machining and CNC has been through Vocational schools and Apprenticeship programs. These programs usually run two to four years and provide hands on experience while the students work on the job during the day and then take classes in the evenings. Coursework typically teaches shop math, blueprint reading, machining practices and machining theory. CNC coursework was reserved for the end of technical training and only available to the individual that proved high proficiency and understanding in all of the machining disciplines such as machine setup, tool selection, material selection, material removal rates and other critical knowledge that is viewed as essential to a thorough understanding of CNC application.

While this may have been an effective way to train workers in past years, it is no longer appearing to be so. Zelinski (2008) states that companies "hire employees for shop floor positions who had no formal machine-shop training… because the skilled employees were getting too hard to find" (Molding Personnel section, para. 3). Employer's need people that are fully functioning at the job and do not tend to want to invest in long term company training programs in house or do not have the resources to develop these types on training programs. Today's machine tool technology moves at an amazingly fast pace, especially CNC equipment. Fast pace and ability to respond quickly to customer needs represents the current trends in technology that require constant change and re-education to stay up to date and competitive in the manufacturing world. In such a fast paced and fluid environment it becomes imperative that training also be fast paced and up-to-date to meet the demands of industry. No longer will manufacturers be able to wait two to four years for an employee to be thoroughly trained. The employee will need to learn what needs to be known as soon as possible so that he or she will be able to start performing right away.

While the researcher has been involved in the machine tool industry for many years and has a fairly good grasp of the requirements to be considered competent in CNC programming, it still is imperative to look at other materials and publications to seek out additional resources and best practices. In regard to course design for industrial technology education, Gerhard Salinger (2005) states three questions concerning the design process in technology education:

> "The first question is "what is the goal?" The second question is "what is the evidence you will accept that the goal is achieved?" This does not mean how you obtain the evidence – but what success looks like. What will you know and be able to do if you reach the goal? Then, and only then, the third step is to develop the activities to reach the goal." (p. 2)

Salinger was referencing these questions as a way for technology educators to think in regards to education in the classroom. It is this reference that the writer takes into consideration in determining the goals needed for making an improvement to CNC curriculum and course content and the objectives that will be observed to determine student success.

The Skill Sets and Curriculum

Before a discussion of the skill sets and curriculum used to address the issue of designing an effective CNC curriculum can occur, one must first take a look at the learner and try to make a determination as to the learner's conceptual framework in regards to machine tools. What prior knowledge base and skill set does the typical Industrial Technology College student possess? How will the student's previous knowledge acquisition and retention affect levels of learning that occur during the course of the fifteen week semester? What previous coursework has been undertaken that may have an effect on additional learning? Once these questions have been answered then decisions about course content and curriculum can be made.

Industry examples previously shown have already informed the reader that proficiency on a CNC machine tool requires a student to develop "the necessary skills and knowledge." (Bureau of Labor Statistics, 2008) One must now establish what is deemed to be necessary. Just as in industry, it is important for the curriculum designer of any course work to establish protocols for teaching both skills and knowledge. One must look to industry for a description of what those skills and knowledge levels will be.

According to the Illinois Occupational Skills Standards there are five skill standards for CNC milling machines. They include the following:

- Write a program, including speeds and feeds, to drive an endmill through a continuous path around three sides of a part requiring the development of a linear interpolation tool path as well as circular interpolation. Store the program on computer media (Illinois occupational Skill Standards and Credentialing Council, IL.96.MFG.MACH.42).
- Operate a CNC mill, change tool values as necessary and replace and qualify tooling as necessary (Illinois Occupational Skill Standards and Credentialing Council, IL.96.MFG.MACH.43).
- Write a program to drive a collection of tooling through the toolpaths needed to produce the part shown on the blueprint. The program will require change of tools, change of planes and use of "canned cycles" and tool offsets. Use a computer to write and store the program (Illinois Occupational Skill Standards and Credentialing Council, Il.96.MFG.MACH.63)
- Use a graphics-based software package to develop a program to drive a collection of tooling through the toolpaths needed to produce the part shown on the blueprint. The program will require change of tools, change of planes and use of "canned cycles" and tool offsets (Illinois Occupational Skill Standards and Credentialing Council, IL.96.MFG.MACH.64).

- Set up the tooling and workpiece. Qualify the workpiece to the control. Prepare tools or load tools into tool magazine as required; qualify the tools to the control with respect to the work; match their identity to the program. Establish initial tool values or offsets. The part specified should have at least two steps with +-.001 tolerances, one Unified National Coarse (UNC) tapped hole and an arc/tangent surface and require the use of at least one canned cycle available on the mill (Illinois Occupational Skill Standards and Credentialing Council, IL.96.MFG.MACH.65).

The Illinois Occupational Skills Standards that have been developed were adapted from national skills standards for machining. There have also been several skills standards developed by industry over the last fifteen years that can also be looked at to determine what skills training would be needed. They include programs such as Machine Tool Advanced Skills Technology (MAST), and the National Institute for Metalworking Skills, Inc. (NIMS) Competency-Based Apprenticeship System for the Metalworking Industry Curriculum Guide. These programs, with their industry focus, are a lot more in depth and geared more towards training skilled machinists as well as CNC programmers and operators instead of college students working on a degree in Industrial Technology. This poses no problems for their use in the design of classroom curriculum as more and more industry looks to fill positions with degreed individuals.

The MAST program prepared in 1996, utilized a DACUM process to identify job duties and tasks performed by a machinist and then developed a recommended curriculum based on the findings by Texas State Technical College that performed the DACUM. The MAST program presented the researcher with information that encompasses all areas of knowledge and skills needed for a CNC machinist or CNC programmer. This DACUM and the information collected back in the early 1990s is of course a valuable resource for a current course design, however for the scope of this particular class all that information is not needed. It is however a great resource to cherry pick items specifically related to CNC programming in order to take a look at the knowledge and skills that a student should have upon leaving a class on CNC.

A review of the MAST (1996) list of technical workplace competencies for Tool and Die Maker finds several areas of knowledge and skills required for the operation of CNC equipment. These competencies are as follows:

"E. Demonstrate Knowledge of Manufacturing Processes

1. Know Operation of Vertical and Horizontal Mills and Tooling

e. Explain milling processes

f. Discuss milling machine safety

g. Discuss CNC machining centers and processes

h. Calculate speeds and feeds based on materials and tooling

i. Set-up and operate CNC machining center

F. Perform CNC Programming/CAM Tasks

1. Prepare and plan for CNC machining operations

a. Plan sequence of machining events

b. Determine proper tooling/fixtures required for machining

c. Calculate speeds, feeds, and depth of cut for machining

d. Explain the x, y, and z, axis on CNC machines

2. Select and Use Tooling Systems for CNC Machines

3. Manually Program CNC Machines

    a. Plan and write programs for CNC machines

    b. Use MDI panel on machine to program/edit programs

    c. Set and use tooling offsets at CNC machine

    d. Discuss/use canned or bar cycles in program

4. Use Computer-Aided Manufacturing(CAM) System

    a. Create toolpath geometry using CAM system

    b. Interconvert CAD and CAM files using acceptable exchange format

    c. Transfer files from CAM system to machine

    d. Configure CAM system parameters (p. 24-27)"

The researcher would like to note that this information is almost 20 years old and while still valuable, changes have come along in that 20 years so it's a baseline but may not have all the answers to the questions that are currently being sought.

For a more current list the researcher reviewed the NIMS documentation on CNC programming and the list of tasks required for individuals to be able to perform in order to gain the NIMS certification for CNC programming. NIMS is currently getting more distribution throughout the country and is becoming widely excepted as a way to prove out competency in the machine-tool industry. Several community colleges in Illinois have adopted the NIMS certification and do have their students seek out these certificates as part of their curriculum and training programs for associates of science degree. Danville area community college in Danville Illinois and the Chicago city colleges in Chicago Illinois have all adopted and started to use these certificates as part of their curriculum. Students specifically work towards the benchwork certificate and the measurement certificate. The

CNC programming certificate may not be a part of the community college curriculum as yet but community colleges use of the lower certificates definitely gives credit to the validity of the certificates towards training new individuals to learn the knowledge and skills needed to be able to perform these tasks.

The NIMS (2006) standards and competencies also appear to be derived from some form of DACUM process. Their documentation provides a Credentialing Achievement Record (CAR) for use in their CNC credentialing program. This CAR is a skill checklist to follow and provides a tremendous amount of information about what knowledge and skills should be a part of the curriculum. Many of the KSA's on the CAR are the same as the ones found on MAST's and on the Illinois Skills council's list.

As one looks over the definition of skills needed to perform the jobs, one realizes that these are highly technical. The definition of skills makes an assumption that a student already has a prior knowledge base with which to work from and build upon. The typical college student studying Industrial Technology may or may not have this knowledge base so any instructional design would have to take this into account and plan for the possible inclusion in instruction of other related topics. These related topics include safety, mathematics including geometry and trigonometry, linear measurement techniques, material properties, cutting tools, blueprint reading and interpretation, and workholding. The course designer can utilize these resources but may not be able to fully incorporate all of the skill sets into the training for a variety of reasons.

Teaching Methods and Strategies

Experienced teachers in CNC programming have noted that students experience "frustration and apprehension" while attempting to learn CNC programming. It is believed that this frustration and apprehension is due to the "number of separate operations they must master." (Payne and Creger, 2000) Ndahi noted that a CNC user "must be familiar with the programming language, the process of writing a program, and the basic skills and practices that are required to safely and efficiently use the machine."(Ndahi, 1999) What is not mentioned is how much information, skills and knowledge a student needs to be able to safely and efficiently use the machine.

Perhaps a better way to look at what skills and knowledge will be required of Industrial Technology students is to look at a study done on CNC machining that compares individuals that received different training methods for programming to potential changes in their cognition level. Such a study was done by Martin and Beach (1992). The study took a look at 45 individuals involved in some fashion with CNC machining and tried to determine how these individuals had arrived at their skill and knowledge sets and what cognitive changes occurred with the introduction of CNC machining. (Martin & Beach, 1992)

This research provides a curriculum designer with some very important information concerning all the educational domains that must be accessed for a student to effectively learn CNC programming. According to the authors, the study showed the following in regard to learning:

> "Knowledge and skills associated with CNC machining do not exist independently of mechanical machining knowledge and skills. When an experienced machinist learns programming and the use of CNC machines, some of what occurs mentally is transformational such as thinking more linearly... some of it is discontinuous... learning the programming syntax... and some of it is continuous... knowing the speed

you need to turn a particular type of stock. Information used... is accessed directly through the sensory aspects of hands-on activity..." (Martin & Beach, 1992)

To apply what was shown in the previous study, an effective curriculum in CNC machining would have to include all of the following; some aspect of mechanical machining knowledge and skills, a process or system design to go from one step to another (transformational), learning and communicating the language of CNC (discontinuous), calculation of machining feeds and speeds (continuous) and a teaching strategy that openly encourages hands on learning.

Recommendations for Training

In addition to looking at the skills needed upon completion of a CNC course it is also important for curriculum design to look at and consider how the training should be delivered and which teaching methods would work best. The course designer should consider learning types and plan instructional activities accordingly. The researcher looked at research studies, trade magazines and industry experts for recommendations on training methods and techniques.

One research study conducted in the early 1990's took into consideration the worker's perceptions in three technical industries to gauge what skills are used on the job and how firms integrated technology training into their work environment. The report indicated that "time should be spent with students in classrooms working on hands-on problem solving projects." (McGraw & Forrant, 1992) Also of interest while reading this report was that workers participating in the study indicated that "to be prepared for the workplace, students must work on group projects which require them to plan a job from start to finish, including sequencing of tasks, designing quality control measures and figuring cost of the work." (1992)

While this study was done primarily to see how technological change was impacting workers in the machining, automotive repair and printing industries, it still provided suggestions for training from the primary source of the worker that is doing the job on a regular basis.

Hands-on or project based learning tended to be a recommendation for training that was indicated in multiple articles reviewed that looked at and considered the workers performing the tasks. Martin and Beach (2002) in their study, mentioned that "the majority of informants felt that hands-on experience supplemented by classwork for certain basic topics is the most efficient way to develop skills in machining." (p. 25) Her study was also of interest because it specifically looked at the tasks performed in the CNC machining process. It indicated the importance of three task areas; job planning, programming, and machine operation. (p. 26)

Martin and Beach's (2002) research also yielded excellent information on important aspects needing to be considered in a class on CNC machining. This study asked participants the question, "What would you have to think about before you actually began making the part?" (p. 28) The responses shown in Table 11 of her work indicates the importance of blueprints, material specifications, tools, machines, program, procedures, economy and social relations for an understanding of CNC usage among different job titles and experience levels associated with CNC. The study looked at traditional roles of machine operator, setup operator, low CNC, high CNC, and engineers. This data indicated that there is a high emphasis placed on blueprints, materials, tools and procedures. Her research also showed the interrelationship of blueprint features, material, cutting tools, type of machine, machining process, part fixturing, and job size in Figure 2. (p. 32) This research yields a better idea of what classroom discussion topics should be included as part of the training being delivered. It also provided recommendations for training that included the following:

- Incorporate hand's on activities
- Include course work in the basics and up-to-date techniques
- Develop curriculum that incorporates cognitive information processing theory (p. 53)

Martin's research was primarily looking at the knowledge acquired over time by machinists, machine operators and engineers and how that knowledge would be transformed by introducing CNC concepts to their work environment. College students following an Industrial Technology program certainly would not need to have this extent of knowledge unless they specifically plan to enter into a machining environment but the information provided by the study should still be considered and implemented into the course curriculum. (Martin & Beach, 1992)

Another recommendation for training is provided by industry expert Mike Lynch in his article, "Is manual programming really important?" He indicates that an understanding of manual programming "form the foundation of a person's understanding of CNC." He also justifies manual programming as a safety issue for setup people that have to navigate through a new program to make sure that the command code will be executed safely. He further explains several CNC utilization techniques that can only be accomplished by manual programming such as set-up and cycle time reduction, secondary offsets and parametric programming. The advanced techniques mentioned in the article may not be needed in an introductory course on CNC but a thorough understanding of manual programming techniques in a class would provide the necessary knowledge to be able to grasp advanced programming later on in one's career. (Lynch, 2002)

Summary

The purpose of the review of literature was threefold:

- First was to find out what knowledge needs to be learned and what skills or competencies need to be achieved by students.
- Second was to find out teaching strategies and methods that could be incorporated into the instructional activities to help increase student learning
- Third was to determine what other researchers, teachers and industry professionals were recommending for any training that would occur.

Industry standards from Illinois and national trade organizations were used as the resource to obtain the required knowledge and skills to be incorporated into a CNC course curriculum. Knowledge areas include machining knowledge, drafting principles, operational procedures and programming language. Teaching strategies based on research and recommendations should include hands on or project based activities, problem based learning, reinforcement of basic or prior knowledge and to apply informational processing cognitive approaches to whole subject learning.

CHAPTER 3

METHODOLOGY

After reviewing the literature to determine what needed to be taught and what skills need to be trained in a CNC class the researcher compiled this information and began to design the coursework associated with the CNC class to be taught. The MAST Tool and Die Maker Technical Workplace Competencies and the NIMS Level 1 Machining Skills duties and standards were compared. The Illinois Occupational Skill Standards were looked at but considering that the Illinois standards were adapted from national skills standards the decision was made to follow national standards.

Both MAST and NIMS followed a DACUM format using Duties and Tasks. MAST identifies eleven duties required. NIMS incorporates seven duty areas. It is important to recognize that NIMS additionally breaks down seven additional areas that are classified as KSAO area which stands for Knowledge, Skills, Abilities, and other Characteristics. (National Institute for Metalworking Skills, 2001) Table 1 shows the breakdown of these duty areas. In looking at the table one can see the correlation between MAST and NIMS in the following ways:

- MAST Duty A correlates with NIMS Duty Areas 5 and 6
- MAST Duty B with NIMS KSOA Area 2
- MAST Duty C with NIMS Duty Area 3
- MAST Duty D with NIMS KSAO Area 7 (sub-heading KSAO 7.3 is specific to material properties)
- MAST Duty E with NIMS Duty areas 1 and 2

- MAST Duty F with NIMS Duty area 2 and KSAO area 8 (sub heading 2.9 is specific to CNC Programming)
- MAST Duty G with NIMS KSAO Area 1
- MAST Duty H and J with KSAO Area 5
- MAST Duty I has no correlation with NIMS. Computer usage by personnel is probably assumed by the time NIMS Standards were released.
- MAST Duty K has no correlation with NIMS and is not directly related to CNC

Table 1. Comparison of Job Duties

MAST-Technical Workplace Competencies		NIMS-Duties and Standards for Machining Skills	
Duty A	Practice Safety	Duty Area: 1	Job Planning and Management
Duty B	Apply Mathematical Concepts	Duty Area: 2	Job Execution
Duty C	Demonstrate Quality Control and Management	Duty Area: 3	Quality Control and Inspection
Duty D	Demonstrate Knowledge of Manufacturing Materials	Duty Area: 4	Process Adjustment and Improvement
Duty E	Demonstrate Knowledge of Manufacturing Processes	Duty Area: 5	General Maintenance
Duty F	Perform CNC Programming/CAM Tasks	Duty Area: 6	Industrial Safety and Environmental Protection
Duty G	Demonstrate Communication Skills	Duty Area: 7	Career Management and Employment Relations
Duty H	Perform Drafting/CAD Tasks	KSOA Ares: 1	Written/Oral Communication
Duty I	Use Computers	KSOA Area: 2	Mathematics
Duty J	Interpret/Use Blueprints and Related Documents	KSOA Area: 3	Decision Making and Problem Solving
Duty K	Perform Die Operations	KSOA Area: 4	Social Skills and Personal Qualities
		KSOA Area: 5	Engineering Drawings and Sketches
		KSOA Area: 6	Measurement
		KSOA Area: 7	Metalworking Theory
		KSOA Area: 8	Introduction to CNC

Both of these industry standards are designed as a total curriculum solution for skilled workers. A current course on CNC would not need students to be fully versed in all of the duties listed so it became necessary to go through and determine which duties were required for CNC. One of the recommendations for training was to reinforce basic knowledge and to use cognitive information processing theory to achieve complete subject learning. With this in mind the researcher identified basic knowledge and skills needed by students at the beginning of a class, knowledge and skills that needed to be taught during the class, and then designed appropriate activities to ensure knowledge and skill acquisition.

Basic knowledge encompassed safety awareness, mathematics including geometry and trigonometry, drafting/CAD and blueprint reading, types of machines used in parts machining, types of cutting tools used, and other soft skills that are typical of college level coursework. These areas were used to develop an assessment to be administered on the first day of class to determine student's prior knowledge (See Appendix F).

By the time students register for a CNC class at EIU they already have coursework on types of materials, manual machining processes, and blueprint reading or CAD. Mathematics should also have been covered either at the high school level or during the first or second semester of college course work. The assessment administered at the beginning of the class served to reinforce those areas of knowledge for the student and to let the instructor know what areas were strong points or weak points for the class population.

The knowledge that needed to be mastered in a CNC course was broken down into four areas; machining knowledge, operational procedures, programming techniques, and CAD/CAM principles. Areas of machining knowledge included tool selection, feeds and speeds of cutting tools based on material type and workholding methods appropriate for a

CNC milling machine. The lab had a limited amount of tooling and workholding methods available for use (Figure 3).

Figure 3. Tool Cabinet

Figure 4. Toolholders, Insert Tooling, and Endmill

Tooling included Cat-40 toolholders with shell mill adapters, endmill holders and ER-25 collet style holders (Figure 4). Cutters consisted of inserted shell mills for facing operations, high speed steel (HSS) and carbide endmills and drills of various sizes (Figure 5). Workholding capabilities included a Kurt Precision Vise (Figure 6), parallel set, 1-2-3 Block set, and one step block and strap clamp set.

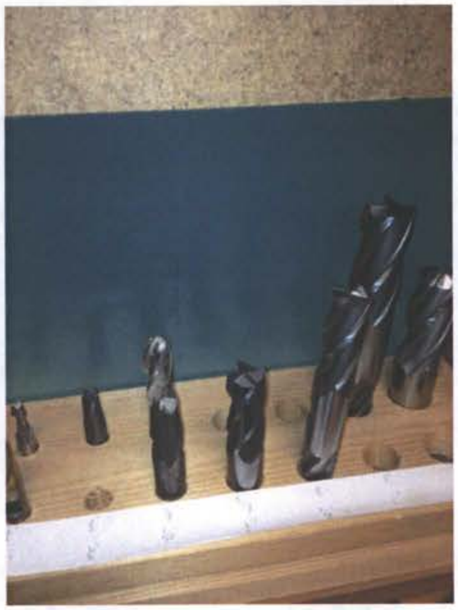

Figure 5. High Speed Steel Endmills

Figure 6. Kurt Precision Machine Vise

Operational procedures consisted of tasks needing to be performed such as job planning, shop order travelers (See Appendix A), tooling sheets (See Appendix B), and program sheets (See Appendix C) for CNC set-up people and operators. Programming practices dealt with coordinate systems, g-code symbology and the appropriate syntax of g-code for correct machine movement. Drafting principles are also included and these include the skills needed to draw a part into the appropriate software, write the tool paths associated with machine movement and then post-process the code out of the software into a useable form for the machine tool.

Skills were also identified as critical to success. These skills were associated with the type of CNC machine being used in the laboratory and included the following:

- Lab safety concerns during operation of the machine
- Turning the machine on and off
- Setting height offsets
- Setting fixture offsets
- Writing a program
- Using manual data input (MDI) to input program (Figure 7)
- Calling up a program from the controllers memory
- Load/unloading a toolholder (Figure 8)
- Proving out or dry running a program

Figure 7. Fanuc Controller

Figure 8. Tool Spindle

These skills would be taught by demonstration during lab hours and then tested by observing students performing the task.

A pen and paper assessment was also prepared to be used as a final exam for grading. (See Appendix D) This test consisted of seventy questions in True/False, Multiple Choice, Fill-in-the-Blank, and matching format. The questions were broken down by categories of knowledge. Machining knowledge regarding tool selection had twelve questions. Machine utilization accounted for eleven questions. Operational procedures consisted of six questions. Seven questions were related to skills required to operate CNC Milling machine. Programming related questions made up the bulk of the test with twenty matching questions used to test recognition and recall of important G-codes. Five questions dealt with coordinate positioning and sixteen questions were comprised of G-code and the related syntax writing of a line of code.

A CNC course survey was also designed to be administered to students on the last day of class. (See appendix F) This survey asked for student opinions on their perceptions of learning in regards to the coursework. The survey had students rate their understanding on the topics covered in lecture and their abilities to operate the machine in the lab. It also asked them questions related to the amount of time spent outside of class learning and their textbook usage. Two open ended questions were also included asking students to list and describe the positive and negative aspects of the course.

Additionally a group project was developed to replicate a job shop environment in the second half of the class. Students were assigned to a team for a company project and allowed to select a part to manufacture using the CNC mill. This part would be taken from raw material to finished part. Teams would discuss and collaborate on a job routing, tooling sheets, programming, set up and operation of the CNC mill. A company project individual performance review was also designed. (See Appendix G) Each group member would also then conduct a performance review on each of their teammates. Just like in a real work environment team members would have to work harder to make up for the non-performance of any team member not present during class and lab.

At the beginning of the semester the assessment in Appendix E was administered at the beginning of the class to get an idea of what level of knowledge current students already possessed and where the instructor may need to spend additional time in classroom instruction.

The same questions were asked again on a later test as part of the score and grade students received on a final exam. Data was compared between the two to determine if improvements had been made. Data was compiled from both of these to help determine how well information was received by the students and if they felt learning had occurred. This data would be used to make changes to coursework and improve upon delivery of materials in order to help students achieve full competency whenever possible.

The final exam was also administered to a group of industry professionals to test validity of the exam. This group consisted of machine operators, supervisors, programmers and process engineer. Scores shown on the test administered to industry professionals with limited college coursework and lots of on-the-job training would be analyzed for correlation between the two data sets. Correct answers on the test by industry professionals would validate the need for students to know the information covered.

Summary

After reviewing the literature to determine what needed to be taught and what skills need to be trained in a CNC class the researcher compiled this information and began to design the coursework associated with the CNC class to be taught. A pre-test was administered at the beginning of the course to get an idea of what level of knowledge current students already possessed and where the instructor may need to spend additional time in classroom instruction. The same questions were asked again on a later test as part of the score and grade students received on a final exam. Data was compared between the two to determine if improvement had been made.

A group project was designed in order to provide students with practical hands-on applied learning experience. The project required teams to read a blueprint, create a shop traveler indicating the operational process, write programs for each operation and then machine the part complete. A grading rubric was created to assess performance in writing programs, preparing program documentation, machine setup, and running programs. The ultimate goal was a good part machined to blueprint specification.

A course survey was prepared and filled out by students at the end of class to get their feelings and opinions on learning that they felt they had achieved during the class. Data was compiled from both of these to help determine how well information was received by the students and if they felt learning had occurred. This data would be used to make changes to coursework and improve upon delivery of materials in order to help students achieve full competency whenever possible. The final exam was also administered to a group of professionals to confirm validity of the questions asked.

CHAPTER 4

RESULTS

The purpose of this research was to determine what should be covered in a modern CNC course based on industry standards to ensure that students are taught the required knowledge and skills needed in industry to prepare students for technical positions in the manufacturing industry? Using these industry standards curriculum and learning objectives were prepared and then taught. Tests were created to gauge student learning of objectives and an analysis of student learning by learning objectives was used

The research was intended to find out what knowledge and skills would best prepare students to enter into a CNC manufacturing environment and succeed. Additionally the research looked at the perceived value of the course from the students' perspective to determine if it increased their knowledge and interest in CNC machine related activities.

Description of Sample

A total of fourteen participants from Eastern Illinois University were involved in this sample. These participants were enrolled in the Industrial Technology departments INT 3203 Computer Numeric Control Programming course. Thirteen of these students were undergraduates and one student was a graduate student taking the course as an independent study course with additional requirements on top of fulfilling the requirements for the class. All students were male. Ten students were majoring in Industrial Technology and 3 students were majoring in Career and Technical Education. Two students withdrew from the course before the end of the semester and had minimal participation in the group project and did not participate in the final exam.

Explanation of Pre-test Results

The purpose of the pre-test was to gauge student's current ability levels to identify possible learning needs. The researcher wanted to determine to what extent students were prepared to take the course. The questions asked covered students' ability to recognize Cartesian coordinates based on MAST Duty B and NIMS KSOA Area2, read a blueprint based on MAST Duty J and NIMS KSOA Area 5, perform basic mathematical calculations and trigonometry based on MAST Duty B and NIMS KSOA Area 2, identify tooling needed for CNC machining based on MAST Duty D and NIMS Duty Area 2, and identify machine tools that might have a CNC control based on MAST Duty E and NIMS Duty Area 1(See Appendix E). The assumption was made that student's would have no prior knowledge of G-Code, G-Code programming syntax, operational procedures or skills acquisition. These areas would be taught during lecture, lab and group project work. These would be accessed in the final exam after receiving training.

Question 1 had students identify Cartesian coordinate points. 13 out of 14 students identified the points correctly. The incorrect response was given by Sample 18 who answered with the correct number but did not have the correct sign or "polarity". Results indicated that students recognized and were able to identify Cartesian coordinate points (See Table 2).

Table 2. Student response to Cartesiona Coordinate Point Recognition

1 Please identify the following points in space	# of Correct Responses
Point A	13
Point B	14
Point C	14
Point D	13

Question 2 required students to be able to look at a drawing of a part and recognize the math calculations that would be needed to determine positional coordinate movements of the machine tool off of the dimensional sizes given by the drawing. ΔY1 and ΔY2 were both simple math recognition to subtract one given dimension from another. ΔY was only important for the calculation of the positional coordinate needed to be obtained by ΔX. Both ΔX1 and ΔX2 required the use of Trigonometry to determine the X coordinates. Results in Table 3 indicated that the majority of students were able to recognize and calculate the basic dimensions of ΔY. Only one student showed competency on trigonometry. This question would be asked again on the Final test to show improvement.

Table 3. Student score on calculations related to positional coordinate

2 Calculate the following	# of Correct Responses
ΔX1	1
ΔY1	10
ΔX2	1
ΔY2	11

Question 3 again tested a student's ability to read a blueprint and determine Cartesian coordinate points for hole location. Table 4 shows that all students answered correctly and were able to perform this task.

Table 4. Student score on hole locations from blueprint

3 Fill in hole locations	# of Correct Responses
Hole A	14
Hole B	14
Hole C	14

Question 4 was used to determine student recognition of tooling used in a CNC machine environment. Table 5 shows the number of students indicating that they could define or explain the terms listed. The results were to be expected given students pre-requisite coursework.

Table 5. Student response to CNC terminology

4 Indicate with a checkmark the items or terms that you could define or explain.

Endmill	8
Retention Knob	1
G-Code	3
Counter Bore	7
Cat-40 Adapter	0
M-Code	1
Reamer	11
Boring Head	10
Conversational Language	0
Tap	11
Insert	9
DNC	2
Indicator	5
HSS	2
MCU	1
Edge Finder	7
Carbide	9
Datum	1

Question 5 was asked to find out student awareness about different types of machines used in industry. The class dealt primarily with CNC programming on a milling machine however more and more machine tool types are utilizing CNC to control machine movement. Students learning about CNC would need to have an awareness of its usage throughout industry. Table 6 shows the types of machines and the number of students that had knowledge of different machines in industry.

Table 6. Student response concerning industrial machinery

5 Indicate with a checkmark the Industrial Machines that you have heard about.	
Lathes	14
Water Jet	13
Turning Centers	8
Drill Press	14
Mills	14
OD/ID Grinder	6
Machining Centers	8
Surface Grinder	13
EDM	3
Centerless Grinder	1
Laser Jet	12
Robots	13

Upon grading and review of the pre-test survey on the first day of class several decisions were made regarding instructional material. The Cartesian Coordinate system would only need to be reviewed in relationship to the difference in programming between absolute and incremental positioning of coordinates. Trigonometry applications would have to be taught based on the responses to question 2 on the Pre-test. All terminology and tooling mentioned question 4 would need to be included in instruction.

Explanation of Final Exam Results

The final exam questions (Appendix D) were broken into seven categories based on MAST and NIMS Duty areas. These categories are machining knowledge related to tool selection (MNK-TS), machining knowledge on utilization (MNK-U), operational procedures (OP), programming related to G-Codes (PG-CODE), programming related to coordinate measuring systems (P-GMM), programming related to correct G-Code syntax (P-GS) and skills achieved (SK). Each category represents separate learning goals needing to be achieved.

Table 7 shows the results of the questions asked about tool selection. These questions covered the types of tools to use for cutting applications, calculations of speeds and feeds and the correct tooling steps to achieve dimensional and positional accuracies. There were a total of 12 questions asked to determine knowledge gain over the semester. The mean score across the category was 19.44% indicating combined class learning at 80.56% in tool selection. Median response was 2. Mode response was 1. Range was 7.

Table 7. Machine Knowledge: Tool Selection

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
13	MNK-TS	6	50.00%			1	1	1	1	1						1		6
14	MNK-TS	2	16.67%											1		1		2
17	MNK-TS	1	8.33%											1				1
26	MNK-TS	4	33.33%			1		1	1					1				4
28	MNK-TS	1	8.33%												1			1
29	MNK-TS	3	25.00%		1										1	1		3
30	MNK-TS	3	25.00%		1		1								1			3
31	MNK-TS	2	16.67%				1								1			2
35	MNK-TS	1	8.33%				1											1
58	MNK-TS	0	0.00%															0
59	MNK-TS	1	8.33%							1								1
60	MNK-TS	4	33.33%			1	1			1						1		4
			19.44%	0%	17%	25%	42%	17%	17%	25%	0%	0%	0%	25%	33%	33%	0%	

Table 8 shows the results of test questions related to the category of Machine Utilization. These questions covered the how, when, where and why to use a CNC machine tool. The mean score of incorrect answers across the category was 30.30% indicating combined class learning of 69.70% in CNC Machine Utilization. Median response was 2. Mode response was 2. Range was 9.

Table 8. Machine Knowledge: Machine Utilization

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
16	MNK-U	6	50.00%				1	1	1	1			1		1			6
32	MNK-U	2	16.67%					1							1			2
33	MNK-U	1	8.33%												1			1
34	MNK-U	2	16.67%			1	1											2
37	MNK-U	1	8.33%				1											1
48	MNK-U	0	0.00%															0
50a	MNK-U	8	66.67%		1	1	1	1	1					1	1	1		8
50b	MNK-U	7	58.33%		1	1	1	1	1						1	1		7
50c	MNK-U	7	58.33%		1	1	1	1	1						1	1		7
50d	MNK-U	4	33.33%			1	1	1							1			4
50e	MNK-U	2	16.67%			1		1										2
			30.30%	0%	27%	55%	64%	64%	36%	9%	0%	0%	9%	9%	64%	27%	0%	

Table 9 relates to operational procedures. Six questions were asked. Mean score of incorrect responses achieved was 8.33% indicating a 91.67% learning rate. Median response was 0.5. Mode response was 0. Range was 4.

Table 9. Operational Procedures

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
11	OP	2	16.67%					1								1		2
12	OP	0	0.00%															0
15	OP	0	0.00%															0
19	OP	0	0.00%															0
20	OP	3	25.00%			1		1							1			3
49	OP	1	8.33%													1		1
			8.33%	0%	0%	17%	0%	33%	0%	0%	0%	0%	0%	0%	17%	33%	0%	

Table 10 shows the results of questions asked on programming coordinate positions. Five questions were asked. Mean score achieved was 8.33% incorrect indicating a 91.67% learning rate. Questions 54 thru 57 were the exact same question as question 2 in the pre-test. Mean score achieved on the pre-test was 46.43%. Median response was 2. Mode response was 2. Range was 4. Removing question 21 from the final exam results yields a mean score of 12.5%. Comparing the results of the two tests in this category shows that students went from a pre-test score of 53.57% to 87.5% indicating a 33.9% increase in learning between the two tests.

Table 10. Programming Coordinate Positions

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
21	PCMM	2	16.67%		1		1											2
54	PCMM	0	0.00%															0
55	PCMM	2	16.67%					1							1			2
56	PCMM	1	8.33%												1			1
57	PCMM	3	25.00%					1	1						1			3
			13.33%	0%	20%	0%	20%	40%	20%	0%	0%	0%	0%	0%	60%	0%	0%	

Table 11 shows response rate to the learning objective of understanding G and M Codes. 21 questions were asked pertaining to G and M Code recognition. Mean score responses to this category was 17.86% incorrect indicating a 82.14% acquisition of knowledge. Median response was 2. Mode response was 2. Range was 5.

Table 11. Programming G-Code

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
1	PG-CODE	2	16.67%				1									1		2
2	PG-CODE	3	25.00%				1		1							1		3
3	PG-CODE	2	16.67%						1							1		2
4	PG-CODE	4	33.33%				1	1	1							1		4
5	PG-CODE	3	25.00%					1	1							1		3
6	PG-CODE	1	8.33%													1		1
7	PG-CODE	2	16.67%						1							1		2
8	PG-CODE	3	25.00%				1		1							1		3
9	PG-CODE	2	16.67%						1							1		2
10	PG-CODE	2	16.67%						1							1		2
27	PG-CODE	3	25.00%				1	1	1									3
38	PG-CODE	1	8.33%						1									1
39	PG-CODE	2	16.67%						1							1		2
40	PG-CODE	3	25.00%				1		1							1		3
41	PG-CODE	3	25.00%				1		1							1		3
42	PG-CODE	2	16.67%				1									1		2
43	PG-CODE	3	25.00%		1		1									1		3
44	PG-CODE	1	8.33%													1		1
45	PG-CODE	0	0.00%															0
46	PG-CODE	1	8.33%													1		1
47	PG-CODE	2	16.67%		1											1		2
			17.86%	0%	10%	0%	43%	14%	62%	0%	0%	0%	0%	0%	0%	86%		

Table 12 shows response rate to the learning objective of understanding syntax of CNC coding. 16 questions were asked to determine student ability to recognize the correct formatting of lines of code and sequence of blocks. Mean score responses to this category was

32.81% incorrect indicating a 67.19% acquisition of knowledge. Median response was 4. Mode response was 4. Range was 7.

Table 12. Programming Syntax

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
36	P-GS	2	16.67%				1									1		2
53a	P-GS	5	41.67%		1	1	1								1	1		5
53b	P-GS	5	41.67%		1	1	1								1	1		5
53c	P-GS	4	33.33%		1	1	1									1		4
53d	P-GS	4	33.33%		1	1	1									1		4
53e	P-GS	4	33.33%		1	1	1									1		4
61	P-GS	2	16.67%			1	1											2
62	P-GS	1	8.33%													1		1
63	P-GS	8	66.67%		1	1	1		1	1				1	1	1		8
64	P-GS	5	41.67%		1	1			1						1	1		5
65	P-GS	1	8.33%													1		1
66	P-GS	6	50.00%		1	1	1		1						1	1		6
67	P-GS	4	33.33%		1				1						1	1		4
68	P-GS	2	16.67%				1									1		2
69	P-GS	7	58.33%		1	1	1		1	1					1	1		7
70	P-GS	3	25.00%			1			1							1		3
			32.81%	0%	63%	69%	69%	0%	38%	13%	0%	0%	0%	6%	44%	94%	0%	

Table 13 shows response rate for skills acquisition. There were a total of seven questions asked regarding the knowledge gained through skills acquisition on the machine tool. These questions were directly related to skills utilized in the lab while running the Hardinge machine. Mean score responses to this category was 3.57% incorrect indicating a 96.43% acquisition of knowledge related to skills needed on the machine tool. Median response was 0. Mode response was 0. Range was 3.

Table 13. Skills Acquired

Q#	Category	Student ID # Incorrect Responses	% of Class incorrect	11	12	13	14	15	16	17	18-W	19-W	20	21	22	23	24	Student ID # Incorrect Responses
18	SK	0	0.00%															0
22	SK	2	16.67%											1		1		2
23	SK	0	0.00%															0
24	SK	0	0.00%															0
25	SK	0	0.00%															0
51	SK	0	0.00%															0
52	SK	1	8.33%													1		1
			3.57%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%	0%	29%	0%	

Review of the breakdown of student answers on the final exam yield the following results for the class as a whole. High scores were achieved in the categories of skill acquisition, operational procedures, and coordinate positions. The categories of G-Code recognition and tool selection also achieved greater than 80% knowledge acquisition. The categories of G-Code syntax and machine tool utilization scored the lowest. Reviewing the median and mode results for the class in these two categories reveals that the majority of the students in the class did not fully grasp the subject material.

Explanation of Survey Results

A wide variety of survey questions (see Appendix F) were asked of students participating in the class. The survey was completed after the final exam was taken. The survey was intended to gauge student opinion on areas where understanding of CNC, manufacturing processes, industrial technology and student abilities in operation and programming of CNC equipment was increased. Questions were also asked concerning the amount of responsibility and study time that student's put into accomplishing the grade received in the class. Another topic that the researcher was interested in and asked about on the survey was regarding whether the course increased student interest in machining, manufacturing and industrial technology. It was assumed that an increased interest on the student's part would lead to possible pursuit of a career in machining. Survey results were only compiled from 13 participants as Sample 24 had to take the final at a different time and was not able to complete the survey.

. Questions 1 and 8 on the survey dealt with student opinions on their increase in knowledge. Table 14 shows the results from question 1. Overall students largely agreed that the class increased their understanding of industrial machinery, machine tools, tool holding, tool cutters, workholding, machine processes, CNC operations, CNC tooling, and CNC programming. The class was divided on whether or not it increased understanding in blueprint reading, part tolerance (G,D &T), coordinate measuring systems or shop mathematics. The response received about coordinate measuring systems and shop mathematics was puzzling to the researcher especially since there was a clear increase in the application of shop mathematics as demonstrated in the test scores from the Pre-Test to the Post-test.

Table 14. Student opinion on benefit of the class

1 Taking this class has increased my understanding of:	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
Industrial Machinery	0	1	0	7	3
Machine Tools	0	1	0	4	6
Tool Holding	0	1	1	4	5
Tool Cutters	0	0	1	5	5
Workholding	0	1	1	5	4
Machine Processes	0	1	1	4	5
CNC Operations	0	1	0	3	7
CNC Tooling	0	0	1	4	6
CNC Programming	0	0	0	5	6
Blueprint Reading	0	3	5	3	0
Part Tolerance (G,D & T)	0	1	4	5	1
Coordinate Measuring Systems	0	0	4	5	2
Shop Mathematics	0	1	5	4	1

Question 8 on the survey demonstrates that students felt confident in their ability to operate, set-up and program a CNC machine (Table 15). Students did not however, believe that they were competent to be a CNC programmer without additional training. The group was also split in regard to whether the class prepared students to manage other individuals in a CNC environment. The high agreement rate on understanding the complexity of CNC shown on Question 7 may help to explain student's responses in regard to becoming a CNC programmer or managing others. The course work and labs may have presented individuals with enough knowledge to realize the sophistication behind CNC machinery and the amount of knowledge that needs to be acquired in relation to all the categories presented.

Table 15. Student response to skills developed

8 After taking this class, I feel confident	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
that I could operate the Hardinge VMC 480P	0	0	1	6	4
that I could set up a CNC machine	0	0	1	8	2
that I could write a G-code program	0	0	2	8	1
that I could be a CNC programmer with no additional training	2	5	2	2	0
that I know enough about CNC to manage other individuals involved in CNC related activities	2	2	4	2	1

Table 16 shows student response to their personal responsibility for learning in the class. Seven students agreed that they applied themselves fully to learning the subject material. The researcher would agree with that assessment based on class participation during lecture and lab. Half of the class expressed the need for using the textbook to increase their learning and half of the class had no opinion or disagreed. The majority of the class agreed that it met their expectations. Survey question 14 shows the amount of time students spent trying to master the material outside of the normally scheduled class times. Students spent the majority of their time outside the class doing assignments, reviewing sample programs provided or reviewing notes taken during lecture. Students spent the least amount of time watching online videos or reading the textbook. They also didn't spend a lot of time looking at online resources. This indicates to the researcher that students in a college class still look to the individual instructor to teach them what needs to be learned.

Table 16. Student response to time spent on coursework

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
2 I applied myself fully to learning this subject material	0	1	3	5	2
3 I used the textbook to help further my understanding of concepts that were unclear in lecture	1	1	3	6	0
4 This class met my expectations about CNC	1	0	2	3	5
14 Outside of lecture and lab time, the time I spent each week to learn about CNC	0-1 hour	1-2 hours	2-3 hours	3-5 hours	5+ hours
Doing assignments	0	8	2	1	0
reading the textbook	8	3	0	0	0
reviewing sample programs given in class or in the textbook	1	8	1	1	0
looking at online resources	6	5	0	0	0
watching online videos of CNC machining	9	2	0	0	0
reviewing notes taken during lecture	2	8	0	1	0

Survey results also indicated that the course increased student interest in machining, manufacturing processes, and industrial technology. Table 17 shows student response to questions 9-12 on the survey. Not surprisingly, the majority of responses concerning the most positive aspect of the class were in regard to the ability to run the machine.

Table 17. Student response on increase in interest

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
9 The course increased my interest in CNC manufacturing activities	0	4	0	6	1
10 The course increased my interest in machining	0	2	1	7	1
11 The course increased my interest in manufacturing processes	0	1	1	8	1
12 The course increased my industrial technology knowledge	0	0	0	8	3

Summary

Data was collected from a pre-test on the first day of class, a final exam, and a survey given on the last day of class. The pre-test data showed a gap in student knowledge in performing trigonometry calculations needed to find Cartesian coordinate positions related to parts manufacturing. The final exam data analyzed showed high acquisition of knowledge in the learning objective categories of skill acquisition, operational procedures, and coordinate positions. The learning objective categories of G-Code recognition and tool selection were achieved with 80% knowledge acquisition. The learning objective categories of G-Code syntax and machine tool utilization experienced the least amount of success for students. The course survey indicated that students felt the class increased their overall understanding of CNC machining, manufacturing processes and industrial technology. Likewise student's felt confident in their ability to operate, set-up and program the Hardinge machining center in the school lab but not program CNC machines as a whole without additional training. The survey also indicated that all students felt the class increased their industrial technology knowledge.

CHAPTER 5

CONCLUSION

The purpose of the study was to analyze current industry standards to develop learning objectives and curriculum for what should be taught in a modern CNC course for industrial technology students. The course was taught to an undergraduate class and course assessments were analyzed to determine extent of student learning. Student participants were also surveyed to gain feedback concerning the extent of student learning and increase of interest in machining processes as a result of taking the course.

Significance of the Study

Industry projections continue to show a need for training of a high skilled workforce in regard to machine tool technology and precision machining. The study provides categories of learning objectives based on the industry standards reviewed to be used in designing curriculum. It also used test questions developed from the content of the course or taken from the NIMS standards to determine the achievement of learning goals associated with the study.

Conclusion

The utilization of the MAST (1996) list of technical workplace competencies and NIMS standards and competencies proved to be a good resource for determining and subsequent development of curriculum to be taught in a CNC related course. The inclusion of higher level mathematics like trigonometry are needed for teaching manual programming techniques and can be easily taught during the course in a way that students will understand and master. The continued evolution of CAD/CAM systems may simplify the task of calculating coordinates using trigonometry which may change the need for this to be taught.

Students struggled in the first seven weeks of classwork to understand the course material being covered. The researcher believes this to be a result of the high extent of new terminology, programming symbols and technical knowledge that needs to be learned in a relatively short time period. Students showed proficiency in recognition of G-Codes and positional coordinates based on a part drawing. There was not a full understanding of the correct syntax to be used. They also mastered the skills required to set-up and operate the machine and even write simple programs. A course in CNC could easily teach students how to program the positional movements that a machine would need to make to perform its cutting task. This was not the area that the researcher found that students struggled with. They struggled with job planning, shop routing and show to write tooling sheets so that others would understand what was happening in a program. Surprisingly student responses in the survey indicated that all students felt these were very simple tasks but that was not what the research observed while the students were going through the course work and performing the tasks. The researcher provided a lot of direct assistance and guidance on the job planning tasks, shop routing and tooling requirements needed.

Students entering the class had limited exposure to the wide variety of tooling, material workholding and operational procedures required by a CNC machine. The researcher designed the course to have students completely manufacture a part from start to finish following the ideal behind the NIMS Machining Skills Job Duty for CNC Milling. This included the full planning and machining of a part complete from a part drawing. Students were not prepared for this level of manufacturing complexity. Students were unaware of the overall "big picture" of how to make a part out of raw bar stock. Students were also unaware of the need to use and change from one type of cutting tool to another based on tolerance requirements needing to be held on parts. As an example, a part with a hole diameter tolerance of .0002 would require multiple cutting tools to hold that size. Students in the class had no concept of that and only recognized it as a hole to be drilled, not a hole to be drilled and reamed. The students also had a limited knowledge of workholding methods and techniques as well so lab activities were limited by the researcher to machine parts that could be held in a vise. In this regard the researcher found some of the NIMS curriculum to be too advanced for the students in this class.

Recommendations

The research and achievement of learning objectives indicates that students learned how to set-up, operate and program the Hardinge CNC machine in this class. The researcher believes that this is not the technically "hard" part of CNC machining. The researcher observed gaps in student knowledge on types of cutters, when they would be needed or even how cutter selection relates to the machining operation needing to be performed. There was also no recognition among students of the correlation between cutting tool and machining tolerances that need to be held. Industry needs CNC programmers to be well versed in these methods. The question this leads to is when and how should students achieve this. Is it something to be taught in the classroom or is it something that would only come through experience.

The industry recognizes NIMS standards and credentials. This research indicates that students taking this class were not prepared to succeed with the NIMS curriculum. Further research is needed to look at how individuals attain knowledge related to machining sequences for tight dimensional and positional tolerances. The machining of a part with four place decimal tolerances on size or location is different from the machining of a part with a three place decimal tolerance.

The research also showed that students spent very little time using online resources or watching online videos of machining processes and still relied heavily on teacher lecture and instruction. The actual task of writing a CNC programming and teaching someone to write a program can be fully taught through the use of online resources. More research into online delivery of instruction could facilitate more individuals learning to program a CNC machine.

Lastly the research indicates that programming was not what students struggled with but instead struggled with basic machining theory and practices that were unrecognized. Likewise basics of the application of part G, D and T in determining the machining process was also unrecognized. Additional research should be conducted in these areas to determine what should be acquired knowledge before a student takes a course on CNC programming.

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APPENDICES

Appendix A

Eastern Illinois University Shop Traveller

Job #	Part #	Date
2	T-Bolt	2/09/2009

Op. #	Machine	Description	Qty
10	Saw	Material 4140 ¾" x 1 ½" Bar Stock Cut 7 ¾" long	20 pcs.
20	Programming	Program Mill for _VMC 480 P Program # M-7020	20 pcs.
30	VMC 480P	M-7020-1 Finish Mill 1" dimension	20 pcs.
40	VMC 480P	M-7020-2 Mill shoulders, Drill and Tap holes	20 pcs.
50	Heat Treat	Case Harden to 40-45Rc	20 pcs.
60	Surface Grinding	Finish Grind .750" dim	20 pcs.
70	Inspection	Inspect part Complete	20 pcs.
80	Shipping	Hold for Shipping	20 pcs.

Additional Notes:

Appendix B

Eastern Illinois University
School of Technology
CNC Tooling Sheet

Dr. David Melton
G.A. – Brad Curry

Part #_T-Bolts_ Program # _M-7020-1________ Op # ___30____

Programmer: ______Brad Curry________________Date: ___2/09/2009____________

Work holding Method:	Set-up notes:
Machine Vise Space part equally in the X-axis	Part must extend above vise jaws by ½"
Part Origin:	
X0 – Center of part Y0 – Center of part Z0 – Top of part	

Tool #	Tool Type	Description	Z Depth	Offsets
19	3" Shell Mill	Faces top of part Establishes part Z0	Z=0	H19

Eastern Illinois University
School of Technology
CNC Tooling Sheet

Dr. David Melton
G.A. – Brad Curry

Part #_T bolts_   Program # _M-7020-2________   Op # ___40___

Programmer:______Brad Curry__________________Date: ___2/09/2009__________

Work holding Method:	Set-up notes:
Machine Vise Set Stop on Left Side of part	Part must extend above Vise Jaws by 3/8“
Part Origin:	
X0 – Center of part Y0 – Center of part Z0 – Top of part	

Tool #	Tool Type	Description	Z Depth	Offsets
19	3” Shell Mill	Faces top of part Establishes part Z0	Z=0	H19
2	½” 4-Flute Roughing Mill	Rough mill Shoulders	Z= -.275	H2, D2
3	½” 4-Flute Finish Mill	Finish mill Shoulder	Z= -.285	H3, D3
4	# 3 Center Drill	Spots 5 holes	Z= -.235	H4
5	27/64” Drill	Drills 5 holes Thru	Z= -.650	H5
6	Counter Sink	C-Sink 5 holes	Z= -.375	H6
7	½ - 13 UNC Tap	Taps 5 holes Thru	Z= -.750	H7

Appendix C

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O7020 (M-7020-1)(Face milling of 1" Dimension)
N10 G0 G17 G40 G49 G80 G90 G98 ;
N20 G0 G90 G10 L2 P1 X_ Y_ Z_ ;
N30 M06 T19 ; (3" face mill)
N40 G90 G0 G54 X-5.75 Y0.0 ;
N50 G43 H19 Z1.0 ;
N60 M3 S770 ;
N70 M08 ;
N80 G01 Z0.0 F23 ;
N90 X5.75 ;
N100 G0 Z1.0 M09 ;
N110 G91 G30 Z0 M05 ;
N120 G28 Y0 ;
N130 G90 ;
N140 M30 ;
%

O7021 (M-7020-2)
N10 G0 G17 G40 G49 G80 G90 G98 ;
N20 G0 G90 G10 L2 P1 X_ Y_ Z_ ;
N30 M06 T19 ; (3" face mill)
N40 G90 G0 G54 X-5.75 Y0.0 ;
N50 G43 H19 Z1.0 ;
N60 M3 S770 ;
N70 M08 ;
N80 G01 Z0.1 F23 ;
N90 X5.75 ;
N100 G0 Z1.0 M09 ;
N110 G91 G30 Z0 M05 ;
N120 M01 ; (FLIP PART OVER)
N130 G43 H19 Z1.0 ;
N140 M3 S770 ;
N150 M08 ;
N160 G01 Z0.0 F23 ;
N170 X-5.75 ;
N180 G0 Z1.0 M09 ;
N190 G91 G30 Z0 M05 ;

N200 M06 T02; (1/2 ROUGH MILL)
N210 G90 G0 G54 X-4.0 Y0.5675 ;
N220 G43 H2 Z1.0 ;
N230 M3 S460 ;
N240 M08 ;
N250 G01 Z-0.275 F10.0 ;
N260 X4.0 F2.76;
N270 G0 Z0.1 ;
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N280 G01 Z-0.275 F10.0 ;
N290 X-4.0 F2.76;
N300 G0 Z0.1 ;
N310 G91 G30 Z0 M05 ;

N320 M06 T03 ; (1/2 FIN MILL)
N330 G90 G0 G54 X-4.0 Y0.5575 ;
N340 G43 H3 Z1.0 ;
N350 M3 S460 ;
N360 M08 ;
N370 G01 Z-0.285 F10.0 ;
N380 X4.0 F2.76;
N390 G0 Z0.1 ;
N400 Y-0.5575 ;
N410 G01 Z-0.285 F10.0 ;
N420 X-4.0 F2.76;
N430 G0 Z0.1 ;
N440 G91 G30 Z0 M05 ;

N320 M06 T04 ; (CENTER DRILL)
N330 G90 G0 G54 X-2.75 Y0.0 ;
N340 G43 H3 Z1.0 ;
N350 M3 S1538 ;
N360 M08 ;
N370 G81 X-2.75 Y 0.0 Z-.235 R.1 F4.6 ;
N380 X-1.375 ;
N390 X0.0 ;
N400 X1.375 ;
N410 X 2.75 ;
N420 G80 ;
N430 G91 G30 Z0 M05 ;

N440 M06 T05 ; (27/64 DRILL)
N450 G90 G0 G54 X2.75 Y0.0 ;
N460 G43 H5 Z1.0 ;
N470 M3 S548 ;
N480 M08 ;
N490 G83 X2.75 Y 0.0 Z-.650 R.1 Q.4 F3.8;
N500 X-.375 ;
N510 X0.0 ;
N520 X-1.375 ;
N530 X-2.75 ;
N540 G80 ;
N550 G91 G30 Z0 M05 ;

N440 M06 T07 ; (1/2 13 TAP DRILL)
N450 G90 G0 G54 X-2.75 Y0.0 ;
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N460 G43 H7 Z1.0 ;
N470 M3 S230 ;
N480 M08 ;
N490 G84 X-2.75 Y 0.0 Z-.650 R.1 F17.69;
N500 X-1.375 ;
N510 X0.0 ;
N520 X1.375 ;
N530 X2.75 ;
N540 G80 ;
N550 G91 G30 Z0 M05 ;
N560 G28 Y0 ;
N570 G90 ;
N580 M30 ;
%
```

Appendix D

Final Exam

Spring 2009
INT 3203
Dr. David Melton
Brad Curry-GA

Name: ______________________

Score: ______________________

Matching (1 pt each) Put the letter of the description in the blank that best relates to that Code

______ 1.G81	a. Absolute Programming Mode
______ 2.G41	b. Spindle Stop
______ 3.G90	c. Coolant Off
______ 4.G03	d. Tool length compensation
______ 5.G17	e. X-Y plane Selection
______ 6.M05	f. Circular interpolation CCW
______ 7.M30	g. Cutter Compensation left
______ 8.G43	h. Incremental Programming Mode
______ 9.G91	i. Spot Drill Cycle
______ 10.M09	j. Program end

True and False (1 pt each) Circle T for True or F for False

T F 11. CNC stands for Coordinate Numbering Control.

T F 12. CNC provides better machine control which increases cutter tool life.

T F 13. Boring Bars can hold a tolerance of +or- .0005 on the hole diameter.

T F 14. A reamer will guarantee positional accuracy.

T F 15. A lathe is used to shape round work pieces.

T F 16. Point to Point Tool movement is used for Contour Milling.

T F 17. Radial tool movement is a series of multiple points of straight line moves to generate a curve.

T F 18. The X-Axis is the first axis to send to machine home position when starting up the CNC Machine.

T F 19. The most efficient machining operation to remove material is Drilling.

T F 20. The milling machine is the most common machine tool used in industry.

T F 21. The use of cutter compensation eliminates the need to calculate tool diameters into the dimensional coordinates of a program.

T F 22. The tool height offset on the Hardinge is measured from the machine table to the top of the workpiece.

T F 23. Data input keys on the control input alphabetic, numeric and other characters.

T F 24. When proving out a program one should put the machine in single block mode and reduce the rapid rate.

T F 25. A toolholder must be oriented in the spindle correctly in order for the tool changer to function properly.

Multiple Choice (1 pt each) Circle the best answer for each question.

26. Identify the appropriate drilling operation for cutting a recess for a socket head cap screw:
    a) Counterboring
    b) Spotfacing
    c) Countersinking
    d) Recessing
27. Identify the appropriate canned cycle for counterboring a hole:
    a) G81
    b) G82
    c) G83
    d) G84
28. Which of the following best describes the procedure for reaming a hole to guarantee positional tolerance:
    a) drill, center drill, redrill, ream
    b) center drill, drill, bore, ream
    c) center drill, drill, ream
    d) drill, center drill, ream
29. The correct RPM for a 0.750 diameter high speed steel end mill machining D2 Tool Steel at 50 sfm is:
    a) 533 RPM
    b) 133 RPM
    c) 256 RPM
    d) 458 RPM
30. Calculate the feed in inches per minute for O1 tool steel with a cutting speed of 55 SFM. The HSS end mill has a diameter of 0.875 inches with four flutes. The chip load per tooth is 0.008 inches.
    a) 7.73 IPM
    b) 77.3 IPM
    c) 17.8 IPM
    d) 29.6 IPM
31. The CNC milling machine uses a feed rate given in inches per revolution (IPR). What is the feed in inches per revolution for a four fluted end mill with a recommended chip load per tooth of 0.014 inches?
    a) 0.014 IPR
    b) 0.028 IPR
    c) 0.042 IPR
    d) 0.056 IPR

32. Motion along the ________ is the longest travel perpendicular to the spindle. Motion along the ________ is the shortest travel perpendicular to the spindle. Spindle movement is primarily along the ________.

   a) Y-axis, X-axis, Z-axis
   b) Y-axis, Z-axis, X-axis
   c) X-axis, Z-axis, Y-axis
   d) X-axis, Y-axis, Z-axis

33. An edge finder has a tip diameter of 0.200 inches. What distance must be added or subtracted to the work offset coordinate to align the center of the edgefinder to the edge of the workpiece?
   a) 0.050 inches
   b) 0.100 inches
   c) 0.200 inches
   d) 0.400 inches

34. Climb milling is typically recommended on a CNC mill for all of the following reasons except:
   a) Work is pushed down and into the cutter
   b) Less clamping and machine horsepower are required
   c) Weight and rigidity of the CNC machine eliminate backlash problems
   d) More fixture hold down force is required

35. Cutting speed (in surface feet per minute) is determined by:
   a) The type of material being machined
   b) The size of the CNC milling machine
   c) The rigidity of the workholding device
   d) The number of cutting edges on the tool

36. The correct syntax for counter clockwise circular profile milling in the XY plane is:
   a) G02 Xn Yn In Jn
   b) G02 Xn Yn Jn Kn
   c) G03 Xn Yn In Jn
   d) G03 Xn Yn Jn Kn

37. All of the following are advantages of using cutter compensation except:
   a) Mathematical computations are simplified
   b) A variety of different tool cutter diameters can be used
   c) The same program can be used for a variety of different parts
   d) Inside as well as outside cuts can be programmed

Matching (1 pt each) Write the letter of the Code in the blank that best relates to that function

______ 38.Linear Interpolation	k. G00
______ 39.Rapid Positioning	l. G80
______ 40.Return to Reference Point	m.M03
______ 41.Cancel Cutter Comp	n.M08
______ 42.Fixture offset location 1	o. G01
______ 43.Cancel Canned Cycles	p. G54
______ 44.Spindle on clockwise	q. G40
______ 45.Tool Change	r.G83
______ 46.Coolant on	s.G28
______ 47.Peck drilling autocycle	l.M06

Short Answer Put the most appropriate word in the space provided

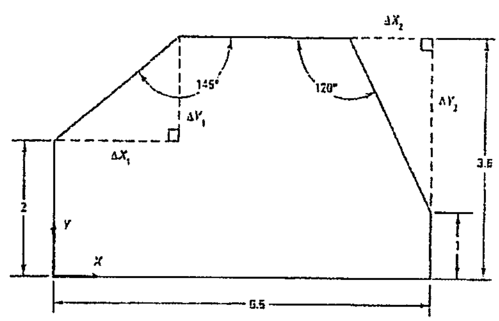
48. (1 pt.) MDI stands for __________ __________ __________.
49. (4 pts.) List four reasons for using CNC over a traditional machine tool.
    a) ______________________________
    b) ______________________________
    c) ______________________________
    d) ______________________________
50. (5 pts.) Name the five components of a modern CNC system.
    a)
    b)
    c)
    d)
    e)
51. (1 pt.) Write a manual line of code to call Tool # 7 into the machine tool spindle.

52. (1 pt.) Write a manual line of code to turn the spindle on clockwise rotation at 375 RPM.

53. (5 pts.) Write the general syntax line of code required for a Peck drilling canned cycle.

Calculate the following (2 pts.)

7.3. Find the distances ΔX and ΔY in the part shown in Figure 7-17.



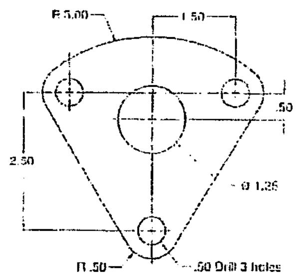
54. $\Delta Y1=$________________

55. $\Delta X1=$________________

56. $\Delta Y2=$________________

57. $\Delta X2=$________________

Examine the part and the program on the right and answer the following (1 pt.):



Identify the cutters needed to drill the hole pattern:

58. T1=

59. T2=

60. T3=

Fill in the missing code using T1 thru T3 from above.

61. N30=

62. N50=

63. N80=

64. N140=

65. N160=

66. N190=

67. N220=

68. N240=

69. N270=

70. N340=

```
O7228
N10 G0 G17 G40 G49 G80 G90 G98 ;
N20 G0 G90 G10 L2 P1 X_ Y_ Z_ ;
N30 M__ T____ ;
N40 G90 G0 G54 X0.0Y0.0;
N50 G43 H__ Z1.0 ;
N60 M3 S1538 ;
N70 M08 ;
N80 G__ X0.0 Y0.0 Z-.235 R__ F4.6 ;
N90 X1.5 Y0.5;
N100 X-1.5 ;
N110 X0.0 Y-2.0 ;
N120 G80 ;
N130 G91 G30 Z0 M05 ;
N140 M__ T__ ;
N150 G90 G0 G54 x0.0 Y0.0 ;
N160 G43 H__ Z1.0 ;
N170 M3 S548 ;
N180 M08 ;
N190 G__ X0.0 Y0.0 Z-.650 R__ Q__ F3.8;
N200 G80 ;
N210 G91 G30 Z0 M05 ;
N220 M__ T__ ; (                        )
N230 G90 G0 G54 X1.5 Y0.5 ;
N240 G43 H__ Z1.0 ;
N250 M3 S230 ;
N260 M08 ;
N270 G__ X1.5 Y0.0 Z-.650 R__ Q___ F17.69;
N280 X-1.5 ;
N290 X0.0 Y-2.0;
N300 G80 ;
N310 G91 G30 Z0 M05 ;
N320 G28 Y0 ;
N330 G90 ;
N340 M__ ;
%
```

<u>Essay</u> Write, in 1-2 pages a response to the following question (15 points)

Assess the importance of documentation for CNC machining operations. Response should include the components of good machine documentation as well as the overall importance behind documentation.

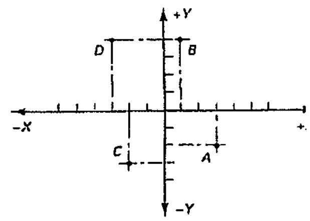
Appendix E

INDUSTRIAL TECHNOLOGY
INT 3203 – Computer Numeric Control Programming (2:2:3)

Professor:	Dr. David Melton	Class Room:	KLEM 3135
Phone:	581-5762	Meeting Time:	TR: 10:00 to 11:40 am
Office Hours:	MWF: 8:00 to 10:00 am	Email:	dwmelton@eiu.edu
Office:	KLEM 3149	Graduate Assistant:	Brad Curry

In order that we may best understand your prior knowledge relating to CNC please answer the following to the best of your ability.

1. Please identify the following points in space.



Point A

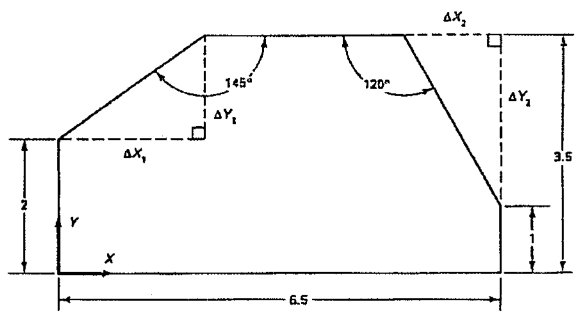
Point B

Point C

Point D

2. Calculate the following

7.3. Find the distances ΔX and ΔY in the part shown in Figure 7–17.



ΔX1

ΔY1

ΔX2

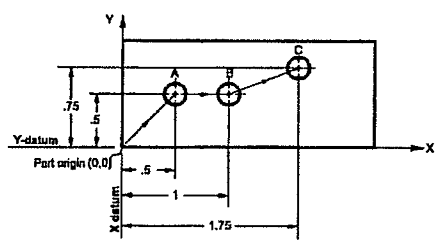
ΔY2

3. Fill in Hole Locations

Hole A

Hole B

Hole C



Tool position	Location	
	ΔX	ΔY
A		
B		
C		

FIGURE 2-19 Datum dimensioning for absolute mode positioning.

4. Indicate with a checkmark the items or terms that you could define or explain.

□End mill	□Counter Bore	□Reamer	□Tap	□Indicator	□Edge Finder
□Retention Knob	□Cat-40 Adapter	□Boring Head	□Insert	□HSS	□Carbide
□G-Code	□M-Code	□Conversational Language	□DNC	□MCU	□Datum

5. Indicate with a checkmark the Industrial Machines that you have heard about.

□Lathes	□Turning Centers	□Mills	□Machining Centers	□EDM	□Laser Jet
□Water Jet	□Drill Press	□OD/ID Grinder	□Surface Grinder	□Centerless Grinder	□Robots

6. (Circle the correct answer) CNC machines are always the fastest and most efficient way to make a part.

True

False

6. What are your personal expectations for this class?

7. What do you plan to do with the information, knowledge and skills that you learn in this class?

Appendix F

CNC Course Survey Results

1 Taking this class has increased my understanding of:	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
Industrial Machinery	0	1	0	7	3
Machine Tools	0	1	0	4	6
Tool Holding	0	1	1	4	5
Tool Cutters	0	0	1	5	5
Workholding	0	1	1	5	4
Machine Processes	0	1	1	4	5
CNC Operations	0	1	0	3	7
CNC Tooling	0	0	1	4	6
CNC Programming	0	0	0	5	6
Blueprint Reading	0	3	5	3	0
Part Tolerance (G,D & T)	0	1	4	5	1
Coordinate Measuring Systems	0	0	4	5	2
Shop Mathematics	0	1	5	4	1

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
2 I applied myself fully to learning this subject material	0	1	3	5	2
3 I used the textbook to help further my understanding of concepts that were unclear in lecture	1	1	3	6	0
4 This class met my expectations about CNC	1	0	2	3	5
5 My prior coursework prepared me to take this class	0	1	2	5	3
6 I have a strong prior knowledge about machining	0	2	5	3	1
7 I fully understood the complexity of CNC machining	0	1	1	8	1

8 After taking this class, I feel confident	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
that I could operate the Hardinge VMC 480P	0	0	1	6	4
that I could set up a CNC machine	0	0	1	8	2
that I could write a G-code program	0	0	2	8	1
that I could be a CNC programmer with no additional training	2	5	2	2	0
that I know enough about CNC to manage other individuals involved in CNC related activities	2	2	4	2	1

CNC Course Survey Results Cont.

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
9 The course increased my interest in CNC manufacturing activities	0	4	0	6	1
10 The course increased my interest in machining	0	2	1	7	1
11 The course increased my interest in manufacturing processes	0	1	1	8	1
12 The course increased by industrial technology knowledge	0	0	0	8	3
13 CNC is more complex than	0	0	0	0	0

14 Outside of lecture and lab time, the time I spent each week to learn about CNC

	0-1 hour	1-2 hours	2-3 hours	3-5 hours	5+ hours
Doing assignments	0	8	2	1	0
reading the textbook	8	3	0	0	0
reviewing sample programs given in class or in the textbook	1	8	1	1	0
looking at online resources	6	5	0	0	0
watching online videos of CNC machining	9	2	0	0	0
reviewing notes taken during lecture	2	8	0	1	0

15 Rate the difficulty of the following on a 10 point scale with 1 being easy and 10 being extremely hard.

	1	2	3	4	5	6	7	8	9	10
developing a shop traveler	2	4	4	0	1	0	0	0	0	0
developing a tooling sheet	1	4	6	0	0	0	0	0	0	0
writing a program	0	1	4	3	0	0	0	3	0	0
setting up a CNC machine	0	3	1	4	2	1	0	0	0	0
proving out and running a CNC machine	1	2	1	2	3	1	0	1	0	0

16 Please list and describe the most negative aspect you take away from this course.

17 Please list and describe the most positive aspect you take away from the course.

Appendix G

Name ____________________

Date ____________________

Company Project Individual Performance Review

Purpose: The purpose of this activity is to review the job performance of your fellow group members.

Procedure: Fill out one performance review for every member in the group and yourself. This is to remain anonymous and will be submitted to the course instructor via WebCt.

1 indicates that the group member did not work on that aspect of the task.
5 indicates that the group member did their very best to insure that aspect of the job was completed.

Each portion is worth 5 points for a total of 50 points or half of the Company Project grade. Once every group member has submitted their evaluations the average will determine the total number of points received by the individual group member. The remaining 50 points on the company project will be graded as a whole.

Group member being reviewed: ____________________

	1	2	3	4	5
Group member actively participated in:					
Job Planning					
Writing Program					
Program Entry					
Job Set-up					
Job Run-Time					
Preparing work piece					
Making decisions and correcting program errors					
Group member was available and communicated about all aspects of the group project					
Group member made every effort to be a team player					
Group member knows and understands what needed to be done to make the part					