

## **Experiences in Continuous Improvement of “Computer-Aided Manufacturing Systems”**

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### **Abstract**

The development and continuous improvement efforts for the industrial engineering course “Computer Aided Manufacturing Systems” at St. Ambrose University are described in this paper. This course has undergone major changes to stay current with computer-aided manufacturing technology and to meet ABET accreditation guidelines for design and integration. Open-ended laboratory assignments were introduced to stimulate thinking and to add design content. Integration with other engineering courses was carefully considered. Improvements in the classroom lectures and laboratory assignments were made.

St. Ambrose University’s industrial engineering program is small and operates on a limited budget. The small budget presented a particularly difficult challenge in determining which equipment and software to use or purchase. Course development has been financed through creative use of existing laboratory equipment, internal department funding, faculty redevelopment initiatives, educational discounts for software products, in-kind gifts, and low cost upgrades of existing laboratory computers. It was discovered that course objectives could be met without having to spend much money, but that improvements had to be phased in over the years. An overview of the course objectives, laboratory equipment and assignments, funding methods, professor and student’s observations, and plans for future improvements are provided.

### **Introduction**

The use of computer-aided technologies by industry has grown enormously in recent years. Practically all modern manufacturing organizations use computers in one form or another: to design and test product ideas (CAD - computer aided design), to control industrial processes (PLCs - programmable logic controllers), to inspect parts (industrial vision systems), to automate material handling and certain repetitive tasks (industrial robots), to operate machine tools (CNC - computer numerical control), and to integrate processes and systems (CIM - computer integrated manufacturing). Engineers are challenged to understand these technologies and their strengths and weaknesses, and apply them in a cost-effective manner. It is also very important that these technologies be integrated to maximize their effectiveness.

In 1991, this author joined St. Ambrose University and was assigned to teach the course IE375 – Computer Aided Manufacturing Systems. The school’s industrial engineering program was seeking ABET accreditation, and the department was carefully reviewing all courses to determine how to meet ABET guidelines. Two aspects of ABET guidelines, the course’s “design” content and course integration, were of most interest. Many years of industrial experience with computer-based technologies prepared the author to teach this course. IE375 had been previously taught by an adjunct professor. With the author being new to the teaching

profession, the challenge was to decide the best and most interesting way to deliver the course, considering ABET guidelines and working with existing materials and lab equipment.

The designated textbook was by Groover [1]. Lack of time to investigate other books led to its continued use. The department lab equipment consisted of three 486/33 PCs, a Light Machines Corporation CNC milling machine (see Figure 1) with its own 286/12 PC, and a Microbot TeachMover industrial robot (see Figure 2) with teach pendant and Apple II computer. Someone had donated a General Electric Series One Junior programmable controller, without documentation. For software, the three lab computers had Microsoft's Windows™ 3.1, Autosketch®, spectraLight™ Mill, and spectraCAM™ (the latter three were all provided by Light Machine Corporation). Autosketch, from Autodesk, was a significantly scaled down version of the product AutoCAD™. Very good documentation existed for the operation of the milling machine [2] [3] [4] [5], and minimal documentation existed for the industrial robot [6]. All equipment and software were tested, and course development began.



Figure 1. Light CNC Milling Machine

## Course Objectives and Development

“Computer aided manufacturing” had to be defined for the industrial engineering profession. What do IE’s need to know about this topic? The catalog description was written as “Theory of feedback control systems and computer control of processes. Classroom, laboratory and field experiences in NC, DNC, CAD/CAM and robotics.” was vague, allowing a professor to define and develop the course in many conceivable directions. The course, as it had been taught, concentrated on CNC programming, motors, and mechanisms. Although the design of automation components is extremely interesting, the topics appeared much more appropriate to mechanical engineering than to industrial engineering.

It was decided that, for industrial engineers, an understanding of the variety of computer-aided devices and their role in improving company productivity, quality, and cost was most important. These improvements occur with the successful application of correct technology. Understanding the capabilities, advantages, disadvantages, and integration of the technologies appeared most important.

The course syllabus now states the objective as “to provide students in industrial engineering a knowledge and an ability to apply computer-aided manufacturing technology as a

cost-effective strategy. NC, CNC, CAD/CAM, robotics, vision systems, PLC's, and other technologies will be investigated and their applications explored. Strategic implementation, optimization, and systems integration issues will be addressed. Laboratory assignments will be used to emphasize important technological issues and provide hands-on design experience with the technologies.” The specific computer-based technologies chosen were: computers and networks, CAD, NC/CNC/DNC, CAM, robotics, automated inspection and vision systems, PLC's, sensors, FMS, automated assembly systems, CAPP, and automated material handling.



Figure 2. Microbot TeachMover Robot

Two problems immediately faced were: 1) a textbook covering all these topics did not exist, and 2) these technologies were rapidly changing. Groover's book, although slightly outdated, did cover many of these topics. Supplemental sources from other books [7] and periodical articles were found for topics not covered in the book. Periodical articles provided contemporary information about application of the technology and updated information from the textbooks.

The course was divided into two components, lectures and labs, giving each approximately the same amount of time. Lectures were presented in a conventional method, focusing on the technology components, application, advantages, and disadvantages. Laboratory assignments reinforced lecture material, and are further explained below. Grading was distributed as follows: Exams - 45 percent, laboratory assignments - 40 percent, attendance and assignments, 15 percent. Exam questions focused primarily on lecture information, but could include questions about laboratory knowledge.

### **Lab assignments**

Six laboratory assignments were used to reinforce lecture information and to give hands-on design experience. It is believed that hands-on experience is required when learning about computer-based technologies. Having students experience old (manual) ways of accomplishing manufacturing tasks, new computer-based approaches, testing and simulating computer results, and producing final operations, were believed to be important. Giving students exposure to several technologies, yet having a common theme across all laboratory assignments was also important. This could have been accomplished with the industrial robot, or even the PLC; but the author chose to use the CNC milling machine since it was the most expensive lab equipment

and using it could accomplish the goals. One major concern was that the author had never personally programmed CNC equipment, so this technology had to be learned.

Open-ended laboratory assignments were developed that offered adequate opportunity for students to use design ideas and creativity. The assignments begin with simple concepts and become more complex – using experience from all previous laboratory assignments. The final lab integrates experiences from previous labs. Although laboratory assignments use a small subset of manufacturing technologies, they were designed to address general technological design and integration issues. Additional time away from normal class time may be needed by students to complete a project. Students were allowed to work in small groups, but each is encouraged to think through the problem. It is important that students explain their approaches, particular problems, and learning experiences. Some assignments include extra credit activities.

Each student submits a professionally written report for each lab. Report guidelines [8] and an example report are provided. The reports are graded according to effort exerted, knowledge gained, and results. Determining which students are really doing the labs and who are not has been relatively easy. Several exam questions about the labs are included on exams.

### Lab 1 - Computers and Operating Systems

This lab exposes students to the computer and to different operating environments. A computer is dismantled and the components discussed. Operating systems and their variations among different manufacturing equipment is discussed. Common computer operations, such as creating files, viewing file contents, editing files, copying files, and deleting files are explored.

The lab computers are connected to other networked computers. From the lab computers, DOS, UNIX, Novell, and Windows operating environments can be illustrated. Students are challenged to create files in one environment and move them to others. The importance of the ASCII text file is explained. Lastly, students learn about networks and how to e-mail files to the professor.

### Lab 2 - Computer Aided Design

Students are introduced to CAD and the electronic drawing – the beginning of many computer-based manufacturing technologies. Students use several CAD products, including AutoSketch [Error! Bookmark not defined.], Cadkey® [9], and Surfcam® [10]. The major goals are: to provide an overview of 2D and 3D design concepts and software; to provide practice designing parts; to understand that there are differences between CAD products in their presentation and use; to introduce CAD industry standards, file compatibility and file conversion issues; and to expose students to file translations.

Students are expected to complete several tutorials. An example of one tutorial's CAD drawing is shown in Figure 3. Students also try to transfer the drawing files over to the other CAD systems using DXF, IGES, and other file formats.

### Lab3 - Robot Fundamentals and Programming

This lab introduces students to the industrial robot (shown in Figure 2), which is another example of a computer controlled industry device. Students program the robot using a teach method – guiding the robot from point to point and recording the progressive steps. Students later learn that a teach method, although easy to perform, has some major productivity drawbacks.

Students design an assembly operation, explore robot performance optimization techniques, and gain an understanding of the advantages and disadvantages of manual programming. Students can videotape the results for extra credit.

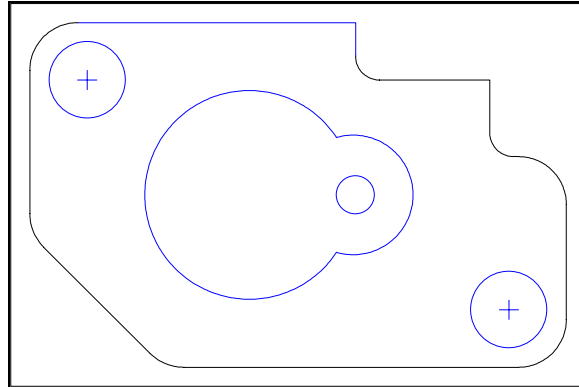


Figure 3. CAD Drawing Produced with Autosketch

#### Lab 4 - Process Planning and NC Parts Coding

This lab introduces students to manual NC parts coding. Students must design the NC code for the part drawing shown in Figure 4. Students are directed to use a 3/16" diameter cutting tool, machinable wax as the material, and to set feeds and speeds to realistic values. Machining techniques and process planning are introduced, and the students must submit an acceptable process plan that includes an estimate for machine time.

Using an editor of choice, students create the NC code required to machine the part on the Light milling machine. This file is saved as an ASCII text file. Students submit their NC programs to the professor via e-mail.

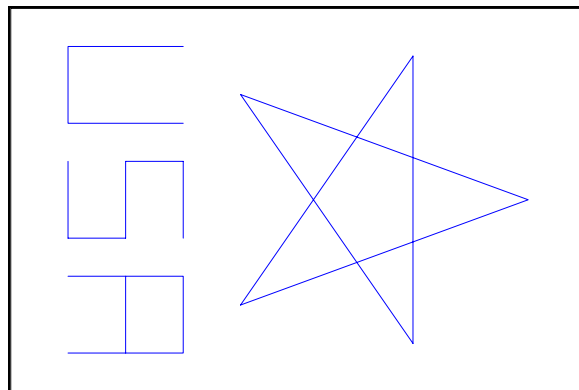


Figure 4. USA Star

#### Lab 5 - Simulation and CAD/CAM Programming

Most computer generated code that will control manufacturing equipment must be tested before producing parts or initiating equipment action. Students use a software product called 3-D

Solid Verification [11], to simulate (animate) their NC code created in lab 4. When their code does not operate properly, they must decide how to debug and fix the code.

Students then learn how to use CAM software to create the same part. The part is drawn with CAD software, the file is converted to DXF format and imported into spectraCAM software [12], the code is post-processed for the Light milling machine, NC code is created, and the code is tested with the 3-D Solid Verification software. An understanding of the advantages and limitations of CAM and simulation software is obtained. Students compare the CAM generated code with their manually created code.

### Lab 6 - Part Design and Production on CNC Milling Machine

Students have the opportunity to use knowledge gained throughout the previous laboratory assignments to manufacture a product. The knowledge includes designing parts with CAD, creating NC code with CAM, testing and verifying the NC code with simulation, and machining the part on the Light CNC milling machine (see Figure 1). Students learn to operate the Light CNC milling machine and execute the NC code. Proper machine safety procedures are also learned.

Students machine two parts: USA Star, which was created in previous assignments, and a second part shown in Figure 5. After creating the CAD drawing, the drawing is imported into spectraCAM (see Figure 6). The cutting path is then generated (see Figure 7). Finally, the NC code is generated, tested in 3-D Solid Verification, and a part is machined on the Light CNC milling machine. The final part is shown in Figure 8.

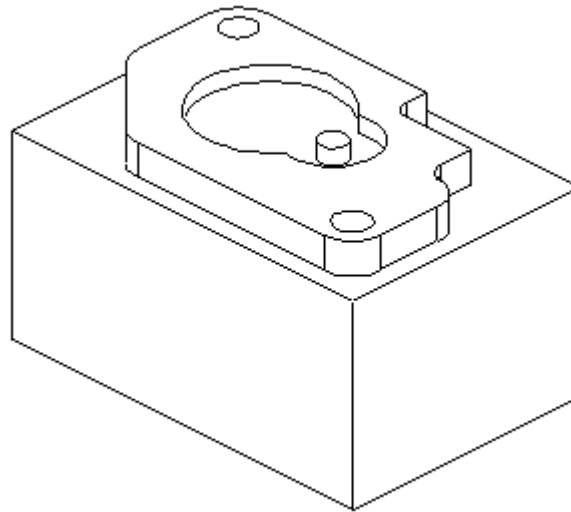


Figure 5. Second Part to Manufacture

Students are asked to compare actual machine times with estimates and explain any differences. Students attempt to optimize their code for minimum machine time. An integrated design challenge is presented for extra credit where students can create an operator incentive standard, develop a process plan, calculate production cost, and discuss quality control issues about the manufacturing process.

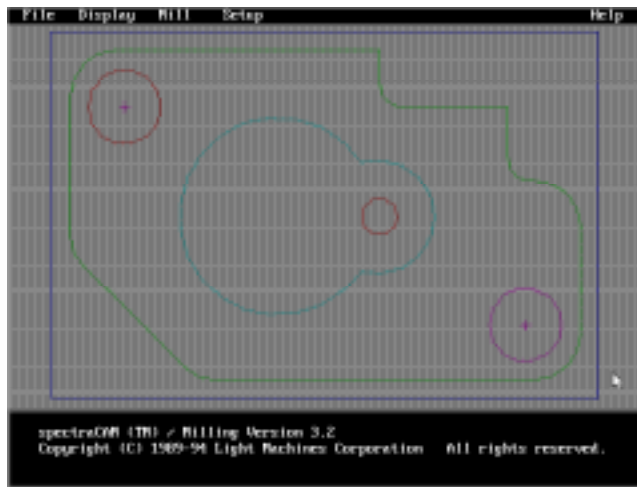


Figure 6. CAD Drawing Imported into CAM Software

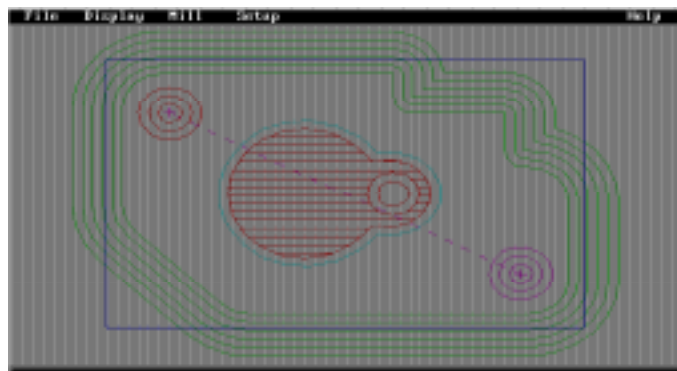


Figure 7. NC Toolpath Generation



Figure 8. Final Part Produced on Milling Machine

### **Continuous Improvements**

Keeping a course related to computers current is an ongoing challenge. When operating on a small budget and using various funding methods to acquire supplies, it was found that only a

few improvements could be made each year. Making improvements each year has created “continuous improvement” for the course.

For example, the original software was found to be outdated and was immediately upgraded using department funds. A goal of equipping the lab with modern CAD/CAM software led to purchasing new products. Educational copies of Cadkey, Surfcam and 3-D Solid Verification were purchased with funds obtained internally by a “Faculty Development” grant. The grant provided an incentive to develop lab assignments, upgrade software, and purchase new software.

In 1997, a grant from the Society of Manufacturing Engineers Education Foundation [13] provided additional copies of Cadkey and Surfcam. In addition, in 1997, an internal “technology focused” grant provided several copies and training for a newer CAD product – Solidworks™ [14]. This grant, under this author’s encouragement, was pursued by another faculty member who taught Engineering Graphics. The new copies of Cadkey, Surfcam, and Solidworks allowed the department to evaluate the products and determine its intended direction with CAD/CAM.

Solidworks required Windows95™; therefore, several lab computers had to be upgraded. This was accomplished with department funds. The department’s approach to upgrading computers was to do so with minimum investment. Realizing that computer technology becomes obsolete every two to three years, it makes sense not to spend more than is necessary on lab computers. The department chose to upgrade the motherboard with a fast, but less expensive, 200 MHz Cyrix-based board. 32MB of RAM and a 4MB graphics card were added, but the existing monitor, hard drive, floppy drive, and network cards were retained. Using this upgrade path, the cost was kept to below \$500. Our experience with these computers has been very positive.

The PCs have undergone upgrades. Our approach has been to upgrade components when possible and to utilize low cost suppliers. It is our belief to not spend money on brand name equipment because computer technology becomes quickly obsolete. Computer upgrades are accomplished from department funds.

## **Observations**

Course reviews by students were very positive. The benefits of an active learning model are derived. Some students complained about the extensive report writing, and the time involved with the lab assignments, but many commented positively about their knowledge gained. Students commented that they enjoyed working in the lab. Many students, at the beginning of the semester, do not believe that they are going to learn enough to machine parts from NC code by the end of the semester.

One highlight of the course has been a tour of Genesis Systems Group – a local welding robotics systems company [15]. During this tour, students saw many technologies learned in the class in action. Genesis Systems Group has provided employment opportunities for the graduates.

An additional benefit to students was that they could claim on their resumes that they had experience with computer operating systems, CAD, CAM, robotics, simulation, and NC programming.

## **Future Development**

All St. Ambrose University students are required to take several “writing-intensive” courses. This course, due to the nature of the lab reports, is a prime candidate to become a writing-intensive course. Several student reviews have reinforced this idea.



A grant pre-proposal to the Society of Manufacturing Engineers Education Foundation has been submitted to upgrade and add several computers to the lab and to encourage greater course integration. Additional copies of Solidworks and Surfcam and a new CNC lathe are included in the grant. The activities in this grant will be coordinated with local industry.

Solidworks, which is now being introduced to students in Engineering Graphics, will be used to design 3D solid models of parts, similar to the one shown in Figure 9. Solids modeling future is very strong. Surfcam is planned to completely replace the Light Corporation CAM software since it can generate NC code and perform simulations (see Figure 10). Eventually, parts with true 3D geometry will be included in the lab assignments and machined by Surfcam, as illustrated in Figure 11.

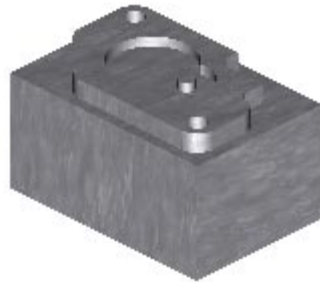


Figure 9. 3D Rendered Solid Model Produced by Solidworks

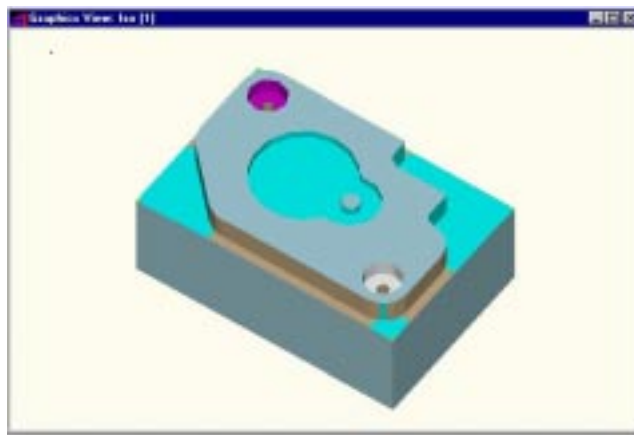


Figure 10. 3D Machined Part in Surfcam

Other computer-based products, such as PLC's, industrial vision systems, digital gages, sensors, and conveyor systems, may eventually be acquired and included in laboratory assignments. Upgrading the existing robot may be considered, but the current robot does offer a significant benefit in that its cable driven design makes it very safe to operate without supervision.

A continuing challenge for this course is to find a textbook that appropriately addresses the chosen topics. Groover's book, which was quite comprehensive, was getting outdated (copyright 1987). Singh's book [16], published in 1996, was eventually chosen for its more

current copyright, but its coverage of the topics was still not satisfactory. Until a better textbook is found, the textbook will be supplemented with periodical articles.

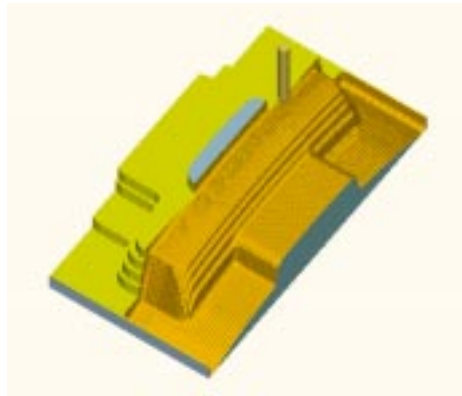


Figure 11. 3D Part, Simulated Machining in Surfcam

Lastly, a challenge to better integrate this course with other IE courses remains. Courses being considered include the following: Engineering Graphics, Problems Solving with Microcomputers, Manufacturing Materials and Processes, Industrial Engineering Methods, Design Fundamentals for Industrial Engineers, Engineering Economy, Quality Control and Reliability, and System Integration and Design.

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