Learning about CIMS by doing Design: An integrative Model for Manufacturing Education

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Abstract

This paper describes an integrated experience to teach students about computer-integrated manufacturingsystems (CIMS) by engaging them in hands-on team projects to design and build useful products for elementary school students. This experience is used in a senior level CIMS course that is team-taught by two faculty members, one from the Manufacturing Engineering Department and the other from the Systems Analysis Department. In this course students learn to integrate computers and computer-machine interface concepts in the design of automated-manufacturing systems. The goal is to enable students to utilize such a methodology in the design and implementation of CIMS to improve product quality and reduce cost. In the past two years, we have been conducting projects to design and produce model toys that demonstrate scientific and engineering concepts for students in a local elementary school. Every year, the class is divided into small groups of students to design a manufacturingsystem that utilizes the concepts of CIMS to produce this model toy. The project is conducted in four iterative phases, where every phase builds on the previous one, but allows students to modify their previous phase based on the customers' feedback (elementary school students), the instructors' feedback, and new material covered in the lecture and lab. In this paper, we will discuss the interdisciplinary approach used in teaching CIMS, the applications of computers in the lecture and lab activities, and the design projects.

Introduction

One goal of manufacturing education is to provide students with an integrated experience in doing design and making things. Integration requires engineering educators to create an effective learning environment that ties both the critical analysis of the theory with the creative practice of the lab. Here, the students learn the process of doing design by linking the scientific principals with the engineering-science concepts to make useful and safe products. In addition, manufacturing education should bring real world applications into classroom realities. Computer-integrated manufacturing systems (CIMS) is an excellent example that can be used to provide such an integrated environment in the classroom.

Although CIMS still means different things to different people, depending on their role in the manufacturing enterprise, we will use the model suggested by the Computer and Automated Systems Association/Society of Manufacturing Engineers (CASA/SME) and is called the CIMS Wheel [1]. This proposes atop-down perspective: a view from the office of the business executive rather than the manufacturing technologist -- those who must derive economic benefit from it, the integrators, rather than those who implement it, the integrates. The Wheel consists of five, fundamental and interconnected dimensions: 1) general business management, 2) product and process definition, 3) manufacturing planning and control, 4) factory automation, and 5) information resource management. Each dimension is a composite of the other more specific manufacturing process and is seen to be a family of automated CIMS processes: An enterprise- wide concept. Most of the inter-famil y integration occurs through information resource management, the Wheel Hub. The Wheel represents the infrastructure that allows the enterprise to use automation as a competitive tool and manage its employees as knowledge workers instead of direct and indirect cost elements. This should lead to the so called "Factory-with-a-future, " or "Factory of the Future. "

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To teach students about CIMS, the traditional approach that is found in published work (for more details, please review the following selected references [2-6]) is to use the lecture to review the different technologies involved in a CIMS environment, such as group technologies, CAD/CAM, and process planning (the texts that are used in such courses have also similar outline for its topics, see for example the following selected texts [7- 11]); and to use the lab to cover some of these topics by using such technologies as robots, automatic-storage and retrieval, and computer-numerical control [3-6]. In some cases, the course and lab experience used design projects to improve the lab by integrating new equipment into it [4-5] or by producing some physical products [2-3], or by linking it to industrial activities [6].

Our approach built on these experiences and attempted a link between the lecture and lab by providing the students with an open-ended design project that utilize both the theoretical aspects covered in the lecture with the practical applications of the lab. In addition, the experience allowed the students to experience a true iterative cycle of the real manufacturing production [11] instead of a sequential approach. This is discussed next. First, we will discuss the structure of the course. This is followed by an explanation of the lab and the integrative design experience, and finally a summary.

The CIMS Course: A Collaborative Experience in Teaching

The CIMS course is a 3 credit, senior level course with one hour of design. The course was developed collaboratively in the truest sense of the word. Professors Byrkett and Ettouney worked closely over several years to broaden the course from one that primarily emphasized computer aided manufacturing to one that showed how computers can be integrated into every aspect of manufacturing including product design, process design, and product manufacturing. During the Spring semester of 1993, Professor Ettouney taught the class independent y for the last time while Professor Byrkett attended all of the classes and laboratories. Their plans were to work collaborative y to develop an interdisciplinary course that would be of interest to both manufacturing engineers and systems analysts. After each lecture and lab they met to discuss course content and to plan changes. The goal was to teach the new interdisciplinary course for the first time during the Spring of 1994.

During the Fall semester of 1994, the two professor met weekly to develop the course from the ground up. They reviewed text books, developed course objectives, selected topics to include in the class, and planned an integrative design experience. It was determined that upon successful completion of the course, the students should be able to:

- Explain the concept of CIMS and the role of manufacturing engineers in CIMS
- Use computers in their daily work for communication
- Understand how computer networks are organized to support computer integration
- Understand and explain how data files are organized to support CIMS
- Understand and explain how computers are used for solids modeling, for design, and for analysis
- Understand and explain how computer integration will support concurrent engineering
- Understand and explain how computer technology and group technology are changing the way manufacturing systems are organized
- Understand how computer technology can be used in process planning
- Understand and explain how information systems are used to support the management and control of a manufacturing system
- Use computers to control a manufacturing system
- Program a numerically controlled machine
- Use simulation software to evaluate a manufacturing system
- Use SmartCAM to automatically y generate an NC program from a CAD drawing
- Design a CIMS process

These objectives were accomplished in many different ways including lectures, class activities, homework exercises, laboratory activities, and an integrative design project.

During the Spring semester of 1994, the course was taught collaboratively. Professor Byrkett assumed primary responsibility for the lectures and Professor Ettouney assumed primary responsibility for the labs, though both professors attended all lectures and laboratories. The design and evaluation of all homework assignments, laboratory exercises, design projects, quizzes, and tests were carried out together. Since that time, the course has been taught in a similar way with a different professor from Systems Analysis. It is felt that by having professors from two disciplines the students will gain a broader perspective about the integration of computers in manufacturing.

The CIMS Lab: Means to Achieve Integration of Course Objectives

The CIMS lab at Miami University is an interdisciplinary effort among three departments: Manufacturing Engineering, Systems Analysis, and Psychology (Ergonomic Center). The major objective of the CIMS lab is to give students the opportunity to integrate computers into a manufacturing environment. This includes the use of computers for designing products, testing materials, controlling manufacturing processes, combining manufacturing processes into systems, and collecting manufacturing information [12].

The CIMS lab is designed to perform five business functions: research and development, product design, process planning, product manufacturing, and production planning and control. These functions are similar to those discussed earlier in the CASA/SME CIMS wheel, but have been modified to reflect our stated objectives and the ability to perform the activity in a lab environment.

The CIMS lab (see Figure 1) is organized into four centers that support the five business functions described above (please see below). In the CIMS lab, the computers are linked through an Ethernet local-area network that is interfaced with the SAS main server. The four-centers are: Computer-Aided Design and Manufacturing (CAD/CAM) Center; Flexible-Manufacturing System (FMS) Center; Computer-Aided Experimentation (CAX) Center; and Computer-Aided Material Testing (CAMT) Center.

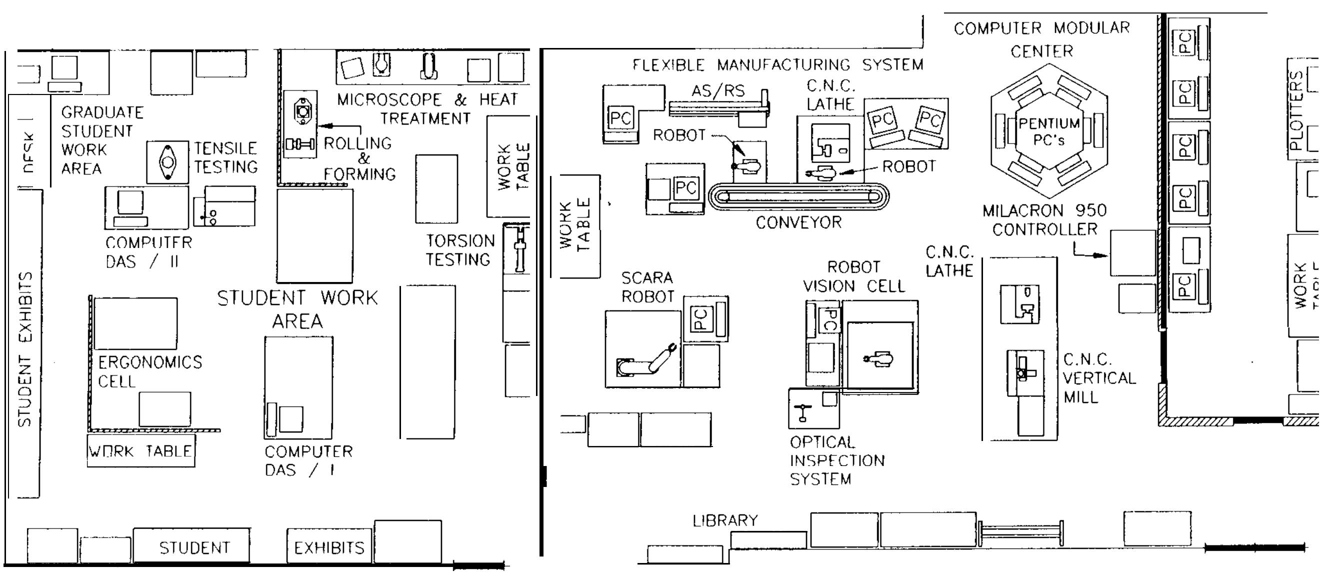

Figure 1. The Layout of the CIMS Lab at Miami University

The lab and the integrative design project activities are designed and linked together with the lecture portion of the course to achieve many of the course objectives as stated earlier. During the weekly lab periods (which are organized around the four phases of the project as will be discussed in the next section), the student work on CIMS' cells that represent industrial examples of computer control systems for manufacturing processes. These are: Flexible-Machining Cell and programming; Amatrol Automatic Storage and Retrieval System (AS/RS); Robotics (RM-501 Mitsubishi Robot); Micron Technology, Idetix Digital

Vision System and Eshed Robotec Vision Systems; Cincinnati Milacron Acramatic 950 CNC Controller; Emco Maier CNC Milling and Lathe machines; and computer-aided Design (AutoCAD) and manufacturing (SmartCAM) software. These weekl y periods help the student to design a small manufacturing company that implements the many concepts of CIMS to produce the model toy.

In the CIMS lab computers are used to communicate our ideas and work, and attempt a paperless environment. For example, lab handouts that describe procedures and activities are communicated to the students by using computers. These handouts were made available on the School's Network. The students weekly lab reports, computer programs, and project were saved in files in special directories, for each group, in the CIMS lab directory, in the Network.

We also communicate with one another through the internet using a special listservs. Although the students are required to submit hard copies for each phase of the term project, they also keep these reports as well as any other accompanied work, such as computer graphics and CNC programs on special files in the CIMS directory and on the World Wide Web (for further details the reader may want to check our address on the www: http: //phoenix. sas.muohio.edu/cim/CIMS.html).

Integrative Design Project: Learning about CIMS by doing Design

One of the unique features of this course is an integrative design project. In the Spring of 1994, students were asked to design an educational toy that illustrates a scientific or engineering concept. Some of the design constraints were that the toy be appropriate for a 7 to 12 year old student, fit in a box of size 24''x24''x12", have at least one exciting feature to hold the student's interest, and cost less that $30. So that the project would fit in with the objectives of the course, we also required that at least one component be manufactured on the numerical control machine in our labs and that the team builds a prototype of the toy. To achieve these objectives, the project was broken down into four phases, initial product design, initial manufacturing process plan, product manufacturing, and product assembly and presentation. Each of these phases addresses one or more of the course's objectives and allows the student to finish their design project.

Below are some more details about the integrative design experience and the four phases. These were given to the students as handouts approximately a month apart, where the first one was at the beginning of the course, in the first lab. Our hope is that this may be useful for other educators who are interested in starting or integrating such experience in their CIMS courses.

Phase 1 - Initial Product Design

The first phase of the project was to develop an initial design. Students were expected to do some research on scientific toys and use their creativity to design an interesting toy. The documentation that they were required to submit in phase 1 was as follows:

a. A description of the product, the scientific principle they are trying to teach, and how they have made it exciting for a 7 to 12 year old.
b. AutoCAD drawings of the assembled product and each component they plan to manufacture.
c. A complete list of components and whether each component is to be manufactured or purchased.
d. The estimated cost of the product.

Students were encouraged to provide design details, but were advised that design is an iterative process and they will likely modify some of the design features later. In fact, the iterative nature of design was probably one of the most useful lessons learned from the integrative design process.

Phase 2 - Design Modification and Initial Manufacturing Process Plan

The clients for this toy were a fourth grade class at a local elementary school. They were invited to the CIMS lab for a field trip. The fourth grade class was divided into groups of three or four students and assigned to each of our design teams. The design teams showed there initial designs to the fourth graders and asked for feedback. Did the toy look like it would be fun to use? Did the fourth graders have any suggestions to-make the toy more fun? Did they understand the scientific principle? The clients were given a tour of the

CIMS lab and shown the robots, the automated machine tools, and a flexible machining cell with an automated conveyor. Everyone, the fourth graders, the college students, and the teachers, had a great time.

In class, we were discussing the ideas of concurrent engineering and the importance of considering the manufacturing processes on the product design. For phase 2, the students were asked to take into consideration the feedback from their clients and the principles of concurrent engineering to revise their product designs. In addition, they were asked to develop an initial manufacturing plan based on the equipment in our labs. This report was to contain the following.

a. A discussion of the feedback they received from their clients on the initial design and any modifications they plan to make based on that feedback.
b. A discussion of how they are going to manufacture their toy and how they plan to modify the design to make it easier to manufacture. This discussion should include an explanation of how they used the principles of concurrent engineering to revise their design so that it retains the functionality the clients desire, but will be easy and less costly to manufacture.
c. Based on the above discussion (and the feedback from the instructors on Phase 1), they were asked to prepare a revised set of AutoCAD drawings of the assembled product and each component they plan to manufacture. We emphasized that these drawings were to include material and dimension details that, in some case, were missing in phase 1.
d. A detailed fabrication plan for each manufactured component of the toy. The plan was to contain a sequence of operations including equipment required and an estimated processing time.
e. A detailed assembl y plan. It, too, was to contain a detailed sequence of operations that show how the manufactured components and purchased components go together and how they are packaged.
f. A list of materials or purchased parts that are not available in the lab that they will need to build the toy. This was for our use in ordering materials for the construction of their prototype.

Phase 3 - Product Manufacturing

In class and lab, the students were learning how to design automated manufacturing systems, how to program numerically controlled (NC) machines, and how to use SmartCAM to convert an AutoCAD design into an NC program. In the third phase of the project, we wanted the students apply this knowledge to their project. As usual, we still wanted the students to revise their product designs. Each group made some design changes at each phase. Specifically the third phase was to contain the following items.

a. An NC program to manufacture at least one of the components of their product. They were to execute this program and make the part. In the report, they were to include a listing of the program and the actual part they made. This insured that they got started early on the construction of the prototype and helped them identify potential manufacturing.
b. Based on the feedback from their instructors on Phase 1 and 2 and their experience in manufacturing the first part, they were to prepare a revised set of AutoCAD drawings of the assembled product and each component they plan to manufacture. They were to discuss the reasons for any changes they made in the design.
c. A design of a computer automated production system to produce at least 200 units of their product per one eight hour shift. Their design could include robots, automatic storage and retrieval systems, conveyors, CNC machines, a computer to control the system, a computer network, sensors, programmable controllers, and other automation features. They were told to assume that the equipment they specified is dedicated to the production of their product. Their design was to specify how many workers are required and the tasks that each will perform. It was suggested that they may want to consider a team of workers with overlapping skills. Their design was to include a schematic drawing of their production system with all components and workers labeled. Along with the schematic, they were to include a narrative describing the flow of parts through the system (starting with raw materials and purchased parts to a packaged product ready for shipment) and describing the function of each element of their production system.
d. Based on estimated processing times, they were to estimate the actual production of their system during an eight hour shift. The report was to include the calculations and justifications.

Though we were not able to accomplish it this semester, it is hoped that in future semesters the students will be able to construct a simulation model of the automated production system. They can use this model to estimate the production capability of their system.

Phase 4 - Product Assembly and Delivery

The final phase of the project was to complete the product prototype and deliver it to the clients. The students completed the projects a few days ahead of the meeting with the clients so that the instructors could evaluate their work. This time our CIMS students took their completed projects to the fourth graders. They showed them to the clients and gave them the opportunity to use the educational toys. The products were left with the fourth grade teacher for later use. Again, a good time was had by the college students and the fourth graders. The final report included the following items.

a. A complete prototype of the toy ready for presentation to the clients.
b. A revised set of AutoCAD drawings of the assembled product and each component (purchased or manufactured) of the toy. This provided one more opportunity for design changes.
c. A revised fabrication plan for each component (using the equipment in our lab) and a revised assembly plan. These plans were to be similar to the ones prepared for Phase 2. Students were asked to discuss changes to the original plans based on their experience building the prototype.
d. A revised cost estimate based on the final design and production plan.
e. A list of NC program files developed to make the prototype.

A new addition in the second offering of this project was to require the students to write a two-page class exercise that the teacher can use to teach her students about the scientific and engineering concepts that your toy demonstrate.

Note About Grading

The lab and term project constitute 35% of the course’s grade. This is divided into 10% for the lab’s weekly activities and 25% for the project. These include: designing, building, and testing physical models; designing the small manufacturing-company; documenting the designed work; programming equipment, documenting weekly work, using the network, internet, and the World Wide Web; and participating and contributing to team work, and evaluating of team’s members. Other criteria that we used to determine the student’s grade include: demonstrating creativity and critical thinking, taking initiatives, and contributing something new to the CIMS lab.

Summary: Lessons learned

In the past few years, we taught this approach twice. In both times we had eight groups of students. The number of students per group varied from three to four (total class enrollment was about 25 students). We allowed the students to form their own groups. (Because the students take this course in their second semester of their senior year, most of the groups are formed along the same groups found in the capstone course which is a two semester sequence.)

Example of students’ projects included making model toys that demonstrate such scientific concepts as Bernoulli’s principle, tornadoes, gear mechanisms, and perpetual motion; others dealt with educating students about patterns, reflection, rotation, and translation by using parts with different colors and shapes, or by using a pocket electronic educator that interacts with the young students in questions & answers format. In addition to these physical models, the students designed small manufacturing companies to produce the product using the concepts of CIMS.

As we reflect back on the design project, several things stand out as important. One, the students had an actual client. Though the client was a fourth grader, an important part of the project was to produce an interesting toy to meet the client’s need. Two, the students saw that design is an iterative process and that manufacturing concerns are equally important to functionality concerns in the product design. Each phase of the project required design changes, many of these based on manufacturing considerations. Three, computers were used at every phase of the project. Computers were used to specify the design (AutoCAD), write reports (word processor), automate a process (phase 3 design), build a part (NC program), and integrate design and manufacturing (SmartCAM). Though other areas of computer integration were discussed in class (simulation, production planning and scheduling), we were not able to integrate all of these in the project. Finally, four, the students worked as teams. Each team member had different skills, some were strong with computers, some were strong in working with clients, some were more creative, and some were better at building the prototypes. Altogether, the final product was better when the combined skills were used. So the students not only learned to integrate computers into the design process, but they learned to integrate personal skills.

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