ENHANCEMENT OF FLEXIBLE MANUFACTURING SYSTEM INSTRUCTION TO IMPROVE UNDERGRADUATE EDUCATION

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Abstract
The Industrial and Engineering Technology Department (IET) at Morehead State University (MSU) has worked on Flexible Manufacturing System (FMS) project funded by a joint grant from MSU and National Science Foundation. The goal of the project is to improve the undergraduate education of IET students in the area of Manufacturing Technology, Electrical/ Electronics Technology and Computer Aided Design & Graphics by teaching students with hands-on type of educational practices and laboratory exercises in the area of FMS.
A MiniCIM 3.2 Amatrol has been selected as the equipment to teach FMS. This equipment is used to modify the curriculum and nine courses and labs in the IET department to enhance the students’ learning. The FMS project serves also as a starting point to accomplish a six-year development plan of the Manufacturing Laboratory in the IET department. The goal is to complete a fully Computer Integrated Manufacturing system in six years. The strategy used is aligning students’ class projects and/or students’ senior projects with the goals of the Manufacturing Laboratory. These class projects not only improved the students’ learning, but they also became an important step in constructing a complete Computer Integrated Manufacturing system.
Class assessments were conducted, where exams, quizzes, homework, class projects were given to students. These assessment tools showed a significant improvement in the students’ learning. Informal questionnaires were also distributed to find out what the students think regarding the use of MiniCIM 3.2 as a teaching tool. All the students agreed that this hands-on type of educational practices helped them to understand both concepts and the technology of FMS discussed in class. Furthermore, about 90% of the graduates were able to find jobs within six months of their graduation. This resulted in a significant increase in the students’ enrollment.
The FMS project opens the way widely for good collaboration between the IET department and local community colleges. The IET department opened its laboratories for the students of these colleges to perform some of their projects. Furthermore, collaboration started between the teachers of the community colleges and the IET department through some joint classes at the IET labs.

Keywords: curriculum development, flexible manufacturing teaching.

1. Introduction:
Morehead State University (MSU) has an enrollment of approximately 9,500 students primarily from eastern, northern Kentucky and Appalachia. Within the College of Science and Technology, the Department of Industrial and Engineering Technology (IET) offers the two-year associate (AAS), the four-year bachelor (BS) and the Master degree in industrial technology and the BS degree in industrial education. The BS degree in industrial technology offers five technical
options: Construction/Mining Technology (CON/MIN), Electrical/Electronics Technology (EET), Computer Aided Design & Graphics (GCT), Manufacturing/Robotics Technology (MAN/ROB) and Telecommunications & Computer Technology. The Department of IET has eight full-time and six part-time faculty members and it is accredited by the National Association of Industrial Technology (NAIT). Since the establishment of the IET Department, the faculty members have continually updated the curricula to meet the changing needs of the industrial and educational institutions for competent personnel and the needs of MSU students for technical training and successful employment. Furthermore, IET graduates have gainfully joined the workforce and made socio-economic contributions in positions such as vocational-technical educators and administrators, technology educators, project managers, production supervisors, quality control engineers, design engineers, mechanical designers, industrial engineers among others.

The goals of MAN/ROB area concentration is to teach students how to perform entry level technical occupations in manufacturing, understand and apply theory and concepts of related disciplines to solve technical problems, apply concepts and skills developed in a variety of disciplines. To achieve these goals, IET Dept. needs a factory model; therefore, the long-term goal of the Department of IET is to develop a fully Computer Integrated Manufacturing (CIM) laboratory, which integrates six functions in manufacturing system. Those functions are production, design, manufacturing planning and control, marketing, finance and human resources [1]. Flexible Manufacturing System (FMS) is an automated production work cell which typically possesses multiple automated stations and is capable of variable routing among stations [2].

The availability of state-of-the-art laboratory equipment is the most significant factor in teaching automation [3]. A major barrier in teaching automated and flexible-manufacturing systems is the lack of state-of-the-art equipment in IET that would provide students with the opportunity to develop skills to prepare them to enter the workforce.

Morehead State University serves a 22-county service region in eastern Kentucky that is comprised of several community and technical colleges, as well as the high schools in the area. Students in these colleges are enrolled in technical courses or programs, but they are not exposed to FMS because of the high cost of instrumentation equipment. None of these colleges has any flexible manufacturing equipment. These community and technical colleges, 45-60 miles from MSU, will benefit from the use of FMS instrumentation: With the FMS, students learning from these community colleges will be able to transfer to MSU and obtain a BS degree in manufacturing robotic technology.

2. Goals and Objectives of the FMS project
   The goal of the FMS project is to improve the undergraduate education of IET students in the area of Manufacturing/Robotics, Electrical/ Electronics
Technology and Computer Aided, Design and Graphics by teaching students with hands-on type of laboratory activities and exercises.

The project’s three objectives are: (1) to enable the students to become proficient in the fundamental concepts and applications of robotics and automation in FMS; (2) to enable students to participate in hands-on, innovative laboratory exercises and (3) to provide opportunities for students to gain technical skills and knowledge using innovative software used in FMS.

The following equipment is available in the Manufacturing/Robotics Laboratory and will continue to be used to teach basic manufacturing concepts and to support the project: (1) Brown & Sharpe PFX Micro-Val Coordinate Measuring Machine (CMM), (2) Educational CNC machines: Prolight Vertical Milling Machine and SpectraLight Lathe Machine, (3) Mazak V 414 Vertical CNC Machining Center, (4) Hitachi Welding Robot, (5) Microbot Educational Teachmover Robots, (6) Motoman SV3 6-axis articulated robot and (7) two conveyors.

Based upon research, the IET faculty selected FMS module called the MiniCIM 3.2. The MiniCIM 3.2 is a state-of-the-art FMS for education. IET selected the MiniCIM 3.2 because it is a more reliable system that is designed for teaching CIM with features to enhance teaching effectiveness. The MiniCIM 3.2 includes Ethernet Network, CIM software, advanced PLCs, servo and non servo robots, conveyors, AS/RS, gaging inspection, vision inspection, CNC machining, CNC routing, Assembly, CAD/CAM and work cells. It features table-top size, industrial performance automation components, PC-base controllers and industrial CIM software. The MiniCIM 3.2 will provide MSU’s IET undergraduate students with modern technological skills needed to improve their skills in a competitive workforce. The MiniCIM 3.2 is a FMS using the current technology. With this equipment, the IET department improved its curricula both in courses and laboratory exercises. Nine courses will be enhanced by having the MiniCIM 3.2 as shown in table 1.

3. Project Plan
3.1 Adapted Curriculum & Laboratory

As a curriculum and laboratory model, the IET faculty selected the Computer Integrated Manufacturing Technology (CIMT) program at Purdue University, Indiana. CIMT program is a manufacturing technology program accredited by ABET. Even though the mission of CIMT program is slightly different from the IET’s program, CIMT program has several courses and a lab which is adapted to the curricula especially for the Manufacturing/Robotics area of concentration as shown in table 2.

3.2 Adaptation and Implementation Plan

The strategy is to adapt and implement practices from the nine courses related to the FMS. For example, IET doesn’t offer CIMT 481 Integrated Manufacturing
System course for undergraduate students; therefore, several exercises conducted in the CIMT 481 course is adapted into the MFT 488 Flexible Manufacturing Engineering Technology course.

The CIMT lab, Purdue University is a 2,800 ft$^2$ facility that is functionally divided into an engineering center, an integrated manufacturing system and an offline work area. For the proposed project, IET will adapt the function of the integrated manufacturing system of the CIMT lab. The equipment proposed in this project parallels the function of the CIMT lab. The project adaptation focuses on the laboratory exercises developed at CIMT lab.

4. Developing the laboratory manuals and enhancing the course syllabi.

The development plan for the nine courses is described as follows. Some of the innovative laboratory exercises were adopted, including innovative laboratories exercises, referenced and enhanced versions of laboratories already performed at IET Department. The faculty developed a teaching-learning laboratory manual for each course and each course syllabi was enhanced/revised to include innovative laboratory exercises, developed by the faculty, related to FMS. Based on feedback from the project evaluators, the faculty team incorporated changes in the manuals and syllabi as a result of student assessment.

Course adaptation will encompass innovative laboratory exercises and/or special projects. The laboratory exercises/special projects represent a sampling of how the courses will be enhanced or adapted.

4.1 MFT 488: Flexible Manufacturing Engineering Technology.

MFT 488 is an elective course and is taken mainly by MFT/ROB students. The students will be introduced to FMS through class and pre-lab reading assignments. The goals and objectives of this class are to teach the students: (i) how to program in the FMS environment, (ii) The components building the FMS and (iii) how to modify the configuration of FMS. All of those goals are achieved by teaching theory and all hands-on activities in the laboratory exercises. In the innovative laboratory exercises:

(1) Communication networks: In this exercise, students will learn the ability to interface automated machines via variety of communication networks. The use of industrial-standard communication method in the MiniCIM 3.2 enables students to learn the current technology encountered in industry. Using the CIM software, students learn manual communication and control of all stations from the cell manager.

(2) Control architecture: With the MiniCIM 3.2, students learn a distributed network structure where separate station controllers control the operations of each station. Students will learn to start, stop, monitor production, collect production statistics and track alarm status.

(3) Programmable Logic Controller (PLC): Students learn how to program a multi-station pallet transfer conveyor to automatically move material from station to station on pallets with advanced command set. The PLC receives raw material
routings from the cell manager and controls pallet movement by receiving tracking data via an RS-485 network from barcode readers located at each station.

(4) Automatic Storage and Retrieval System (AS/RS): Students learn the multi-bay AS/RS, which provides various types of inventories to the manufacturing process.

Special Project: By incorporating knowledge gained during the semester, students were able to build an automatic system integrating machine and robots. Students utilize existing equipment and also the MiniCIM3.2.

4.2 MFT 386: NC-CNC Manufacturing Technology.
The major purposes of this class are: (i) to introduce students to several numerical control and computer numerical control machines, (ii) to teach students how to machine parts using CNC machines, starting with drawing the part with CAD software and then preparing the program using CAM software and running the program in the CNC machine and (iii) to prepare students for a higher level course, MFT 488 Flexible Manufacturing Engineering Technology. Laboratory exercises will involve programming and machining 3D-part.

Special Projects: Students do a reverse engineering project where students use a Coordinate Measuring Machine (CMM) to digitize a 3D-part (a sculptured surface) and remodel and machine the 3D part. With the MiniCIM 3.2, several new/additional lab activities are conducted in order to achieve the overall course objectives. Students learn not only how to program on one machine but also how to program on several machines as a continuous process. For example; students learn to prepare parts to be machined in a lathe machine and then in a milling machine. Students will have better understanding of the complete process to manufacture parts.

4.3 ROB 270: Robotics Systems Engineering.
The class is systems engineering for variable sequence, playback, numerical control, and intelligent industrial robots. The students examine economic justifications, applications, safety, maintenance, and programming. They experience a hands-on approach to programming the individual educational and industrial robots in the current laboratory. In the innovative laboratory exercises:

(1) Robotic Programming. These laboratory exercises introduce various programming and playback systems available with current industrial robots in the laboratory. The students program various robots, documenting the differences and similarities in programming languages. The programming assignments include controlling components of a work cell with output commands, as well as, to program decision-making commands based on input signals from various sensors on the work cell. It also allows the students to prepare, plan, program and perform a safe robotic task. This prepares the students for the robotic programming necessary for safe and efficient operation of robotic integration into the FMS station.
(2) FMS Robot Control System.
This exercise gives the students hands on opportunity to program a robot for the use of machine tending (loading / unloading). The students program the required inputs and outputs for the robot(s) within the FMS cell.

(3) FMS Robot Program Efficiency. This exercise allows students to analyze each FMS program of robotic movements and offer an objective critique in order to make each movement a time efficient move. The students solve the work cell/machine capacity and efficiency problem. This allows the students to apply the problem solving skills to the CIM cell, in order to operate efficiently.

(4) Flexible End of Arm Tooling. The students are given a problem to solve involving the end of arm tooling for a robot in a FMS. The students conduct research on materials, design and manufacture a flexible end of arm tooling solution to the problem. The students apply knowledge of hydraulics/pneumatics and electrical application. This exercise allows the students to prepare for those challenges met during a FMS implementation.

4.4 ROB 370: Robotics Interfacing Engineering.
The Robotics Interfacing class builds on the programming experiences from the ROB 270 class and incorporates the selection of switches and interfacing sensors to allow the robot to interact with the equipment in the work environment. The laboratory exercises include the use of relays and devices to match the Input/Output capability of the robots to the specifications of the equipment being controlled and the sensors available on the work cell.

Special Projects: The project includes the following components: (i) select or design a product to be manufactured, (ii) select the Robot(s) and Machines to be used, (iii) determine the sensors, relays or switches needed, (iv) wire or connect all controls and components to the Robots and Equipment, (v) produce a sample batch of parts. The MiniCIM 3.2 (FMS) equipment provides an upgrade to this project and allow for more laboratory activities related to current requirements in manufacturing industries.

4.5 ROB 470: Robotics Applications Engineering.
This class incorporates all previous manufacturing and robotic material into engineering design of a specific manufacturing problem and implementation in the laboratory. There’s strong emphasis on industrial engineering techniques, end-of-arm tooling, part orientation, and control devices for unmanned machine cells.

The class structure and laboratory projects and experiments deal with all previously learned material and incorporate it into an unmanned automatic work cell. This project/experiment directly relates to the CIM cell proposed. It leads into more experimentation and research dealing with CIM and flexible systems. In the innovative laboratory exercises:

(1) Workcell Development: The students from the previous ROB 370 Robotics Interfacing Engineering choose two ROB 370 projects. The instructor makes one minor and one major change to the two previous projects simulating a customer
request and adds a new project simulating a new customer order. The students develop the flexible workcell in order to accommodate the indicated orders from each customer and document all procedures.

(2) Workcell Analysis. The students use the CIMsoft Software to compare and analyze the workcell progress and determine an approximate maximum flexibility. The students then use lean techniques to fulfill customer orders and using increased flexibility, add a new customer and order. This equipment assists in the learned components of industrial engineering, customization of end-of-arm-tooling for the robots and implementation of an array of control devices for complete production.

4.6 EET 215: Basic Control System.

The EET 215 course is taken by students from Electrical/Electronics technical options. The availability of the FMS allows the students to put into practice the theories they learn in the control courses. The ability to show examples of and the need for application of control systems help students develop a better understanding of the overall manufacturing process. Two innovative laboratory exercises are developed utilizing the MiniCIM 3.2 are: (1) Identifying an electrical control requirements and (2) Application of switch for position indicators.

4.7 EET 346: Programmable Logic Controller.

This course is taken by almost all EET technical options. By having the FMS system, students will learn the real application of programming using logic controller. As an example of one innovative laboratory exercise is the utilizing sequencer for control of manufacturing operation.

4.8 IET 260: Hydraulics and Pneumatics.

The course emphasis robotics applications and students design fluid power control techniques for both CNC and robotics use. An example of a laboratory exercise is the control value and cylinder use, which has direct application to FMS. The class includes an even balance between hydraulics and pneumatics.

4.9 GCT 301: Tool Design.

In this course, students learn how to design fixtures / jig. By having the MiniCIM 3.2, students are able to understand the real complex problems encountered in manufacturing. An example of a laboratory exercise requires students to design a working model or to simulate a model of a transfer table or mechanism to transfer parts from, into, or out of a machine or work cell in the process of manufacturing a product.
5. Progress Evaluation
There are three evaluation methods: (1) the internal and external evaluation on planned laboratory exercises, (2) student feedback (3) faculty feedback and (4) community and technical college feedback. The progress evaluation includes the planned laboratory exercises. This step is conducted by the IET faculty and external evaluator: (i) the laboratory manuals and student laboratory reports and (ii) quizzes and homework assignments regarding both the operation of the FMS. The progress evaluation that focuses on student feedback on the laboratory exercises and how those learning exercises impacted their understanding of specific course concepts during the project term. Faculty feedback determines how the laboratory exercises impacted student learning. Community and technical college feedback assists IET in planning and adapting the IET curricula to provide transfer students sufficient training for their career choices in manufacturing/robotics.

Class Assessments are conducted, where Exams, Quizzes, HW, Class Project were given to students and the student learning has been improved. Informal questionnaires were distributed to find out what students think regarding the use of MiniCIM 3.2 as a teaching tool. All students agreed that by having a complete integrated CIM/FMS, it helps them to understand both concepts and the technology of CIM/FMS discussed in class.

References:

Table 1. Nine IET courses to be enhanced

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<td>NC-CNC Manufacturing Technology</td>
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<td>3</td>
<td>ROB270</td>
<td>Robotics Systems Engineering</td>
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<td>4</td>
<td>ROB370</td>
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<td>ROB470</td>
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<td>6</td>
<td>EET215</td>
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<td>7</td>
<td>EET346</td>
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Table 2. Nine CIMT courses will be adapted to IET curricula

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<td>CIMT 100</td>
<td>Introduction to CIM</td>
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<td>CIMT 243</td>
<td>Automated Manufacturing I (PLC’s)</td>
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<td>CIMT 248</td>
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<td>ECET 233</td>
<td>Electronics &amp; Industrial Controls</td>
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<td>CIMT 481</td>
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