A LABORATORY BASED PROGRAMMABLE LOGIC CONTROLLER (PLC) COURSE FOR A MANUFACTURING CURRICULUM

Andrew Otieno and Clifford Mirman,

Department of Technology,
Northern Illinois University
otieno@ceet.niu.edu or mirman@ceet.niu.edu

Abstract

The need for continuous reengineering of the curriculum is evident in this era where most companies are downsizing their engineering staff in an effort to provide cost reduction. In this cost conscious environment, industry is looking for employees that can fill numerous roles within their manufacturing facility. To fulfill these multifaceted industry needs, the Department of Technology at Northern Illinois University constantly assesses the program goals for the Manufacturing Engineering Technology (MET) and Electrical Engineering Technology (EET) programs. Over the past year, the Department has identified the area of controls and the integration of these control concepts into real life applications as an area for improvement. Based upon input from regional industry and the Departmental industrial advisory boards, the Department determined that many new engineers and technologists who enter the manufacturing industry have a good knowledge of PLC programming, however, they have very limited exposure to interfacing. To address this problem and solve the needs of our diverse student population, the NIU Department of Technology has developed a new laboratory based PLC course. This course, while teaching the basics of PLC ladder logic and programming, also provides valuable hands on experience in the integration of a PLC with sensors, motion control, vision systems, and robotics. The laboratory experience also includes the development of human interface to the PLC in typical automation applications, both with hand held devices and Microsoft visual basic tools. The students are also involved in a two-week lab based project that requires advanced PLC functions. The current PLC experience was implemented during the spring 2002 semester, the summer 2002 semester and is on its third phase in the fall 2002. This paper describes how this course has been implemented and improved over the three semesters, and some important outcomes from course evaluations received from students and our Industrial Advisory board. This new course will provide improved preparation for the MET and EET students in this important area of control and thus, produce graduates that are more competitive in industry.

1. Introduction

<u>1.1 Current State of the Art</u>

The applications of PLC's in industry are diverse, ranging from very simple process control to complex maintenance and data management applications[1,2]. PLC technology and applications are changing rapidly. There has been a major shift in PLC industry to introduce modules that can utilize remote off-line programming, increasingly making use of Ethernet communications[2,3,4]. Another major trend has been the move towards computer based control systems that either interface with systems directly using input/output (I/O) cards or utilize special purpose software which emulates the PLC. PC based controls are especially suitable for processes that utilize analog signals[5]. Despite these developments, common PLC's continue to dominate the automation market especially as they become smaller, cheaper, and more adaptable to harsh industrial environments[6]. In order to educate undergraduate students with the ability to perform satisfactorily in industry under these changing trends, the subjects that are taught must parallel those skills used in industry. This is especially true in the newer emerging areas of controls.

There are many engineering and technology departments at the University level which teach a variety of PLC courses. In these institutions the majority of the courses tend to concentrate on theory and simple laboratory applications especially with discrete programming[7,8]. Introductory level classes generally exclude in-depth applications involving sensor integration and motion control applications. There are cases win which PLC courses have been developed to address the needs of specific types of engineering students, for instance electrical engineering students[9] or industrial engineering students[10], to cite a few examples. In addition, innovative approaches have been utilized to enhance instruction in the area of PLC's by using web-based instruction and multi-media simulation[11]. Despite all of the advances and developments in the instruction of PLC's, educators need to develop PLC courses which include both the programming basics and advanced applications involving integration with sensors and other components such as vision and robotics.

1.2 Technology Curriculum Structure at Northern Illinois University

The NIU Manufacturing Engineering Technology (MET) program has been in the process of revising its curriculum to reflect needed industry skills[12]. Through feedback from Departmental industrial advisory boards, several areas were identified for improvement or incorporation into the curriculum. Some of the areas specifically modified included metal fabrication and forming, mechanics, strength of materials and solid modeling. To strengthen the automation courses, the following areas were included into the program or underwent major revisions: robotics, vision applications and NC/CNC. Very significant changes took place in the structuring of these courses especially in the "newer or emerging" technology areas. While the curricula reform process was in progress, it was determined, through discussions with graduates, employers, and the MET advisory board, that the PLC and the manufacturing automation courses needed to be altered extensively. The manufacturing automation course now includes both theory and laboratory components in areas including:

- vision systems
- sensors
- actuators
- PC-based and PLC-based controls,
- motion control with pneumatics
- hydraulic and electrical drives
- robotics
- automatic identification and tracking and systems integration

For the PLC course, like in many other institutions, it was found out that while the basic instruction of programming techniques received good coverage, students received very little application of the control principles and interfacing. Therefore, a new laboratory and curricular structure was incorporated into this important course. In the NIU Department of Technology the PLC course serves as a foundation for other advanced courses such as manufacturing automation and senior design. The newly designed PLC course, which now includes ladder-logic programming, sensor interface, component selection, motion control systems, and user interfaces, is described in the next section. This type of course, in which the basic and applied principles are covered, must include a laboratory component. As part of the redesigned course, the authors have developed low cost laboratory modules that can be utilized effectively. This paper also outlines the advances the department has made in the new PLC course, including curricular and laboratory improvements, as well as how this intermediate level course meshes with the various upper level courses.

2. Structure of the New PLC Course

Based upon the input from former graduates, employers, and the MET advisory board, it was determined that the newly designed PLC course must include the following components:

- PLC Basics and Ladder-logic programming
- Sensor interface and motion control
- Component selection (voltages, current, and compatibility)
- Component manufacturer literature search
- User interface
- Computer-based control and integration

The NIU PLC course is taught each semester, to approximately 45 students; a combination of Industrial Technology, Engineering Technology, and Engineering students. The course is taught at the junior/senior level, and is designed to integrate theory and operation of the PLC, where students learn theory backed up with an intensive laboratory component. The theory portion of the course is taught in a 2 hour lecture/discussion session occurring the week. The concepts that are covered in the course lecture includes

- basic concepts of PLC's
- types of PLC's
- number systems and their relevance to PLC's
- the PLC I/O structure and types
- PLC programming languages with emphasis in ladder logic
- PLC applications in data acquisition and control

To enhance the course presentation, an intensive laboratory component is included. The students are divided into three laboratory sections, each lasting between 2-3 hours a week. The laboratory component examines the utilization of PLC's with various field devices, including the development of programs to perform various simple applications. To outfit the experimental component of the course, the Department purchased GE Fanuc VersaMAX™ micro PLC's, Each relatively low cost, relatively, VersaMAX module has 8 inputs and 6 outputs (Figure 1). To ensure that each VersaMAX PLC can handle the wide range of experiments performed within the laboratory, low cost expansion units (also shown in figure 1), providing an addition 8 inputs and 6 outputs, were purchased for each station. This low cost PLC was chosen for two practical reasons. The first reason is cost; GE provides a very reasonable price point for this entry model. The second reason for utilizing this model PLC was the ability to provide low cost expansion and a low cost user friendly interface. The interface data panel (figure 2) allows the user to read and alter the contents of a memory location of the PLC without using a PC. In addition, the VersaMAX system includes easy to use graphical based Windows programming software, VersaPro™ (figure 3), that allows the students to program off-line.

Figure 1 - PLC and expansion unit

Figure 2 - Data panel for PLC programming

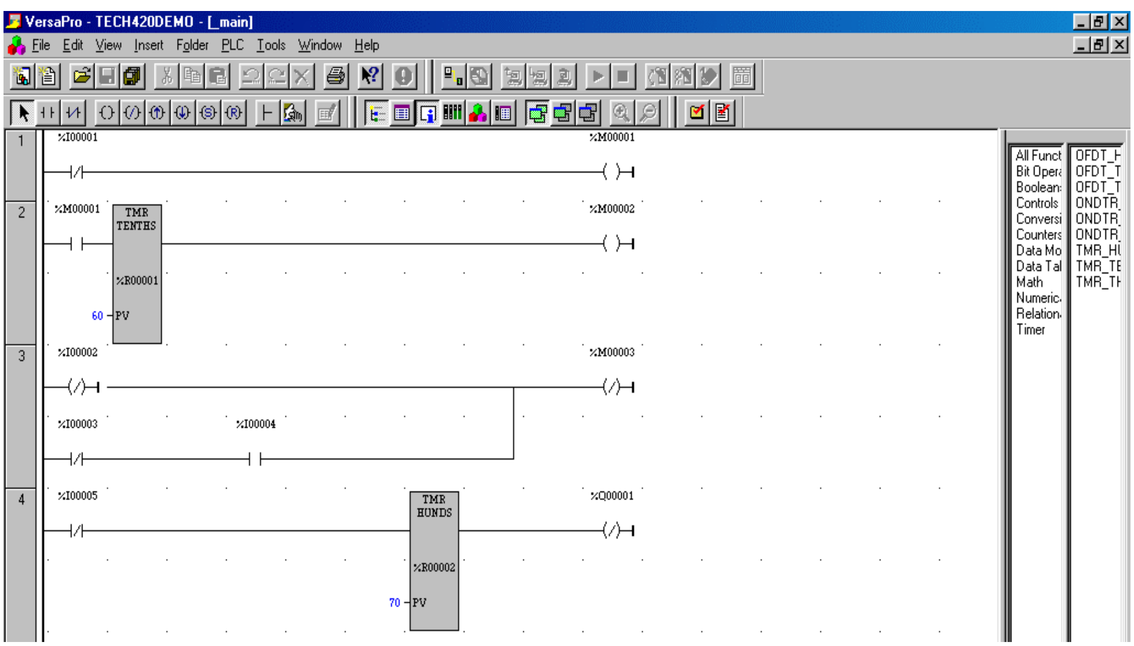


Figure 3 – Versa PRO graphical programming interface

3. PLC Course Experimental Component

As part of the basic PLC course, the authors have developed a series of ten laboratory experiments, nine of which are carried out on the modules that were fabricated in-house. The experiments start with basic wiring and electrical fundamentals, and progress through programming and interfacing techniques, centering on the GE Fanuc controller. The basics of ladder logic programming and wiring has three lab exercises in total, the first being basically a wiring activity and familiarization with the PLC components. The next two introduce the students to the programming environment where they learn how to perform a hardware configuration and write a simple program involving contacts and coils. In the next three lab activities the students learn to program intermediate functions such as timers and counters. This is then followed by two labs in advanced applications where students develop programs with math functions, data manipulation, and simple sequencing and programming with bits. The next lab activity on this experimental module is the ninth one and it is a project in which the students have to implement a simple phone testing operation to run a re-furbished phone tester that was obtained from a donation by Motorola. In this lab the students write a program that turns on pneumatic actuators in sequence, emulating a real life phone testing procedure. This lab typically lasts 4 to 6 hours and sometimes even more depending on each individual student's ability. The lab station used for these activities is shown in figure 4. One section of this station has toggle switches and push buttons as inputs, and lights, buzzers and a fan as output devices. The second part of this station is a lever or key operated toggle switch that changes the PLC outputs to control the re-furbished pneumatic phone tester (figure 5). The polycarbonate frame houses the PLC, the expansion unit and the input and output devices shown in figure 4 was also obtained from the donated Motorola test cells.

Finally the students undertake projects involving sequencing of traffic lights or operations of a washing machine. Each student is allowed to make a choice of either the traffic lights or washing machine. For this the department has purchased modular PLC Traffic Signal Control and Automatic Washing Machine training kits from Feedback Instruments Limited (UK). These are shown in figures 6 and 7 respectively. This is typically the final laboratory activity for this class. The laboratory component comprises 40% of the course.

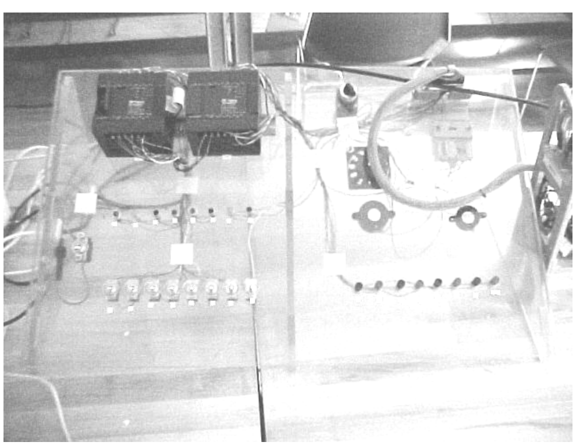


FIGURE 4. PLC STATION

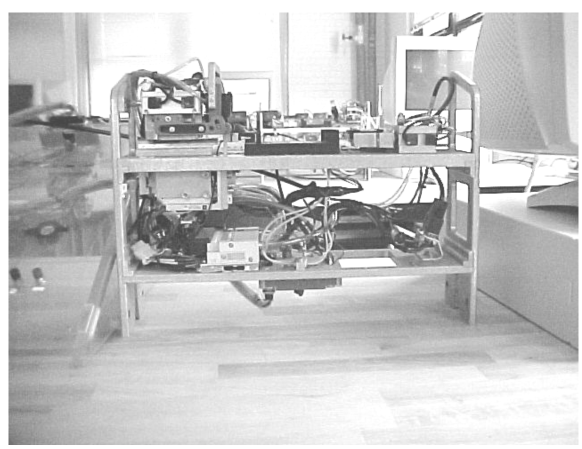


FIGURE 5. PHONE TESTER

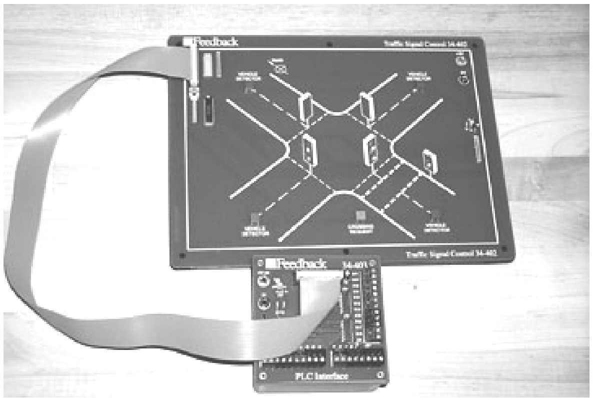


FIGURE 6. TRAFFIC LIGHT MODULE

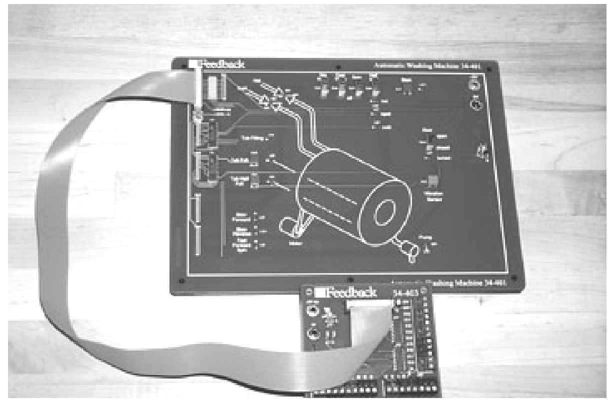


FIGURE 7. WASHING MACHINE MODULE

4. Advanced Integration and Senior Design Projects

The introductory programmable logic controller course (as described in this paper) is the point at which the MET students are introduced to the concept of the PLC and it's usage, however, the students are required to utilize this PLC knowledge, extensively, in the senior level manufacturing automation course and senior projects course. During the past two years, the manufacturing automation course has gone through several revisions. The current revision of this senior level course emphasizes integration techniques that are current or emerging in the automation industry. These areas include robotics and vision applications, as well as the integration and control of pneumatics and automatic identification. The advanced automation course is the culmination in a series of three courses, which include the PLC course, computer integrated manufacturing, and automation. The senior level automation course presents topics on system integration and the use of the PLC to control various automation devices producing both input and output signals. The course is taught with a laboratory/lecture format, with equal weight placed upon theory and application. Throughout the course, there are mini projects in which the student group performs various PLC control tasks. The final lab project involves the implementation of an assembly cell where robots are used to perform pick-and-place assembly tasks on a conveyor loop. Each assembled product is inspected using the vision system and a PLC is used to integrate all these activities in the cell and manage the "handshaking" of programs and I/O's between the different components. According to the feedback from the Industrial advisory board and the graduating students, this advanced course provides the students with a solid background in automation concepts.

The MET students are required to take a two-semester senior projects course during their senior year. In this course, most of the projects are supplied and sponsored by regional industry, and most involve automation concepts. In the majority of the projects students are required to utilize a PLC to control a piece of automation which has been designed by the student team. In addition, the project must incorporate various forms of input and output. In the prior years, student teams have interfaced PLC's with vision and pneumatic components, sensors, and other automation components. The experience in this course from the previous years has been that although the students were able to select a proper PLC according to the system requirements, they could not select the components which were compatible and would interface with the PLC. Thus, another goal of the revised PLC course is to introduce students to the correct procedures for sensor and component selection, and ordering. To order components the students research the various manufacturers, sensor requirements, and compatibility requirements. Each design team must then select the appropriate sensors and components that will implement their project. The project is then presented in written form with a complete bibliography of suppliers and materials list. A working project is usually presented at the end of the two semesters.

Figures 8,9, and 10 present examples of senior design projects which involve PLC controls. In figure 8 is a senior project that was undertaken for a local manufacturing company in DeKalb, IL. The students designed a steel loading system which utilizes pneumatic actuators, position sensors, and a hoist mechanism to automate a physically challenging task. The control of all the functioning of each of these components is done by using a PLC. In this application, the PLC took inputs from three sensors on the linear actuator, and the position of the hoist was incremented accordingly. The second project, figure 9, was completed for the same company, and was designed to automate another physically challenging task involving the loading of 20 foot long steel bar stock. The final project, shown in figure 10, involves an automation process for the transition of a part from one machine to another. In this application, the parts are being produced on a rotary platform, and must be picked and transitioned to a linear gravity fed machine, however, the production and feed rates between the two machines are different. Therefore, using sensor and actuators, controlled through the PLC, the parts are transitioned as needed.

The need for PLC knowledge in the upper level MET courses is evident. Whereas the lower level PLC course enhances basic understanding of PLC's and their applications, it allows the students to enter the upper level MET courses with the base knowledge needed to both program the controllers and integrate the various field input and output devices into a complex automation system.

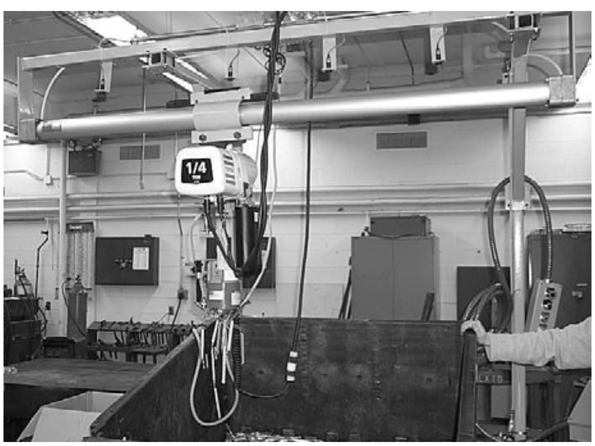


FIGURE 8. PLC INTEGRATION

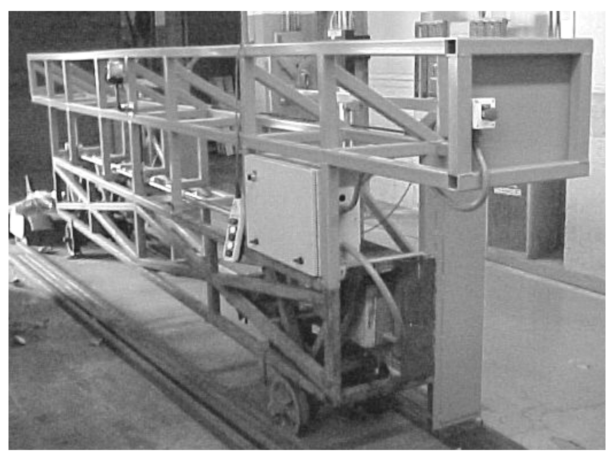
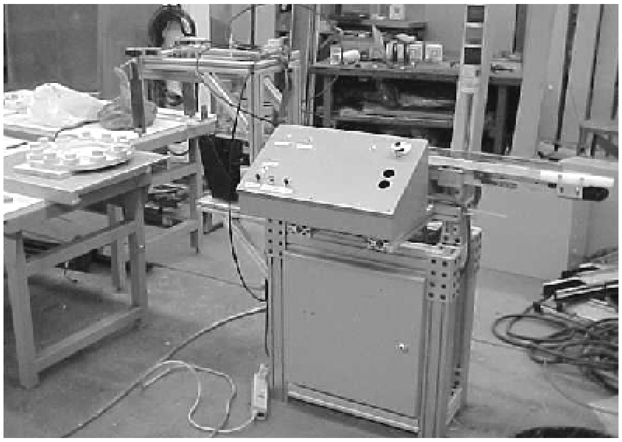


FIGURE 9. AUTOMATED BAR STOCK LOADER



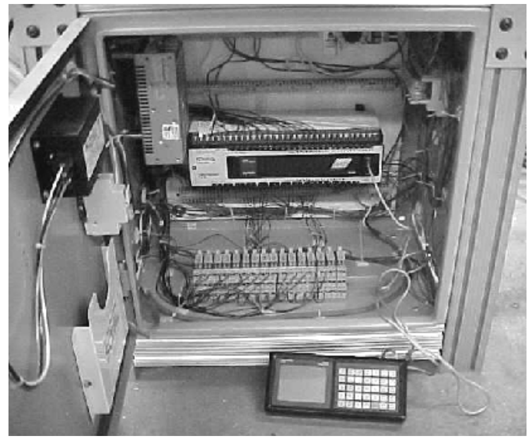


FIGURE 10. PICK AND PLACE OPERATION

5. Course Assessment

As part of curricular assessment, the students at NIU are asked to complete an evaluation at the end of each semester for each course they have taken. The first part of the questionnaire is used to evaluate faculty while the second consists of 14 goals that have been identified by the Department as being relevant to the baccalaureate experience. They are listed in table 1. The questionnaire asks the students to give their opinion on how they felt these goals were met by the specific course. In this section the students circle responses from A through E showing how adequately or inadequately they feel the course has met these goals. The responses obtained from the student surveys are usually used by faculty and the department for purposes of continuous quality improvements.

#	Question/item	#	Question/item
1	Use knowledge to engage in Scientific inquiry	8	Engage in integrative thinking
2	Use knowledge to engage in philosophical inquiry	9	Synthesize knowledge derived from varied disciplines
3	Use knowledge to engage in imaginative thinking	10	Use of modern technology
4	Use knowledge to engage in creative thinking	11	Understand modern technology
5	Use knowledge to engage in abstract thinking	12	Develop effective habits in logical thinking
6	Use knowledge to engage in creative thinking critical thinking	13	Effectively utilize communication skills
7	Use knowledge to engage in the solving of problems	14	Effectively use quantitative skills

Table 1. List of Department Goals for Course Evaluation

To assess the impact of the curricular changes and improvements on the PLC course, student responses for six of these goals (#1, #4, #7, #10, #11 and #13 in table 1) were studied for the course offerings in Fall 2000, Spring 2002 and summer 2002. Student evaluations for spring and Fall 2001 were not available since the course was not offered during these periods. The following results show the percentage of students who responded to A (Very adequately) and B (Somewhat Adequately). Since this assessment is not intended to be very elaborate, only two of the responses are chosen. The number of students responding to each of the questions was studied over the three semesters that the course was offered. The results are shown in figure 11 below.

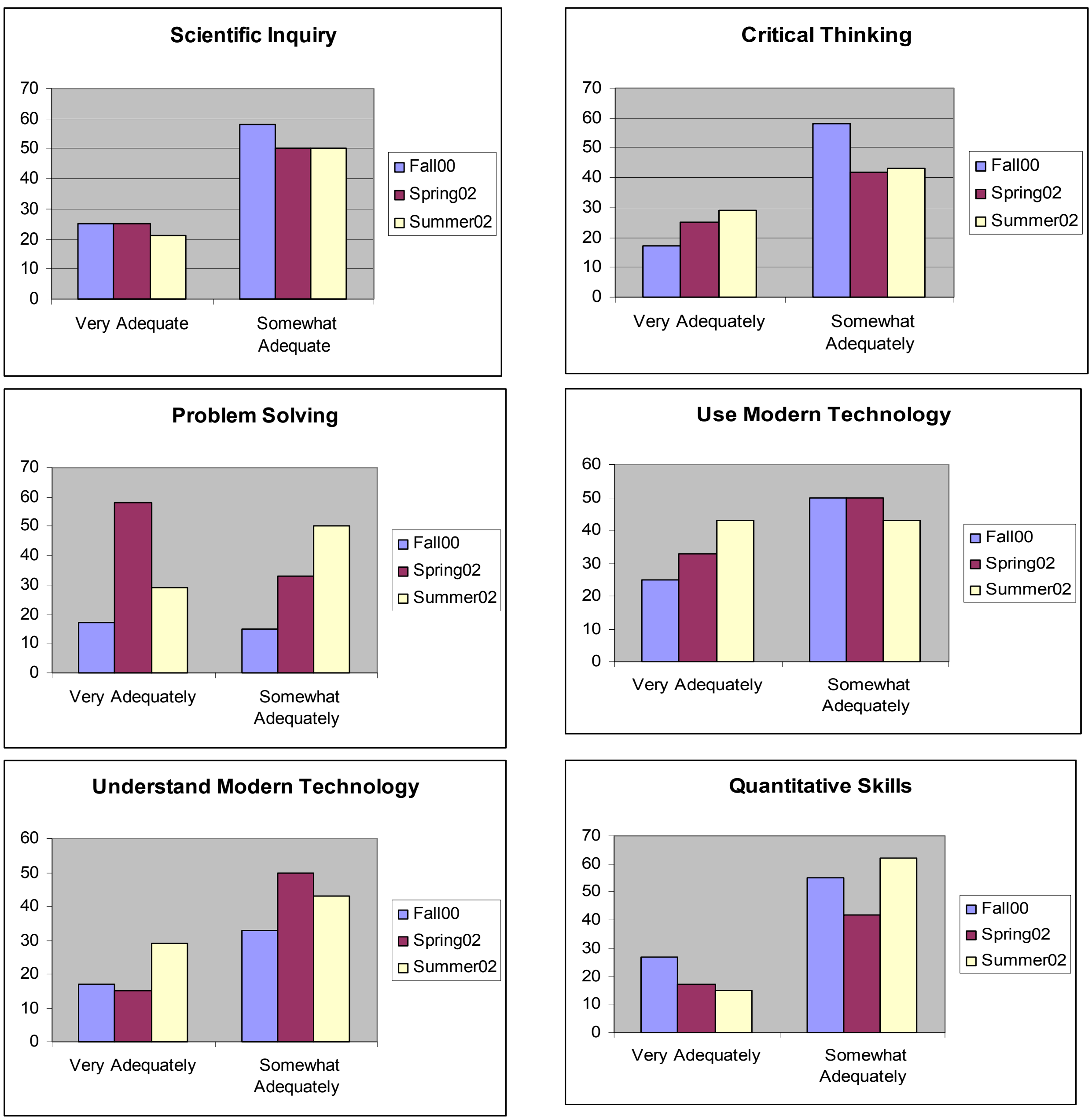


FIGURE 11 RESULTS OF STUDENT EVALUATION

From these assessment results there is an indication that the students felt the departmental goals were better met with the new PLC course. Given that the course was first offered in Spring 2002 we are still at a stage in determining the effectiveness of the changes. However some general trends can be seen from the last three successive offers. The students felt that there was an increase in the use and understanding of modern technology but there was a general decline in the use of quantitative skills. This may be attributed partly to the introduction of new and more lab experiments and less theory, and also to the change in instructorship. Prior to summer of 2002, the course has been offered primarily by an adjunct faculty who was available on campus only once a week. In this new PLC course it would also appear that a greater percentage of students feel the course offered more critical thinking and problem solving activities than in the previous course offerings. These results demonstrate that the curricular changes we made for the PLC class have had not only a more positive impact on the student's learning outcomes but also in their ability to apply PLC skills and knowledge to solve real life industry problems in their senior design class. This evaluation is not a proven research tool and cannot be relied on entirely for assessing the impact of the curricular changes. However it offers an opportunity for the Department to have an overview as to whether these curricular changes have had any positive impact on the course. In due course, as the department continues with its curricular improvement efforts, more data is being collected and an elaborate analysis of the impact of the new PLC course and the overall changes will be reported in due course.

6. Conclusion

The Northern Illinois University Manufacturing Engineering Technology program has just updated the introductory level PLC course. Based upon input from industry, graduates, and advisory board members, the Department found that PLC area represents an important knowledge base that our MET graduates must possess, and has also used the input to determine what is required to make the course more competitive and up to date. The knowledge gained in this course is also used in several of the upper level courses in the program. The PLC course that has been redesigned incorporates theory with an intensive laboratory component. The laboratory experience incorporates various aspects of PLC programming and sensor integration. A significant outcome of this revised PLC laboratory experience is the development of experiments that are inexpensive but very valuable to the student learning experiences in automation. In addition, the students are taught how sensors and output devices are integrated together and controlled through the PLC. In general, this "new" course has been designed to build a strong knowledge base in the area of PLC usage and integration. The topics that are taught in this introductory course are augmented in the latter upper level automation courses. The combination of this course and the upper level automation courses allows the Department of Technology to produce MET students who will serve the regional industry better.

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Biographical Information

Dr. ANDREW W. OTIENO received his Ph.D. from Leeds University, UK in 1994 and has been at NIU since August 2000. He has been actively involved in the restructuring of the MET curriculum and development of the Automation laboratory. His research is in the area of finite element modeling, machining processes, tool wear monitoring and structural health monitoring. He has experience in hardware/software interfacing with special applications in machine vision. He is a member of the ASEE and the SME.

Dr. CLIFFORD R. MIRMAN received his Ph.D. degree from the University of Illinois at Chicago in 1991. From 1991 until 1999, he was at Wilkes University's Mechanical Engineering Department. He is currently the Chair of the Department of Technology at NIU. His research areas are CAD, Finite-Element-Analysis, and kinematics, both securing grants and writing publications. Dr. Mirman is actively involved in ASEE and SME.