Manufacturing Automation Education for Mechanical and Manufacturing Engineering Technology

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Abstract
With global competitiveness as the motivation, industry and academia must join forces to eliminate competency gaps in the capabilities of engineering technology graduates. Manufacturing automation and its specialized machinery are often the realm of manufacturing and mechanical engineering technology graduates. This paper discusses the approach developed by the mechanical and manufacturing engineering technology programs at Arizona State University to address a critical competency gap, one dealing with manufacturing automation (as identified by the Society of Manufacturing Engineers). The six courses composing the automation concentration of ASU's Bachelor of Science in Mechanical Engineering Technology degree are briefly described. A more detailed description of the MET 451, Introduction to Automation, course is also provided. The course's content and the accompanying laboratory equipment are described. Due to the industrial partners' donations, the laboratory is based on full-scale, standard industry components.

Introduction
As the U.S. manufacturing industry continues its quest for increasing efficiencies and reducing operating costs in this global marketplace, it is turning to automation as the means to that end. Industrial automation and related technologies have evolved from their initial introduction into the factory. As one aspect of this evolution, the microprocessor is now a staple of the modern manufacturing enterprise. As a result, the responsibilities of today's manufacturing engineers have broadened and become more diverse. The once clearly defined boundaries of responsibilities between engineering disciplines has blurred as industry continuously pushes for higher efficiencies and reduced operating costs. This is especially true as companies consolidate their workforce, requiring mechanical and manufacturing engineers to adapt to technologies traditionally supported by their electrical engineering counterparts.

The Society of Manufacturing Engineers (SME) documented this need in their publication *Manufacturing Education Plan: 1999 Critical Competency Gaps*[1]. The application of automation principles is one of the eight categories identified as "well below" expectations in the skill set of graduates. Thirty one percent of the survey respondents indicate some level of dissatisfaction with the ability of recently hired engineering graduates to interface with automated manufacturing systems. Personnel needs in automation are not really new. Kelly commented in 1988 that individuals who "can integrate the elements, build the links and establish the material and data highways that support the transport of product from design through marketing"[2] were needed. The engineering workforce must draw from multiple disciplines and skills to become the system integrators, bridging the activities of product marketing, process development and, ultimately, production.

The real educational challenge is to cross the boundaries of conventional academia to support a more contemporary multi-disciplined approach to a mechanical or manufacturing engineering technologist's education. To be truly successful, the process must focus on the goal of providing an interdisciplinary approach to an engineering education emulating the expectations that industry places upon their engineers.

Strategic Approach

In order to provide industry with mechanical and manufacturing engineering technology graduates knowledgeable in the concepts and integration of industrial automation, a comprehensive course strategy must be used. To be truly effective, the strategy must include a multi-disciplined approach, focusing on practical application and problem solving techniques across a broad spectrum of automated manufacturing systems. In addition, partnering with local industry aids development and maintenance of the coursework and necessary laboratories.

Automated manufacturing is a broad term encompassing several disciplines. It includes conventional areas like production planning and cost estimation but also extends into areas traditionally outside the expertise of a manufacturing engineer, such as systems integration, microcomputer technology and computer-controlled machinery.

For this reason, it is a more effective educational strategy to develop a concentration instead of just adding a course or two into an existing curriculum. Manufacturing automation represents a wide spectrum of technologies that can be applied to an even wider range of areas. Therefore, it is difficult to teach automation as a single discipline. What becomes necessary is teaching an approach to automation and solving automation problems.[3]

Automation Degree Concentration

With this in mind, the automation concentration for the mechanical engineering technology program at Arizona State University (ASU) consists of six multi-disciplinary courses providing the student an in-depth analysis of industrial automation from project planning through integration. Course selection and definition was a joint effort of the Industrial Advisory Board (IAB) automation sub-committee and the MMET faculty. Initially convened in spring 2002, the IAB automation sub-committee is comprised of a diverse cross section of local industry leaders committed to higher education. The IAB automation sub-committee is an integral part of the automation concentration for the mechanical engineering technology program at ASU, providing a voice for industry, general direction for course content and potential equipment donors. Through their collaborative approach, the MMET faculty and the IAB automation sub-committee strive to maintain current technology in the classroom to support the demands of a dynamic manufacturing industry.

The MMET faculty and the IAB believed it was important to place the automation concentration within the Mechanical Engineering Technology program. One specific aspect of the program goal was to educate graduates that would be employed in the design and manufacture of automated manufacturing equipment. The ASU Mechanical Engineering Technology program already includes significant manufacturing processes content, thus graduates have a solid background in all aspects of the automated manufacturing world.

The courses included in the automation concentration are listed in Table 1. These courses were selected by the IAB automation sub-committee and MMET faculty because they encompass the broad spectrum of integrating automation into the modern automated factory. They provide the student real world experience with a preview of the duties and responsibilities of an engineer working in the automated manufacturing industry.

Table 1 – *Automation concentration courses.*

COURSE SEQUENCE	COURSE NUMBER AND TITLE	COURSE DESCRIPTION*
1	MET 341, Manufacturing Analysis	Organizational and functional requirements for effective production. Analysis of industrial specifications, GDT, costs, and group technology. Writing assembly production plans.
2	MET 416, Applied Computer Integrated Manufacturing (CIM)	Techniques and practices of computer-integrated manufacturing, with emphasis on computer-aided design and computer-aided manufacturing.
3	MET 438, Machine Design II	Applies mechanics to the design of machine elements and structures. Emphasizes basics of gears, springs, brakes, clutches, and bearings. **
4	MET 451, Introduction to Automation	Introduces automation. Topics include assembly techniques, fixed and flexible automation systems, robots, material-handling systems, sensors, and controls.
5	EET 403, PLCs, Sensors and Actuators	Applications, programming and troubleshooting using PLCs. Interfacing to motors, sensors and actuators.
6	MET 455, Automated Systems Integration	Applies sensors and devices and their integration with PLCs and computers into automated devices and systems.

* MMET and EET course information and descriptions are from the current ASU on-line catalog.

** By consensus of the MMET faculty and the IAB automation sub-committee, MET 438, Machine Design II now includes kinematics content.

The course sequence includes two courses from the department's ABET accredited manufacturing engineering technology program, MET 341 and MET 416. These courses educate the mechanical engineering technology program's automation concentration students about the fundamentals of manufacturing specifications, i.e., writing MOTs (methods, operations and tooling sheets), routings, and manufacturing cell design as well as the "big picture" of computer-integrated manufacturing (ERP, MRP, etc.). The machine design course is the second design course and includes significant material on kinematics, a subject often important in automated systems.

Primarily a survey course, MET 451 explores an array of industrial automation concepts (additional detail is included in the next section). One of the many automation content areas the students are introduced to is programmable logic controllers (PLCs). Since PLCs are an important automation topic, a second course, EET 403, provides more in depth coverage on PLCs, their programming and interfacing to sensors and output devices.

The MET 455 course serves as an "automation capstone" course. (However, the automation students still take the two-semester capstone sequence required for all mechanical and manufacturing engineering students—MET 460 and MET 461.) This course is in its second offering during the spring of 2005. This course focuses on the students building up systems of automated equipment. For instance, the focus of the spring 2005 offering is on integrating ADEPT robots and their specialized controllers with other systems being controlled by PLCs. A picture of this laboratory space is provided in the appendix.

INTRODUCTION TO AUTOMATION (MET 451)

As the foundation for the automation component of the concentration, MET 451, Introduction to Automation, serves dual purpose. [As a side note, due to the "introductory" nature of the course, this course is being changed to a 300-level number.] The course provides a requisite understanding of manufacturing automation principles for the student to progress to the next level in the concentration. The course also serves as a means for a non-automation upper-division student to gain exposure to industrial automation concepts before graduation.

For automation students, MET 451, Introduction to Automation, provides a strong foundation and bridge to both EET 403 (PLCs, Sensors and Actuators) and MET 455 (Automated Systems Integration). The course incorporates an interdisciplinary approach by introducing electrical and computer engineering concepts. The students are introduced to the theory and application of industrial automation in the classroom and then reinforce their classroom learning with a hands-on, interactive laboratory sessions. In order to provide an enhanced laboratory experience, the students work with real world industrial components. By recommendation of the IAB, the laboratory equipment is identical to the equipment found in a modern automated factory. Table 2 provides an overview of interdisciplinary concepts explored in MET 451 during the semester.

The Introduction to Automation course has an applied learning focus, offering flexibility to the student through an open laboratory philosophy. Since the concepts of industrial automation are best conveyed through application-based learning, the course is divided into two components: a classroom lecture component and an associative laboratory component. The laboratory equipment is central to the course and is available to the students outside of normal class time. This allows the students the freedom to explore the concepts of each lesson without time constraints inhibiting learning. The intent of the open laboratory environment is to have the student concentrate on the subject matter rather than the clock.

The classroom lecture component of the course is designed to introduce the concepts and theory behind industrial automation. Starting with the basics of automated control, the course utilizes a

Table 2 – *Interdisciplinary concepts explored in MET 451.*

MECHANICAL	ELECTRICAL	COMPUTER
Fluid power concepts and applications	Reading and developing electrical schematics	Microcomputer set-up and configuration
Component identification and function	DC circuit analysis	Software installation and configuration
Selection and application of automation components	Electrical wiring applications	Cable and software driver selection
Project development	Electrical component identification and function	Logic development and programming
Engineering cost analysis	Selection and use of electrical instrumentation	Volatile and non-volatile memory concepts

structured format, exploring topics that cross the spectrum of industrial automation. Each topic is a step to the next, allowing the students to first explore the lecture topic as a stand-alone automation concept and again as that particular concept interfaces with the next topic. Since the series of lecture topics are arranged to provide a foundation to support the next topic, the final result is an integrated systems level understanding of industrial automation concepts. As an example, the student leaves the course with an understanding of the principles of an inductive proximity sensor, as well as, the application of the sensor as a feedback device for the position of an actuator within an automated manufacturing system. Table 3 lists the recommended course outline. Only 10 topics are listed for the semester to provide flexibility to the instructor for evaluations, manufacturer / vendor visits or deeper exploration of the topic.

The laboratory section of the course is what truly defines MET 451. The approach varies between institutions, but for many introductory automation courses either offer no laboratory component or use a few set pieces as demonstration models. Many times these set pieces are kits intended to represent industrial automation rather than introduce the student to the actual components they will be expected to work with in industry. A primary reason for this approach is the high cost of industrial automation equipment. It is simply beyond the means of many colleges to expend the capital required to adequately support an industrial automation laboratory. This is a contributing reason why a competency gap in the application of automation principles exists today in many new graduates.

To help bridge the competency gap in the application of automation principles, the faculty in the Mechanical and Manufacturing Engineering Technology Department at ASU turned to their Industrial Advisory Board for assistance. The result was the creation of an IAB automation sub-committee. In collaboration with the MMET faculty, the IAB automation sub-committee has proven instrumental in attaining support from local industry. By working closely with the IAB

Table 3 – *Recommended lecture topics for Introduction to Automation.*

WEEK	LECTURE TOPIC
1	Introduction to Control Systems
2	Microprocessor–Based Control
3	Principles of Direct Current Circuits
4	Switches, Relays and Power Control
5	Mechanical Systems
6	Sensors
7	Actuators: Electric, Hydraulic and Pneumatic
8	Relay Logic and Programmable Logic Controllers
9	Motors: Direct Current, Alternating Current and Stepper
10	Feedback Control Principles

automation sub-committee and local industry, the laboratory equipment for MET 451 is a collection of common industrial components found in the modern automated factory. This is the same equipment the students are expected to work with when they enter industry. Utilizing this approach provides the students exposure to real world, industrial automation equipment in the early stages of their academic study of automation. In addition, the students have the advantage of understanding and applying current automated control technology. Therefore, the discord between what academia can deliver and what industry expects has, for all intents and purposes, been resolved through partnering.

Specially designed workstations have been developed for the course as a part of this practicum, and are necessary to complete many of the exercises. The laboratory exercises are closely tied to the classroom lecture topics but due to the interdisciplinary approach; require the student to explore and use supplemental resources to complete the exercises. In that regard, components on the workstations were selected to promote an interdisciplinary understanding of the automation concept behind the device and facilitate an applied understanding of how the particular component is integrated into an automated manufacturing system. During the laboratory exercises, the students have an opportunity to apply their knowledge by integrating several components together to develop an integrated solution to a manufacturing problem. A picture of the workstation layout, including the component bill of materials, is provided later in the paper. To instill the team concept, desired by industry, the students are required to use a collaborative team approach in completing the exercises. Table 4 lists the outline of recommended laboratory exercises. Once again, only 10 topics are listed to provide flexibility to the instructor for evaluations, manufacturer / vendor visits or deeper exploration of the topic.

Table 4 – L*aboratory exercises for Introduction to Automation*.

WEEK	*EXERCISE TOPIC*
1	Automation Components Identification
2	Basic DC Circuits – Schematics
3	Basic DC Circuits – Applications
4	Automation Components – Switches & Relays
5	Automation Components – Sensors
6	Automation Components – Actuators
7	Introduction to Automated Control Circuits
8	Introduction to Programmable Logic Controllers (PLC)
9	PLC Programming – Fundamental Concepts
10	PLC Programming Principles

Currently in its third year with the revised structure, MET 451, Introduction to Automation, has proven successful in introducing students to the concepts and applications of industrial automation. This success is evident in the student's desire and ability to integrate automation into their capstone projects. Capstone, a senior year project course, is intended to integrate elements of the student's academic program into a single comprehensive project. The project, typically solicited from local industry, is an actual manufacturing problem requiring an innovative solution, allowing the students an opportunity to demonstrate their understanding of manufacturing competencies. Introduction to Automation, MET 451, provides the students the skills necessary to evaluate and, when practical, integrate automated solutions when resolving the complexities of their Capstone project.

MET 451 Laboratory Workstation

The laboratory component of MET 451, Introduction to Automation, utilizes specially designed workstations to provide students a hands-on approach to learning the concepts and integration of industrial automation systems. The IAB and MMET faculty, to promote an interdisciplinary understanding of the automation concept behind the device and facilitate an applied understanding of how the particular component is integrated into an automated manufacturing system, selected the components placed on the workstations. The devices represent common industrial automation equipment found in a modern automated manufacturing enterprise and are tied directly to the classroom lecture topics.

The devices are arranged on the workstation according to functionality, allowing easy integration as the student's knowledge of the automation concepts broadens. Open space is provided between devices for equipment to be added as new concepts are incorporated into the laboratory exercises.

The devices are mounted to a ¾ inch thick sheet of white melamine to ensure electrical isolation and abrasion resistance for extended use. In addition, the melamine surface allows the instructor to write directly on the workstation, using standard dry erase markers, to elaborate on the automation concept being taught. Similar to a classroom white board, the markings can easily be altered or erased at any time using standard dry erase markers and cleaning supplies.

The mounting surface measures seventy-two inches wide by thirty-six inches high. A twelve-inch wide shelf, running the width of the workstation, is provided as a work surface and can be used to support auxiliary equipment or instrumentation as needed.

To ensure a safe and effective learning environment, each workstation is equipped with regulated electrical and pneumatic energy sources. Although the workstation requires 120 volt alternating current (VAC), electrical hazards are minimized through current limiting circuit breakers and a drop down power supply. Additionally, all 120 VAC circuits are clearly identified and shielded from accidental contact. The control circuits the students work with directly during the laboratory exercises have been reduced to a safe, industry standard, 24 volt direct current (VDC). The incoming 120 VAC electrical circuit passes through dual 1.5 amp circuit breakers (electrical disconnects) and then to an industrial power supply to condition the control circuits to a safe 24 VDC potential.

Similarly, all pneumatic energy is reduced from an industry standard source pressure of 100 psig to a safer regulated laboratory pressure of 40 psig. A system exhaust valve is incorporated into the delivery circuit as a safety mechanism to exhaust all stored pneumatic energy while the students are working with the automation devices. Thus, a pneumatic delivery system, including system exhaust valve and adjustable regulator / dryer, is included on the workstation.

A picture of the workstation and complete bill of material (BOM) are provided in the appendix. Devices were selected based upon functionality and availability, not specific manufacturers.

Conclusion

Automation is difficult to teach as a single discipline. It is important to teach an approach to automation and solve automation problems[3], not simply present automation as the solution. Thus, ASU has developed a set of courses, briefly described here, in an attempt to address automation in an integrative manner. Student assessment data will be gathered in coming years to assess the impact of the automation concentration courses on the skills and success of the graduates.

More specific information has been provided about a key course in the sequence, MET 451, Introduction to Automation. As a foundation course, it may be of particular interest to other engineering technology educators.

Bibliography

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Biographical Information

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Jerry Gintz is now a Senior Lecturer in the Mechanical and Manufacturing Engineering Technology Department at Arizona State University. Prior to the fall of 2004, he was a senior technical instructor for Rockwell Automation after working as a manufacturing engineer responsible for industrial automation and manufacturing control systems. He has extensive expertise in programmable logic control systems and robotic systems integration.

SCOTT DANIELSON

Scott Danielson is the Chair of the Mechanical and Manufacturing Engineering Technology Department at Arizona State University. Before moving to Arizona State University, he was at North Dakota State University where he served both in the Industrial and Manufacturing Engineering Department and as Chair of the Engineering Technology Department. His research interests include mechanics education, aircraft, and manufacturing. He holds P.E. registration and worked in industry for over eight years.

Appendix

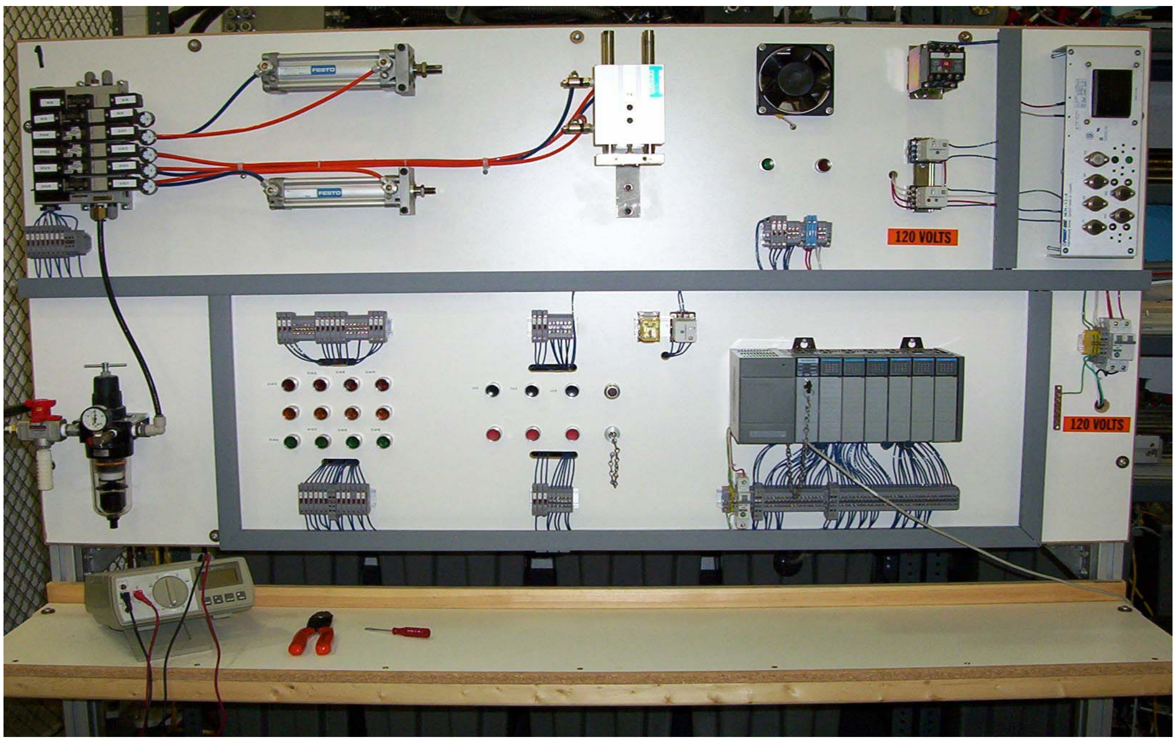

Figure A-1. ***Automation Laboratory Workstation***

Table A-1. ***Automation Laboratory Workstation Bill of Materials (BOM)***

Component Description	Manufacturer	Required
SLC 500 Modular Control System	Allen-Bradley	
-SLC 5/03 Programmable Logic Controller	Allen-Bradley	1
-1746 OB16 24VDC Discrete Output Module	Allen-Bradley	3
-1746 IB16 24VDC Discrete Input Module	Allen-Bradley	3
-1747-P2 Power Supply	Allen-Bradley	1
120 VAC Ice Cube Relay	Allen-Bradley	4
120 VAC Motor Starter	Allen-Bradley	1
120 VAC to 24 VDC 10 amp Power Supply	Power-One	1
120 VAC Disconnect 1.5 amp	Allen-Bradley	2
120 VAC 4" Case Fan	V-Tech	1
2" dia X 6" stroke Pneumatic Cylinder	Festo	2
1" dia. X 4" stroke Guided Pneumatic Cylinder	Festo	2
24 VDC Pneumatic Solenoid Valves	SMC	6
14 ga Din-Rail Mount Terminal Blocks	Allen-Bradley	74
1" X 2" Wire Channel	Panduit	24 '
160 psig Pneumatic Regulator	Parker	1
¾" Pneumatic Ball Valve	Parker	1
24 VDC Limit Switch	Allen-Bradley	4
24 VDC Magnetic Switch	Festo	8

Figure A-2. ***MET 455 Laboratory***