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ABSTRACT

This guide is one of three developed to provide guidelines, information, and resources useful in planning and developing postsecondary technician training programs in high technology. It is specifically intended for program planners and developers in the initial stages of planning a new program or specialized option in robotics. (Two companion guides offer a set of generalizable procedures for systematic program development in high technology and curricular information for planning a computer-aided design, computer-aided manufacturing training program.) The first part reviews the problem, objectives, methods, and outcomes of the project. Information is presented in the second part on industry trends in robotic technology, current projects in industry and education, and the need for training. Part 3 presents curriculum planning guidelines and specifications. Lists of technician-level competencies and sample course titles and course descriptions are provided. Other factors that must be considered in developing and implementing a new program are discussed, including special training for application processes, equipment requirements, faculty capabilities, and future trends. Appendixes include a compilation of site visits by project staff, a list of robot manufacturers and postsecondary programs, a bibliography of robotic technical papers, and a paper on robotics training. (YLB)

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Research & Development Series No. 233

PREPARING FOR HIGH TECHNOLOGY:

ROBOTICS PROGRAMS

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FOREWORD

Robotics has become one of the most rapidly expanding technologies in manufacturing today. The application of robotics spans a broad array of business and industry needs. Predictions for the remainder of the 1980s include a decline in the average cost of a U.S. robot along with a solid growth in sales volume and increased sensory capabilities, including vision, force, and range finding. Greater emphasis will also be put on the application of robots in assembly operations.

Although the development and application of robotics technology is advancing at a rapid pace, the training of technicians to operate and maintain robots has lagged behind. The first two-year postsecondary training program in robotics began in 1980. While a few other programs are now operational, training remains a bottleneck in the process to automate through the use of robots.

As increasing numbers of postsecondary colleges begin planning and developing courses and programs in various high-technology fields, including robotics, they will encounter some of the same questions that other institutions have confronted and answered. What constitutes a robotics program? What competencies are required for employment? What are the trends in robotics applications and where can assistance and information be obtained? In an effort to answer these questions and provide relevant information to program planners, the National Center has prepared this paper as part of its continuing research and development work in the area of high-technology training.

The primary audience for which this guide was prepared includes postsecondary community and technical college deans, faculty, and advisory committee members and trainers and program developers in industrial setting that are responsible for providing education and training in robotics. To date, both the job content and training requirements for robotics technicians and maintenance workers has evolved as the complexity and sophistication of robotic technology has increased. In the main, robotics technology incorporates and builds on hydraulics, pneumatics, electronics, and mechanical technologies. Robotics technology, based on the research in progress, will continue to increase in both the sophistication of sensory and control functions and in the diversity of robot applications in the work place. Robots constitute one component of the emerging technology of flexible manufacturing automation. As the incorporation of CAD/CAM and robotics technologies advances the content and training requirements for technician jobs also will change. Future training programs will need to be flexible so they can be modified and updated as new innovations come on-line. While the contents of this guide can serve as a basic resource for program planning, technical information regarding site specific applications and skill requirements must be obtained through collaboration with the users and suppliers of robot systems. Program development and operation must be viewed as a continuous process and must be responsive to both technical and labor market realities.

The National Center wishes to thank Edward Konopka of Oakland Community College in Auburn Heights, Michigan, for his assistance in the development of the curriculum material presented in the paper. Our thanks are also extended to Lloyd R. (Dick) Carrico of Cincinnati

Milacron Company for his contribution to and technical review of the guidelines and curriculum specifications. Special appreciation is expressed to the staff of Robotics International of the Society of Manufacturing Engineers (RI/SME) for their assistance and for their contribution of information contained in the paper.

In addition, thanks are extended to Russell Jordan, Columbus Technical Institute, and to Arthur Bellinger, Advanced Robotics, Columbus, Ohio, for their assistance in reviewing the paper and suggesting useful revisions. The preparation of this paper also benefited from the ideas and critiques of National Center staff members James Long and Roy Butler.

Appreciation is also expressed to Sharon Fain, editor, Regenia Castle, typist, and Beverly Haynes, word processor operator for their assistance in the preparation of this paper.

The project was conducted by William Ashley and Robert Abram. Their previous research at the National Center focused on the impact of high technology on two year postsecondary programs. Dr. Ashley's background includes an emphasis on research and vocational education. Mr. Abram's interest centered on research and human factors.

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EXECUTIVE SUMMARY

The information and materials contained in this guide were collected from many sources and provide a basic reference for use in planning postsecondary programs in robotics technology. The guide presents a review of some of the problems faced by two-year postsecondary colleges as they address the challenges presented by this changing technology. Such problems include the lack of employment information, the scarcity of technical experts, the obsolescence of existing equipment, the high cost of new robot systems and devices, and the need to upgrade and retrain faculty.

A number of sources of technical information and assistance available to program planners were identified and are discussed in the document:

- Robotics International of the Society of Manufacturing Engineers (RI/SME) is a major resource. The Education and Training Committee of RI/SME provides various types of information and professional development assistance to member chapters and the educational community in general. The Manufacturing Engineering Education Foundation provides funding for schools through grants in the areas of capital equipment, student development, faculty development, curriculum development, and research.

- The Human Resource Research Organization (HumRRO) is conducting research on human factor issues related to robots and automation through its Center for Robotics.

- The Department of Engineering and Public Policy at Carnegie-Mellon University and various departments of other universities are carrying on programs of research and education.

Emerging technological and marketing trends in robotics were reviewed. Forecasts suggest that the sophistication and capabilities of robot systems and the number of units in operation will increase dramatically over the next ten years and beyond. In response to the current and predicted increase in the deployment of robots, an increasing number of community and technical colleges are developing new courses and programs to prepare technicians for jobs in the field of robotics. Both curriculum planning guidelines and specificiations are presented to facilitate the planning of new programs in robotics technology. Technical competencies required to install, operate, debug, and repair a variety of electrical/electronic and electromechanical devices found on robots are presented. Additionally, a suggested list of course titles and course descriptions is provided.

Other factors that must be considered in developing and implementing a new program are discussed, including special training for application processes, equipment requirements, faculty capabilities, and future trends. Finally, sample materials, technical information, and the names of postsecondary college personnel involved in developing new programs are included in the appendices.

PART 1

BACKGROUND

Introduction

This is one of three guides developed to provide deans and faculty in postsecondary community and technical colleges with guidelines, information, and resources that can be of assistance in planning and developing technician training programs in high technology.

Previous research conducted by the National Center (Faddis, Ashley, and Abram 1982) found that postsecondary institutions spend considerable time and energy in obtaining information and advice and in planning new programs for emerging technologies. Among the many constraints they encounter is the limited number of experts and/or experienced workers knowledgeable about new technologies who can be approached for advice and information. Other restrictions that often extend the planning and development time required to institute a new program in a rapidly emerging technology were also identified. Hence the major goal of this project was to collect and compile information that would promote the planning and development of high-technology programs and minimize the redundancy of efforts among postsecondary institutions.

This guide is intended to aid postsecondary program planners and developers who are in the initial stages of planning a new program or specialized option in robotics. Two companion guides offer a set of generalizable procedures for executing systematic program development in high technology and curricular information for planning a computer-aided design, computer-aided manufacturing (CAD/CAM) training program.

This guide is divided into three parts. The first part reviews the project's background, including the problem, objectives, methods, and outcomes. The second part presents information on industry trends, projects in progress and the need for training. The third part presents information and examples of curriculum content for robotics. The information and materials assembled here come from a number of sources, including several two-year colleges that have been involved in training robotics technicians and leading manufacturers and users of robot systems.

The Problem

Currently, the application of robots is rapidly expanding in the United States, with approximately five thousand units now in operation. Projections of the number of robots that will be in operation by the end of the decade range between twenty and sixty thousand (Martin 1982). When nonreprogrammable robots are included in the count, the predictions are greater. While robots can be used in virtually every manufacturing process, spot welding is the predominant application, covering or comprising about half the units in operation. Arc welding, spray painting, and materials handling constitute the remainder of applications in wide use today (Aron 1981). Predictions for new applications suggest large increases in the use of robots for parts assembly, parts finishing, and inspection.

Automobile manufacturers are presently the largest user of robots, operating between 30 to 50 percent of all units in existence. Appliance manufacturers are also significant users and are expected to increase their use of robots during the 1980s (Martin 1982).

The types of applications will expand as robot technology is improved through the addition of more sophisticated feedback capabilities, such as force, vision, and tactile sensing. Increasing numbers of users and future sales predictions suggest a willingness on the part of industry to adopt robotics. However, while the trend is toward increased use of robots, there is a growing shortage of engineers who can design and develop robot installations and technicians who can install, qualify, troubleshoot, and maintain them (Stauffer 1981).

As two-year postsecondary colleges attempt to respond to the need for technicians, they may encounter a number of significant problems. The rapid pace of technological change is itself a most significant condition, as exemplified by the increase in the capabilities of complex computer-directed and sensory controlled robots that are being marketed by manufacturers. Such technological changes require innovative approaches in gathering up-to-date technical information for planning course content, upgrading or recruiting faculty, and gaining access to highly complex and expensive equipment.

The changing nature and educational requirements of jobs is a second condition that complicates educational response. Examples encountered by previous research include changing roles and skills needed for design and production work in the emerging CAD/CAM and robotics technologies.

Because of the speed and revolutionary nature of many new technical advances, access to the up-to-date information needed to design core courses and programs is seriously limited. Few experts (and fewer skilled workers) exist who can be approached for advice and information. Potential advisors have limited time and are often not situated close to the school, even if program planners manage to locate them.

A structural problem for programs that depend on public funding is in justifying their existence on the basis of occupational demand—a process that is usually done through statistics on available jobs. If a school responds early, the statistics may be insufficient for program approval; if the school delays, the eventual response may not help companies that are early adopters of an emerging technology. The delay in providing trained technicians may be crucial to companies that are attempting to achieve or maintain high productivity and improved product quality.

Another problem is the burden that developing new high-technology programs places on school staff members who have limited time to spend in systematic program development and upgrading activities. The same problem exists in upgrading teachers' technical skills.

Many problems affecting appropriate programmatic response to industry's high-technology skill shortages center on the need for innovative approaches, advance information, and curricular guidance from technology leaders. Industry personnel should be involved in planning programs; providing up-to-date information and advice; obtaining adequate funding, and designing, developing, and implementing courses that are of uniformly high quality and relevance and that become operational in time to support the adoption of new technologies.

The National Center for Research in Vocational Education has compiled the materials in this guide with the intention of reducing the time required to plan a robotics program or reducing the duplication of effort among institutions that undertake such planning.

Objectives and Procedures

The project was conducted to provide guidelines and information to postsecondary education leaders and faculty involved in developing and implementing programs in advanced technology areas. A major objective of the work was to develop and report a set of robotics program guidelines and specifications. An additional objective was to develop a set of guidelines and specifications for planning a CAD/CAM technology program. A third objective was to describe a generalizable procedure for program development in other high-technology areas. To accomplish these objectives, project staff carried out a number of different activities, often drawing on the advice and assistance of technical consultants from both education and industry.

Project staff conducted a series of site visits to companies that either use or manufacture robots or CAD/CAM systems and to postsecondary institutions that have developed training programs for robotics, CAD/CAM, and other new technologies. During the visits, staff observed and discussed changes in operational considerations and training requirements due to the adoption of each particular technology. The individuals visited and their respective companies or schools are listed in appendix A.

Project staff contacted the staff of Robotics International of the Society of Manufacturing Engineers (RI/SME) for advice and information about developments in the robot industries and existing educational programs. RI/SME provided several packages of information about different aspects of the robot industry, including lists of manufacturers, universities involved in education and research projects, and postsecondary colleges that offer courses and/or programs in robotics (see appendix B).

Most major manufacturers of robots and robot systems, when contacted, responded by providing product information brochures and technical information documents. The materials were reviewed and analyzed to identify the various technical devices and operational components that are currently being incorporated into robots that are on the market.

A set of robotics technical papers published by SME was attained and reviewed by project staff. A list of the robotics technical papers available from RI/SME is included in appendix C.

Course descriptions and program requirements were collected from several two-year colleges that have initiated robotics training efforts and from vendors that provide customer training for operations and maintenance personnel. Additionally, lists of task statements for occupations closely related to or actually part of a robotics technicians' job were collected and reviewed. (A general task list is presented in appendix D.)

Sample curriculum guides for courses in the maintenance and repair of equipment and devices that are part of a robot system were collected and reviewed. These materials were used as a base of information, along with materials provided by technical consultants, to develop the sample course descriptions contained in part 3 of this paper.

Project staff followed numerous leads in an effort to locate sources of research information, technical information, and projects and activities that other organizations, institutions, or agencies were conducting. When sources of information were identified, copies of available documents and descriptions of ongoing projects were requested and, when obtained and found to be appropriate to the purpose of this document, were either included or cited.

Outcomes

Through contacts, discussions, site visits, and reviews of published materials, the project staff sought to collect and compile information and references that would be useful to postsecondary program planners and developers.

Two criteria guided project development activities and the selection and inclusion of material in this document. First, project activities should focus on the specific problems that confront postsecondary institutions when new programs in high-technology areas are being developed. Second, the materials included in this document should serve the specific information needs of two-year college deans, and faculty who are planning and developing a robotics program. With these two concerns as guiding criteria, the outcomes of the project can be related with the contents of this document as follows:

Questions, Problems or Needs Encountered	Outcome
What is and will be the status and changes in technology?	Trends in Robotic Technology, p. 5.
Where can additional information and assistance be obtained?	Current Projects in Industry and Education, p. 10.
What approaches can be used in program development?	Guidelines for Program Planning, p. 18.
What curriculum is appropriate for robotics training?	Curriculum Specifications, p. 20.
What other institutions are developing programs and who can give advice?	Robot Manufacturers and Postsecondary Programs, Appendix A, p. 33, and Appendix B, p. 35.
What are local employer training needs?	Task Survey Resources, Appendix D, p. 51.

The information contained in the sections listed above represent some of the most up-to-date and currently available information, guidelines, and curricular specifications.

PART 2

CURRENT TRENDS AND RELATED TRAINING

Introduction

There are several constituent groups contributing to the growth and development of robot technology in the United States. Among these groups are the manufacturers and users of robots. In addition, a growing number of university-based and private researchers are contributing to the further development of the technology through numerous research projects and educational programs.

Postsecondary program planners, developers, and faculty need to be informed about the trends and developments in a given technology and its impact on educational institutions. Furthermore, those educators who are considering the possibility of developing a new program wish to know where they can gain additional information and assistance.

In response to such common needs, the following information has been prepared: (1) a review of trends in robotics technology and (2) an updated list of organizations that can provide additional assistance.

Trends in Robotic Technology

The 1980s are being described as the age of the robot. Estimates by a New York-based international market research organization revealed an optimistic outlook for the robot market for the 1980s. As of 1980, there were 3,500 robots operating in American industry—an increase of over 3,000 compared to 10 years earlier (Miller and Silverman 1981, p. 3). Between 1979 and 1981, the use of robots in manufacturing nearly quadrupled (Levitan and Johnson 1982, p. 11). By 1985, robot makers are expected to gain $438 million in sales across all industries as indicated in Table 1.

Robots in industry have become more prominent not only in quantity but also in quality. Since the first robot was installed in the General Motors plant at Turnsted in 1961, many advances have been made in their various functional capabilities. Perhaps the most frequently mentioned and widely anticipated advance in the next generation of robots is improvement in force, vision, and tactile sensing capabilities. Robotics was not, as sometimes assumed, precipitated by the discovery of new laws or principles of physics or by an otherwise newly developed discipline. This fact has important implications for the development of a curriculum for teaching robotic technology. The advent of robotics was prompted by rapidly increasing labor costs, advances in electronics technology, and the combined talents of two very innovative engineers: George Devol and Joseph Engelberger. The former expressed his farsighted ideas about industrial robots or "programmable manipulators" to the latter, who through exceptional entrepreneurial skills, translated the ideas into the production of the first robot in 1961. Later Engelberger founded and became president of Unimation Inc.; the world's first and largest robot company (Saveriano 1981, p. 10).

TABLE 1

THE ROBOT MARKET INTO THE 1980S IN THOUSANDS OF DOLLARS

	1977	1979	1981	1983	1985
Electrical Machinery	3,406	15,840	41,108	58,400	163,812
Automotive	1,924	14,880	21,156	32,120	53,874
Fabricated Metals	11,622	16,480	26,144	56,648	67,014
Electronics	78	1,600	11,696	12,264	70,080
Heavy Machinery	5,512	12,240	18,576	23,944	12,702
Others	3,458	18,960	53,320	108,624	70,518
Total	26,000	80,000	172,000	292,000	438,000

SOURCE: Frost & Sullivan Inc., New York (1979)

Although approximately 55 percent of the robots currently in use are estimated to be in the automobile industry, future applications are envisioned across a broad range of settings. The following lists ten settings for robotic applications—most of which have not yet been realized (Parsons and Kearsley 1981).

- Factories

    Manufacturing (welding, machining, painting, moulding, etc.)

    Light industry (assembly, inspection, repair, loading, packaging, etc.)

- Offices & Institutions (hospitals, schools, prisons, etc.)

    Distribution (mail, supplies, food)

    Cleaning (floors, windows, trash)

- Space

    Space construction and Maintenance

    Satellite retrieval, inspection, and servicing

    Planetary exploration

- Undersea
  - Surveying
  - Search and rescue
  - Cable laying, construction
  - Extraction
- Mining/oil and gas exploration
  - Extraction/drilling
  - Rescue (firefighting, boring)
  - Processing
- Nuclear Plants
  - Maintenance
  - Emergency operations
- Home
  - Housekeeping
  - Food preparation
  - Security
- Agriculture
  - Harvesting and planting
  - Crop dusting
- Construction
  - Excavations
  - Structure erection/demolition
- Military
  - Combat (weapons systems)
  - Supply

Industrial applications are by far the major use for robots. Although die-casting was the initial application area for these machines, spot welding automobile frames is probably their major application in industry today. The following list shows current and future applications of industrial robots. (The "ICAM" designation refers to an U.S. Air Force project called "Integrated Computer-Aided Manufacturing.")

Current Applications

- Die casting
- Spot welding
- Arc welding
- Flame cutting
- Investment casting
- Forging
- Spray painting
- Plastic moulding
- Machine tool loading, changing
- Deburring
- Palletizing (loading, unloading)
- Brick manufacture
- Glass handling
- Press work
- Heat treating, annealing
- Transferring (pick and place)
- Swaging
- Assembly (simple)
- Electroplating
- Foundry work (limited) (ICAM)
- Sheet metal drilling, routing
- (ICAM)

Future

- Machining
- Sheet metal fabricating
- (ICAM)
- Composite materials manufacturing (ICAM)
- Cleaning parts
- Assembly (complex)
- Packaging
- Package distribution
- Warehousing
- Troubleshooting/repair
- Supervision
- Inspection

Future applications await the development of "level two" robots which will exploit sensory capabilities to a much greater degree than current (level one) technology allows (ibid., p. 8).

Level-one and level-two robots have been defined according to the availability of the technology (Miller and Silverman 1981, p. 68). Level-one robots are currently available models that can be purchased "off the shelf" from manufacturers. These robots have the following qualities (Engelberger 1980, p. 117).

- Work space command with six infinitely controllable articulations between the robot base and its hand extremity
- Teaching and playback facilities that make fast, instinctive programming possible
- Local and library memories of any practical size desired
- Random program selection that functions by external stimuli
- Positioning accuracy repeatable to within 0.3 mm
- Weight handling capability up to 150 kilos
- Point-to-point control and continuous path control possibly internalized in one robot
- Synchronization with moving work pieces
- Interface capabilities that are compatible with computers
- Palletizing and depalletizing capabilities
- High reliability with not less than 400 hours MTBF (mean time between failures)

Level-two robots are those that are under development and thus are not commercially available at the present time. They include sensory feedback capabilities as well as other desired qualities listed in the following (ibid., p. 118).

- Rudimentary sense of vision to provide—
  recognition data
  orientation data
- Tactile sensing that gives—
  recognition data
  orientation data
  physical interaction data
- Computer interpretation of visual and tactile data
- Multiple appendage hand-to-hand coordination
- Computer-directed appendage trajectories
- Mobility
- Minimized spatial intrusion
- Energy conserving musculature
- General purpose hands
- Person-robot voice communication

- Total self-diagnostic fault tracing
- Inherent safety (Asimov's Laws of Robotics)

HumRRO researchers have developed a classification scheme based on robot capabilities that roughly parallels the level one and level two distinctions (Parsons and Kearsley 1981, p. 3). The capabilities shown in boxes in figure 1 are those that are not completely operational in industry and which may thus be viewed as level-two capabilities. Those not boxed in are currently operational and may be classified as level-one capabilities.

Current Projects in Industry and Education

Robotics International of the Society of Manufacturing Engineers (RI/SME) is an educational and scientific society for robotics professionals. It was founded in 1980 to provide comprehensive and integrated coverage of the field of robotic technology. RI/SME is the organizational "home" for scientists, engineers, and managers concerned with robotics.

RI/SME is both applications and research oriented and covers all phases of robot research, design, installation, and operation. It also investigates the human factors involved in robot use and robot maintenance within plant facilities. To make sure that its conferences, clinics, seminars and publications are what robot professionals need, RI/SME has nine active technical committees on welding, coatings, aerospace, machine loading and unloading, assembly, human factors, castings and foundries, nuclear, and research development that advise and plan the RI/SME programs and educational materials. There is also an Education and Training Committee chaired by Jack Lane of General Motors Institute in Flint, Michigan.

RI/SME presently has chapters in over twenty U.S. and Canadian cities and foreign countries to help ensure that every member of RI/SME has (1) the opportunity to take part in local technical programs, and (2) the opportunity to discuss mutual challenges with other members on a regular basis.

RI/SME is currently involved in several projects and continues to expand its services to the field. The staff and members of the Education and Training Committee of RI/SME were progressing on the following activities as of November 1982.

- The sponsorship of both the "Education Session" and annual "Education Forum" at the ISIR/Robot Conference.
- The development of a robotic certification exam and handbook.
- The development of the RI/SME Directory of Robotic Education and Training Institutions, which will reflect the results of a survey of 1900 schools.
- A survey of robotics education and training activities in 200 corporations.
- The preparation of a robotic audio-visual catalog.
- Operation of the Computerized Automation and Robotic Information Center (CARIC). (Slated for completion in 1983, the Center will provide computerized literature search capabilities.)

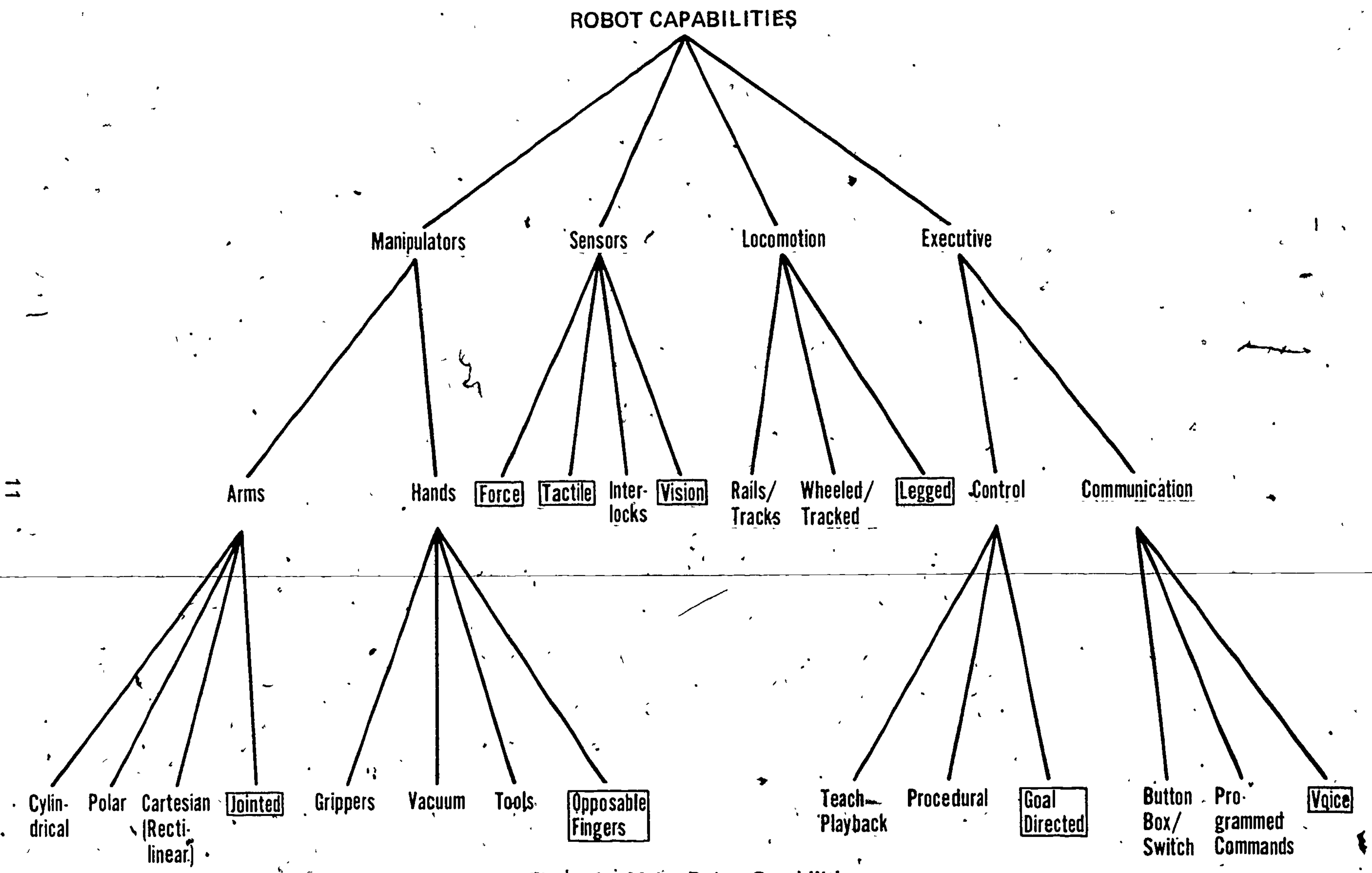

Figure 1. Major Robot Capabilities

SOURCE: Parsons, H. M., and Kearsley, G. P. *Human Factors and Robotics: Current Status and Future Perspectives.* Alexandria, VA: Human Resources Research Organization, 1981.

- The provision of direct support and advice to groups that wish to organize a local chapter of RI/SME.

The Education and Training Committee is also considering a curriculum development project that would produce a curriculum guide for schools wishing to devise a robotics degree program.

The Human Resources Research Organization (HumRRO) entered the area of robotics in 1981, using in-house funds to establish their Center for Robotics. HumRRO staff recognized that R & D emphasis was being placed on the engineering of machine hardware and computer software, but that surprisingly little attention was being paid to the training/retraining, job satisfaction, attitudes, fears, inertia, and other human factors. Through discussions with a large number of robot manufacturers and users, HumRRO staff determined that problems in the application of robotic technology are and will continue to be with the humans involved in the process—not with the hardware.

In an effort to rectify this apparent imbalance in emphasis, HumRRO staff established a center to study and develop the human, social, and organizational sides of robotics technology (see Parsons and Kearsley 1982). In addition to conducting research and development projects, HumRRO provides consulting services to organizations that are developing and/or implementing robot systems.

The Department of Engineering and Public Policy at Carnegie-Mellon University in Pittsburgh, Pennsylvania, has completed several significant studies on robotics and continues to be involved in research and development in robotics. A forthcoming book entitled *Robotics: Applications and Social Implications* by Robert U. Ayres and Steven Miller, Ballinger Publishing Company, Cambridge, Massachusetts, will be out in 1983. Several other ongoing projects include a Technology Assessment of Future Robotic Capabilities (Robert Ayres and Paul Wright); the development of an Improved Methodology to Assess the Substitutability of Robots for Manufacturing Jobs (Robert Ayers and Steven Miller); an investigation of the Potential Use of Robotics by Industry and by Occupation; and an investigation of the Potential Economic Benefit and Human Resource Implication of Robotics.

The United States Congressional Office of Technology Assessment (OTA) in Washington, D.C., has produced a report of an exploratory workshop on the social impact of robotics which is available from the OTA Publishing Office. Additionally, OTA is involved in a number of projects to determine the impact of various technological developments and changes. The OTA should be considered a primary information source by program planners in postsecondary institutions.

The Need for Training

In analyzing the current situation, it would appear that industry is ready for the explosion of robotic technology. Robert N. Stauffer (1981), editor of *Robotics Today*, states that industry indeed is ready in terms of need. However, he cautions that:

> in terms of the availability of engineers and technicians trained in the technology, the answer is no. It is becoming increasingly evident that the education of individuals qualified to install and maintain robots is not keeping pace with the growing demand for such talent. The problem could pose a serious threat to the success of this country's reindustrialization efforts, considering the important role that robots will play in that program.

At the time this editorial was published nearly twenty years after the first robot was installed in industry, there was only one full-scale postsecondary training program that offered courses leading to an associate's degree in robotics technology.

Thus it is not surprising that there is currently a critical need for trained technicians to install, operate, and maintain industrial robots.

In a survey of 112 higher education institutions reported in the 1981 ASEE annual conference proceedings, nineteen of the seventy-three respondents reported that they offered courses in robotics and twenty-nine reported that they were planning to offer such courses (Kovacs 1981, p. 673). Information indicating the college departments offering such courses was not presented. However, the following list of colleges and their subject matter sequences of options in robotics was provided as an aid to other colleges in the development of a strong curriculum (ibid., p. 671).

University of California, Berkley

(i) Manufacturing processes and systems
(ii) Machine tool design and control
(iii) Real-time application of mini and microcomputers
(iv) Computer interfacing

Colorado State University

(i) Introduction to CAD
(ii) Advanced CAD
(iii) CA/numerical control

Purdue University at Fort Wayne, Indiana

(i) Computer programming fundamentals
(ii) CAD
(iii) CAM
(iv) Numerical control machining
(v) Introduction to robotics

Rochester Institute of Technology, New York

(i) CAD
(ii) CAM
(iii) CNC

Southern Missouri State University

(i) Computer programming for industrial applications
(ii) Industrial control
(iii) Robotics

SUNY College of Technology, New York

(i) CAM/robotics
(ii) Economics of robots
(iii) Design for robots applications
(iv) Robotics seminar

Texas A & M University

(i) Digital logic
(ii) Microprocessors
(iii) Database systems
(iv) Real-time control
(v) CAM I & II

University of Wisconsin at Stout

(i) Computer programming
(ii) Microprocessors
(iii) Numerical control
(iv) Robotics

Today, in addition to offering courses in robotics, several higher education institutions are conducting research on increasing the performance capabilities of robots. Some of the university research being conducted is summarized in the following (Albus 1981).

- Stanford University
  - Mobility
  - Vision
  - Three-fingered hand
  - Force sensing
  - Robot programming languages
  - Geometric modeling for vision and programming
- Massachusetts Institute of Technology
  - Pressure sensing
  - Vision
  - Programming languages
- Carnegie-Mellon University
  - Flexible assembly
  - Machining
  - Sensory systems
  - Vision
  - Mobility
  - Intelligent systems
- Rhode Island University
  - Vision for acquiring, orienting, and transporting work pieces
  - Dexterous robot grippers
  - Programming languages

- University of Florida
  Teleoperators

- Purdue University, Indiana
  Robot control systems
  Robot programming
  Languages
  Machine vision
  Modeling of parts flow through industrial plants

- University of Massachusetts
  Visual interpretation of natural scenes and design parts for automatic assembly

- University of Maryland
  Image processing (includes robot vision and methods for using visual knowledge in interpreting images)

- University of Rochester, New York
  Advanced methods of representing three-dimensional shapes in a computer memory through PADL—a computer graphics language

- Rensselaer Polytechnic Institute, New York
  Generation of computer models for three-dimensional curved service objects

- University of Arizona
  Machine vision

- The Ohio State University
  Dynamics and controls of industrial manipulators and legged locomotion systems

- University of Illinois, University of Pennsylvania, University of Washington, University of Texas

  Projects in various areas

PART 3

CURRICULUM GUIDELINES AND SPECIFICATIONS

Introduction

When the National Center for Research in Vocational Education began its research on high technology in February, 1981, only one community college offered a two-year training program in robotics technology, although several others were in the planning stages of doing so. As of October 1982, twelve postsecondary colleges reported that they offered a complete program in robotics and twenty others reported offering one or more courses in robotics. (see appendix B).

From a review of three of the programs currently in operation (as well as a few in the planning stages), it was apparent that postsecondary planners are somewhat perplexed by the possible curricular options for developing a robotics program. There appear to be at least two basic approaches: (1) a sharply focused program on the installation, operation, and maintenance of robots with training considerations given to other components and processes of automated manufacturing systems and; (2) a more broadly focused program with emphasis on the many components and processes of manufacturing systems, including an overview of robots. Such an overview might include the types of robots, their operational characteristics, and general maintenance procedures. When one considers the number of disciplines relevant to the robotics curriculum, the difficulty of choosing a program focus is more understandable. Some of the disciplines useful to the robotics "game" have been compiled by Engelberger (1980, p. 119) and are presented in the following.

Kinematics
Dynamics
Servo design
Fluid power
Digital electronics
Analog electronics
Computer structure
Integrated circuit design
Computer software
Cybernetics
Automation technology
Numerical control
Systems engineering
Rotating machinery
Structural engineering
Tribology
Metallurgy
Metrology
Sensory instrumentation
Character recognition
Industrial engineering
Manufacturing engineering
Physiology
Bionics
Psychology
Sociology
Economics
Futuristics

At this point in time, no clear trend toward either of the two approaches mentioned has emerged. In fact, a third option has been developed at Piedmont Technical Institute in Greenwood, South Carolina. The focus there is toward developing a Robotics Resource Center with the primary objectives of (1) imparting knowledge and training to faculty at other technical colleges in the state, (2) aiding in the transfer of robot technology to local industries, and (3) serving as a learning center for students who receive their technical preparation in various disciplines.

From the limited information available, the strategy that some institutions appear to be following for developing a robotics focus is to modify existing courses in electronics, manufacturing processes, controls, and computers, and other areas to include specific content on robot devices, subsystems and operations.

One way that program developers can deal with the interdisciplinary complexities of a robotics curriculum is to seek guidance from representatives of the businesses and industries where many of their graduates will be employed. As a general practice, postsecondary colleges do seek the advice and expertise of technical advisory committees during the program planning phases of any of their occupational programs. This tactic is even more critical in the area of robotics. Currently, there are only a limited number of postsecondary programs in robotics to serve as models for other colleges. Appropriate equipment and curriculum materials and current instructional expertise are but a few of the elusive but necessary components for a high-quality robotics program. Ideas on what form program content should take and how equipment might be obtained can be gleaned from a high-technology advisory committee. The members of such a committee should be business and industry representatives who understand the current and future needs for skilled technicians. Members may have to be recruited from companies outside the local region. Use of the DACUM technique with a technically knowledgeable group is cost effective and can serve to identify the skill and knowledge competencies upon which a curriculum can be structured. Thus, a partial solution to the problem of which courses to offer, in what sequence, and supported by which basic education and science courses can be achieved quickly through an initial meeting with business and industry representatives. The general model can then be further developed through frequent meetings with local industry representatives.

The following guidelines are provided to suggest some of the key concerns and possible strategies that program planners should address.

Guidelines for Program Planning

As noted previously, robotics technology encompasses a variety of technical specialties. Institutions that are considering offering a program in robotics should first evaluate their present capacity in the several technical areas that constitute the basic core of the technology. Much of the currently available robot hardware incorporates systems and devices that have been in use in industrial equipment for many years. For example, hydraulics, pneumatics, electrical motors, and electronic controls are familiar technologies to many technical educators with industrial work and occupational training experience. These technical subjects will continue to form the core of a robotics curriculum. Current courses and training capabilities in the core technologies can form the basis for a full program. Some modifications in the scope and sequence of instruction and adjustments in skill development however, may be necessary to reflect robot applications and control. Facilities, equipment, and training devices needed for a full program obviously include more than what is needed for basic courses and thus may require the integration of math and science courses offered by the different departments and divisions of the institution. Achieving an efficient integration of all courses into a program may also have implications for major organizational changes and curricular realignments. Administrators should give special attention to potential problems or delays that reorganization might cause.

When evaluating existing courses, it must be remembered that in all probability, the content of the courses is needed to adequately train students; the addition of new technology courses might possibly expand a two-year program to five or even six semesters.

If the concept of comptency-based training is applied when reviewing existing courses or planning new ones, excessive ballooning of the program can be controlled. Combining the content of two courses into a single course (with the major focus centered on teaching essential concepts and job skills) can create space in the curriculum for additional new courses.

In a two-year program, the majority of the graduates are not intended to be "design engineers". They will be expected to perform as technicians. Thus they will need to develop a basic understanding of a subject, and then focus on developing practical skills in the basics of operating or maintaining equipment. This may be referred to as a "modified black-box" approach.

The typical approach to teaching basic electronics can be considered as an example. Normally, courses start out with basics and then expand to DC components, devices, and so on. Then, AC basics are taught in a second course with a large amount of time spent on graphs, transient curves, and so on. An emphasis on tracing current flow and calculating voltage drops, RC time constants, and so on through a circuit (such as a differential amplifier) is not needed for a person at the technician level. A suggested alternative approach is that both DC and AC electronics be taught as a single course with the emphasis on comparing component characteristics of a differential amplifier, the focus would be on the input, basic internal operation, and the output—not on the function of each discrete component.

The reason for suggesting this approach is that most circuit systems that have been and are now being taught are embedded in "chips" or "bugs". They are replaceable modules or "black boxes." Technicians need to know the basic function of the modules and the techniques required to analyze and replace them.

The future technician will be working with technical documents on a day-to-day basis and in some cases will be asked to write those documents. To ensure that graduates have the appropriate skills for such tasks, the teaching of technical writing instead of the more traditional "English Composition" courses should be considered. At the present time, good technical writers are almost nonexistent. Furthermore, most of them have learned their skills through on-the-job training.

By employing a competency-based approach in planning courses, the essential job requirements can be met and the technician will develop useful technical skills. A careful assessment and validation of the skills employers will demand of graduates should preceed course development. Companies that use robots of different types and design may need technicians who have a broad background in generic robot systems and applications and who can maintain existing units and operations. Manufacturers may need technicians with an in-depth knowledge of specialized applications and installations. Such differences can have implications for the overall scope of a robotics program and the types of lab facilities and training approaches required to meet job entry requirements. Variations in labor demand and training requirements make close collaboration between educational institutions and robot users and manufacturers an absolutely essential precondition for program development.

Educational institutions should direct part of their needs assessment activities toward determining the current and future need for management and human factors training for potential users of robots. It is the opinion of several informed persons representing robot manufacturers and users that because of the current shortage of personnel with technical training in robotics, many of those who enter the field in the near future will be rapidly promoted to supervisory and management positions. This phenomenon was experienced by some of the recent graduates of the robotics program at Macomb County Community College in Michigan.

As is the case in most two-year postsecondary colleges, the background and experience of students will determine their point of entry into a robotics program. Those with little or no industrial/technical background will need to enroll in the total sequence of courses, while those currently working in industry may need only specialized courses in robotics and automated manufacturing processes. Retraining and upgrading adult workers for new high-technology jobs is and will continue to be a major need among many employers. Providing training and educational services to these adults requires that training programs attend to both past skills and future job requirements. Courses must be focused, start quickly, have flexible schedules, and teach contemporary skills and knowledge that will increase the trainees' long-term employment potential. Such courses are best developed between schools and the specific firms whose employees are in need of special training. Conducting specific training and retraining courses can provide the basis for starting new courses and programs and expanding them into regular, full-time curriculum offerings as the need arises.

Due to the technological changes occurring in robots and the diversity of future robot applications, program development efforts should follow a strategy that avoids rigid prescriptions and maintains flexible curriculum units that can be modified and adapted to new developments with minimum effort. Extensive investments in apparatus and training materials that might soon become obsolete or incompatible with new developments in local or regional applications should be avoided. Close attention must be given to matching training objectives to families of job tasks and then selecting lab equipment, instruments, and tools that will ensure that students develop the basic competencies generic to robot technology.

The market for training resources will increase as more training programs are developed. There will also be an increase in the availability of training materials and equipment from commercial vendors. Several major publishers are already developing textbooks on robotics. Educational equipment vendors are entering the market with simulators and small-scale robot devices that use full-scale industrial controls and programming systems. When used, commerical trainer systems and materials should be selected to meet specific training needs. Simulation can help reduce program costs by supplementing the need for full-scale robots to provide adequate hands-on experiences.

Curriculum Specifications

This section includes general curriculum planning specifications in the form of (1) a list of technician-level competencies, and (2) sample course descriptions. The competency statements are organized into functional groups and represent a range of duties and responsibilities that a robotics technician might be expected to assume. The course descriptions represent a range of scientific and technical subjects that constitute the core of knowledge and skills required to understand and apply robotics technology. Numbers were assigned to the courses to indicate both a level and a possible sequence of instruction.

Competency statements and course descriptions were prepared by project staff based on material provided by several technical consultants and reviews of course descriptions and training program outlines from both industry and educational institutions.

The materials are intended to serve as general curriculum specifications from which instructors and technical advisors can proceed to select, organize, and develop curriculum materials for specific courses and learning activities.

Robotics Technician Competencies

Technicians must possess a broad range of skills and knowledge in electromechanics that will enable them to access, interpret, understand, and act upon various kinds of technical information presented in various written and graphic forms. Competencies related to dealing with technical information and data include the following.

Technicians will Prepare, Read, Interpret and/or Apply—

- Service schedules
- Installation instruction sheets
- Service Orders
- Record forms
- Blueprints
- Block diagrams
- Logic diagrams
- Ladder diagrams
- Power system diagrams
- Computer logic and programming languages
- Programming flow diagrams
- Electric/electronic schematics
- Control flow diagrams
- Technical manuals/documents (technical writing)
- Technical revisions and updates
- Electrical/wiring codes

Technicians must be capable of performing a variety of job tasks required to qualify and maintain the control functions of robots and other automated devices. Competencies essential to the performance of programming, adjusting and troubleshooting tasks include the following.

Technicians will Install, Program, Adjust, Troubleshoot, and/or Operate—

- Pneumatic logic controllers
- Cam actuated controllers

- Programmable logic controllers
- Digital programmers and controllers
- Electronic sequencers and sensors
- Electronic test equipment such as—
  oscilloscopes
  counters
  ammeters
  ohmeters
  voltmeters
  chart recorders
- Transducers and interface devices
- Microprocessors/electronic circuit boards
- Industrial finishing devices on robots
- Materials handling devices on robots
- Industrial welders on robots
- Encoders and teach modules
- Laser inspection equipment and devices
- Peripheral/host computer communication links

Technicians may be required to perform or direct others in performing a variety of tasks required to maintain the operational efficiency and structural integrity of robot system components and devices. Competencies required to perform such tasks include the following.

Technicians will Remove, Install, Repair, and/or Service—

- Hydraulic pumps, control valves, accumulators, actuators, gauges, lines, filters, cylinders, and servo valves
- Pneumatic pumps, valves, actuators, gauges, lines, and filters
- Electrical power conductors, motors, controllers, switches, and relays
- Electric/electronic drives
- Automatic lubrication systems on robots and transfer line devices
- Mechanical drives and linkages
- Robot end effectors (simple and complex; hydraulic, pneumatic, mechanical, and electrical)
- Transfer line devices and systems

Technicians must function as a responsible member of a business organization and must be able to perform a variety of normal business communications and record-keeping tasks. Competencies required to meet the general business activities that go on in a company include the following.

Technicians will Read, Write, Interpret, Process, and/or File—

- Technical reports and references
- Technical revisions and updates
- Business letters
- Legal contracts (service, warranty, etc.)
- Memos
- Business forms
- Financial forms and reports
- Budget documents
- Charts, graphs, and diagrams
- Estimates of cost, time, and materials
- Travel and expense vouchers
- Policies (company and customer)

Technicians come in contact with a variety of company personnel and customers and must possess effective oral communication skills. Technicians should be competent in both listening and speaking tasks, including the following.

Technicians will Listen to, Interpret, and/or Verbally Present—

- Facts
- Opinions
- Explanations
- Information
- Conclusions
- Policies

Technicians come in contact with a wide range of customer, union, and government policies. Technicians should be aware of the existence of various types of policies and issues which are generally covered by policies. They should be competent in locating, interpreting, applying, or following existing policies in different work situations.

Technicians will Interpret and Apply—

- Customer plant policies
- Safety regulations
- Union policies
- Regulations regarding job skill areas
- Governmental regulations (OSHA)

Suggested Courses in Robotics Technology

The following course titles and descriptions were prepared by project staff with input from many sources and are representative of the courses currently being offered by several postsecondary institutions and industry-based programs to train robotics technicians. The course descriptions are based on specific information obtained during site visits to robot manufacturers, users, and community colleges, and information provided by program developers and faculty currently involved in robot training programs. Algebra, trigonometry, and technical writing skills are also typical requirements.

The arbitrary numbers assigned to each course are intended to suggest both its level and sequence in a two-year program.

Suggested Courses

- **Fluid Power**

  FP 100 Applied Hydraulics and Pneumatics
  FP 101 Hydraulic and Pneumatic Circuit Analysis

- **Electromechanical**

  EM 110 Basic Electromechanics
  EM 111 Servo Valves and Sensors
  EM 210 Electrical Controls and Automation Circuits
  EM 211 Electromechanical Servicing

- **Electrical/Electronic**

  EE 120 DC and AC Circuit Analysis
  EE 121 Transistor Circuit Theory
  EE 122 Drive Circuits
  EE 220 Digital Logic and Computer Circuits
  EE 221 Computer-Aided Circuit Analysis
  EE 230 Microprocessors - Software

Suggested Courses - continued

EE 240 Microprocessors - Hardware
EE 250 Industrial Control Systems

- **Robotics and Automated Manufacturing**

RA 130 Introduction to Robots
RA 131 Machine Tool Processes
RA 230 Robotic Interfacing
RA 240 Robotic Applications (Basic)
RA 241 Robotic Applications (Advanced)
RA 250 Automated Systems Servicing
RA 260 Problem Solving/Internship

- **Quality Control Technology**

QC 150 Metrology (Optional)

Course Descriptions

- **Fluid Power**

FP 100 Applied Hydraulics and Pneumatics: Principles of hydraulic and pneumatic components and functions of common systems as applied in industrial applications (robots, machine tools, etc.)

FP 101 Hydraulic and Pneumatic Circuit Analysis: Advanced study of hydraulic and pneumatic circuit applications and control devices with emphasis on system analysis and troubleshooting procedures.

- **Electromechanical**

EM 110 Basic Electromechanics: Introduction to electromechanical devices, drive trains, and control components; reading and interpreting prints; and operation and repair in robotic and automated equipment/systems.

EM 111 Servo Valves and Sensors: Investigation of servo valves and sensors; emphasis on operation, maintenance and usage in robotic and automated equipment/systems.

EM 210 Electrical Controls and Automation Circuits: Advanced study and practice in feedback control systems, control devices, and circuits with emphasis on electrical motor characteristics and operations, programmable logic controllers, bussway interface units, computer-related design assembly, and troubleshooting techniques.

EM 211 Electromechanical Servicing: Skill development in applying field service practices and test instrumentation to robot controllers, power supplies, manipulative actuators, transfer line systems, and feedback sensors. Emphasis is placed on troubleshooting and repairing problems in CAD/CAM interface systems and devices for automated manufacturing cells and production equipment.

Course Descriptions - continued

- Electrical/Electronic

EE 120 DC and AC Circuit Analysis: Principles of basic DC and AC theory utilizing math analysis; emphasis on characteristics of components in basic circuit transformers, power supplies, etc.

EE 121 Transistor Circuit Theory: Theory as applied to three common configurations; emphasis on oscillators, amplifiers and preamplifiers.

EE 122 Drive Circuits: electronic and transistor theory as applied to electronic drives; emphasis on SCRs, feedback loops, and single and three-phase drive applications.

EE 220 Digital Logic and Computer Circuits: Study of numbering systems (binary, octal, hexadecimal,) Boolean algebra, logic circuits (counters, registers, decoders and storage devices); emphasis on usage in computer circuits.

EE 221 Computer-Aided Circuit Analysis: Study of computer programming utilizing a digital computer in the analysis and design of DC and AC circuits; emphasis on computer languages (BASIC, FORTRAN, etc.)

EE 230 Microprocessors - Software: Theory of applications; emphasis on instruction sets, assembly language, architecture, and programming techniques.

EE 240 Microprocessors - Hardware: Advanced study and practice in working with microprocessors; emphasis on construction, testing, debugging, programming, and design. (Each participant should construct a microprocessor with CPU, I/O, memory, keyboard, and character generator.)

EE 250 Industrial Control Systems: Advanced study and practice in working with the broad spectrum of industrial systems found in a typical industrial environment including electrical energy sources, power distribution systems, industrial control systems, industrial electrical loads, and specification of installation requirements for electrical devices and controls. Emphasis on developing technical knowledge and skills required to install, operate, troubleshoot, and maintain system components and machines according to standard codes and safety regulations.

- Robotics and Automated Manufacturing

RA 130 Introduction to Robotics: Introduction to applications in industry; emphasis on types, classifications, types of motion; relationship to NC, CNC and CAD/CAM; introduction to end effectors.

RA 131 Machine Tool Processes: Introduction to modern machine tool technology with emphasis on the capabilities and applications of automated machine tools including their relationship to CAD/CAM, flexible manufacturing, group technology and robot operations.

RA 230 Robotic Interfacing: Study of hardware and software necessary for connecting a microprocessor to a robotic arm and interfacing to peripheral machines/equipment; advanced information on end effectors.

Course Descriptions - continued

RA 240 Robotic Applications (Basic): In-depth study of low- and medium-technology robot concepts, principles, functions, design parameters; and applications with emphasis on developing the technical skills required to specify, install, program, operate, and troubleshoot point-to-point and continuous path robot systems, components, and devices to achieve operational accuracy and reliability in common industrial applications.

RA 241 Robotic Applications (Advanced): Advanced study and training in high-technology robot operations and applications with emphasis on controlled path robots, programmable logic control systems, and production welding systems and operations. Extended practice in off-line programmable set-up, adjustment, and operation of robot welding and materials handling systems to achieve industrial accuracy and reliability standards.

RA 250 Automated Systems Servicing: Instruction in servicing robotic and peripheral automated systems; emphasis on mechanics, hydraulics and associated electrical/electronics.

RA 260 Problem Solving/Internship: Students are involved in either short-term (2-4 weeks) or longer-term (4-6 weeks) internships in industrial settings and work on actual industry projects. Special problems are brought into the school in conjunction with industrial personnel serving as project team leaders. Experiences provide an opportunity for students to work under actual employment constraints and requirements in preparation for full-time employment.

- **Quality Control Technology (Optional)**

QC 150 Metrology: Introduction and skill development in industrial measurement systems, techniques, instruments and standards including Clean Room procedures; and automatic, pneumatic, and laser gauging and recording instruments. Course will cover basic statistical methods, distribution analysis, process control charts, acceptance sampling, and elements of probability as applied in quality control operations.

Special Training Needed for Application Processes

As previously mentioned, it is essential that local industry be surveyed to determine its needs for technical personnel. One of the key points to note in the survey is the number and type of predominant application(s) in the areas that course graduates will be expected to work. This information should determine the specific focus of the program. In addition to the generic training on robotics, courses should provide a technician with technical knowledge and skills related to robotic applications in the region.

During the application courses, special attention and training should be given to the predominant applications so that during the final semester (but prior to participating in an active work program), the student has gained the applications knowledge needed to function competently and safely in a work setting.

It is important to remember that the key to a rapid and successful robotic application is that the person teaching (implementing) the robot must have a knowledge of the job to be performed. The same holds true for the technician if he/she is to be a beneficial addition to the immediate area's work force. Thus essential aspects of the predominate applications in an area *must* be taught.

Equipment Requirements

It is suggested that at least one of each type of robot be available for lab exercises:

- pneumatic
- hydraulic/electro-hydraulic
- electric

These robots cost approximately $20,000 on up, complete with control and arm. In most cases, additional cost options are readily available.

Of the major robot manufacturers, one company—Cincinnati Milacron—has established a program whereby an electro-hydraulic robot (the T3-500 Series) may be donated to a qualifying institution. Further information can be acquired by contacting the company. (See appendix B.)

In addition, robotic trainers should be utilized to teach robotic concepts. Two of the commercially available robot trainers are the Microbot and the Rhino. These can be purchased in a variety of configurations, ranging in price from approximately $2,400 to $6,000 each.

Another possible trainer is a new robot manufactured in kit form by Heathkit/Zenith Educational Systems Division of Heath Co., Benton Harbor, Michigan. The trainer is called the HERO I and was previewed in the December 1982 issue of *Robotics Today*. (Fully assembled, the HERO I costs $2,495.) In addition, Heath has a two-volume robotics training course available for $99.95. When selecting equipment, look for "general purpose" robots so that they can be adapted to all environments and training needs. In addition, different types of robots should be used in the lab to illustrate the wide range of equipment available.

Two additional ways to acquire robots other than through purchasing new robots or donations from manufacturers, include purchasing used robots, and exchanging services or the use of facilities for the donation of a robot by a professional organization or user.

Such alternative methods are possible for two reasons. First, robots have been in use long enough that some that were implemented three to five years ago are now being replaced with newer robots. It may be possible to purchase these from a user or manufacturer at a major discount.

Second, professional organizations have been known to donate equipment in exchange for the use of school facilities for their organization. The same may hold true for robot users; they have been known to provide equipment to educational institutions in exchange for training services for their personnel.

Staff Technical Capabilities

The most effective training is presented by the most knowledgeable instructors. Unfortunately, there is a shortage of knowledgeable people in robotics technologies. Other than paying exhorbitant salaries to persons from industry, the answer is to "grow your own."

The person responsible for being the "robotics expert" should have a high-technology background and be knowledgeable in electronics (controls, processors, etc.), hydraulics, and mechanics. Several instructors may represent these areas but they should all have current technical skills.

The fastest way to learn robotics, other than from the limited reference books available, is to contact vendors and attend their training courses or have them provide on-site seminars at the institutions.

Also, attending selected technical workshops and seminars can be helpful. Probably the most beneficial information can be gained through workshops where different speakers provide various viewpoints and concepts. In addition, meeting with personnel from other institutions that have courses already established can be very beneficial.

Future Trends

Presently, the technology is at the beginning of a leap forward in applications and manufacturing techniques. The concept of "flexible manufacturing" that is being developed in several industries will marry present technologies and techniques to create the "factory of the future" or "automatic factory." Such factories will incorporate automatic machine tools, transfer systems, robotics, and automated storage and retrieval systems under the control of mainframe computers to maintain increased levels of productivity and flexibility.

In some cases, CAD/CAM systems will be utilized to provide overall control of manufacturing functions. As such factories become a reality, there will be a need for knowledgeable and qualified technicians to maintain and work with the equipment. Presently, there is a shortage of such persons, but educational institutions are striving to catch up to the new technology.

The task facing institutions today is to plan and design courses with a new approach. Programs will need much more flexibility so they can be altered and expanded as the technology changes.

Allowance for more technology options must be planned into a curriculum so that as the technology continues to move forward, the courses can be changed and updated so that the technicians being trained will be prepared for state-of-the-art jobs.

APPENDICES

APPENDIX A

SITES VISITED

Postsecondary Institutions

Dr. Russell Jerd, Dean of Engineering Technology
Professor James J. Houdeshell, Department Chairman, Industrial Packaging and Quality Control Technologies
Professor Nataraj S. Nataraj, Department Chairman, Mechanical Technologies, Electrical Repair and Transfer
Sinclair Community College
Dayton, OH

Professor Ed Konopka, Robotics Technology Program
Oakland Community College, Auburn Hills Campus
Auburn Heights, MI

Professor Jack Thompson, Director, CAD/CAM Programs
Macomb Community College
Warren, MI

National Conference on High Technology
Hocking Technical Institute
Nelsonville, OH

Robot Manufacturers/Users

Mr. Lloyd R. (Dick) Carrico, Applications Engineer
Industrial Robot Division
Cincinnati Milacron
Lebanon, OH

Mr. John B. Franklin, Manager
Advanced Technical Training
Chrysler Institute
Chrysler Corporation
Highland Park, MI

Mr. Dana Holmes, Technical Training Coordinator
GM Assembly Division Plant
General Motors Corporation
Lordstown, OH

CAD/CAM Users

Mr. Michael Baxter, CAD/CAM Application Manager
F. Joseph Lamb Company
Warren, MI

Mr. Bruce W. Dobras, Senior Engineering Associate
Monarch Marking
Pitney Bowes Company
Dayton, OH

Ms. Jane H. Frederick, Manager, Engineering Systems
Mead Digital Systems
Dayton, OH

Mr. Mike Kuntz, CAD/CAM Manager
Harris Corporation
Dayton, OH

Mr. George Mahfouz, Engineering Manager
Davison Corporation
Dayton, OH

Mr. David L. Michaels, Engineering Systems Manager
Monsanto Research Corporation
Miamisburg, OH

APPENDIX B

ROBOT MANUFACTURERS AND POSTSECONDARY PROGRAMS

Robot Manufacturers

Acrobe Positioning Systems, Inc.
3219 Doolittle Drive
Northbrook, IL 60062
(312) 273-4302

Advanced Robotics Corporation
777 Manor Park Drive
Columbus, OH 43228
(614) 870-7778

American Can Company
Automated Handling Systems
1900 Pollitt Drive
Fair Lawn, NJ 07410
(201) 797-8200

The American Robot Corporation
201 Miller Street, Suite 7
Winston-Salem, NC 27103
(919) 748-8761

ASEA, Incorporated
1176 E. Big Beaver Road
Troy, MI 48084
(313) 528-3650

Automation Corporation
23996 Freeway Park Drive
Farmington Hills, MI 48024
(313) 471-0550

Automatrix, Incorporated
217 Middlesex Turnpike
Burlington, MA 01803
(617) 273-4340

Armax Robotics, Incorporated
38700 Grand River Avenue
Farmington Hills, MI 48018
(313) 478-9330

The Bendix Corporation
Bendix Robotics Division
21238 Bridge Street
Southfield, MI 48037

MTS Systems Corporation
Industrial Systems Division
P.O. Box 24012
Minneapolis, MN 55424
(612) 937-4000

Binks Manufacturing Company
9201 West Belmont Avenue
Franklin Park, IL 60131
(312) 992-3900

C. Itoh & Company (America) Inc.
21415 Civic Center Drive
Southfield, MI 48076
(313) 532-6570

Cincinnati Milacron
4701 Marburg Avenue
Cincinnati, OH 45209
(513) 932-4400

Comet Welding Systems
880 Nicholas Blvd.
Elk Grove Village, IL 60007
(312) 956-0126

Control Automation, Inc.
P.O. Box 2304
Princeton, NJ 08540
(609) 799-6026

Copperweld Robotics, Inc.
1401 E. 14 Mile Road
Troy, MI 48084
(313) 585-5972

Cybotech, Inc.
Division of Ransburg Corporation
P.O. Box 88514
Indianapolis, IN 46208
(317) 298-5000

Cyclomatic Industries, Inc.
Robotics Division
7520 Convoy Court
San Diego, CA 92111
(714) 292-7440

DeVilbiss Company
Industrial Robot Operations
837 Airport Blvd.
Ann Arbor, MI 48014

Robomation
573 E. Huron River Drive
Belleville, MI 48111
(313) 699-1930

ESAB North America, Inc.
1941 Heath Parkway
P.O. Box 22861
Fort Collins, CO 80522
(303) 484-1244

Fared Robot Systems
3860 Revere Street, Suite D
P.O. Box 39268
Denver, CO 80239
(303) 371-5868

Gallaher Enterprises, Inc.
2110 Cloverdale
P.O. Box 10244
Winston-Salem, NC 27108
(919) 725-8494

GCA/Par Systems
209 Burlington Road
Bedford, MA 01730
(617) 275-9000

General Electric Company
Automation Systems Division
1285 Boston Avenue
Bridgeport, CT 06602
(203) 382-4571

Graco Robotics, Inc.
12898 Westmore Avenue
Livonia, MI 48150
(313) 261-3270

Hitachi America, Ltd.
Industrial Components Sales and
Service Division
6 Pearl Court
Allendale, NJ 07401
(201) 825-8000

Hobart Brothers Company
600 W. Main
Troy, OH 45373
(513) 339-6011

Hodgers Robotics International Corp.
3710 N. Grand River
Lansing, MI 48906
(517) 323-7427

IBM Corporation
Dept. 9B6/Bldg. 211
P.O. Box 1328
Boca Raton, FL 33431
(305) 994-2979

International Robomation/Intelligence
6353 El Camino Real
Carlsbad, CA 92008
(714) 438-4424

Kohol Systems, Inc.
Robotic Systems Division
2400 E. Dorothy Lane
Dayton, OH 45420
(513) 294-5550

Expert Automation, Inc.
40675 Mound Road
Sterling Heights, MI 48078
(313) 977-0100

Kulicke & Soffa Industries, Inc.
507 Prudential Road
Horsham, PA 19044
(215) 674-2800

LTI Robotic Systems
2701 Toledo, Suite 701
Torrance, CA 90503
(213) 328-0172

Machine Intelligence Corporation
330 Potrero Avenue
Sunnyvale, CA 94086
(408) 737-7960

Manca, Inc.
Link Drive
Rockleigh, NJ 07647
(201) 767-7227

Microbot, Inc.
1259 El Camino Real
Suite 200
Menlo Park, CA 94025
(415) 326-6997

Mobot Corporation
980 Buenos Avenue, Suite A
San Diego, CA 92110
(714) 275-4300

Nordson Corporation
Robotics Division
4937 Mills Industrial Parkway
North Ridgeville, OH 44039
(216) 988-9411

Object Recognition Systems, Inc.
521 Fifth Avenue, Suite 1713
New York, NY 10175
(212) 682-3535

Octek Inc.
7 Corporate Place
South Bedford Street
Burlington, MA 01803
(617) 273-0851

Perceptron Inc.
23920 Freeway Park Drive
Farmington Hills, MI 48024
(313) 333-3271

Pickomatic Systems
37950 Commerce
Sterling Heights, MI 48077
(313) 939-9320

Prab Robots, Inc.
5944 E. Kilgore Road
Kalamazoo, MI 49003
(616) 349-8761

Productivity Systems Inc.
21999 Farmington Road
Farmington, MI 48024
(313) 474-5454

Reis Machines
1426 Davis Road
Elgin, IL 60120
(312) 741-9500

Robogate Systems, Inc.
750 Stephenson Highway, Suite 300
Troy, MI 48084
(313) 583-9900

ROB-CON Ltd.
12001 Globe Road
Livonia, MI 48150
(313) 591-0300

Robot Systems Inc.
110 Technology Parkway
Technology Parkway
Technology Park/Atlanta
Norcross, GA 30092
(404) 448-6700

Sandhu Machine Design
308 S. State Street
Champaign, IL 61820
(217) 352-2999

Schrader Bellows Division
Scovill Manufacturing
U.S. Route 1, North
Wake Forest, NC 27587
(919) 556-4031

Seiko Instruments USA, Inc.
2990 West Lomita
Torrance, CA 90505
(213) 530-8777

Sterling Detroit Company
261 E. Goldengate Avenue
Detroit, MI 48203
(313) 366-3500

Thermwood Corporation
P.O. Box 436
Dale, IN 47523
(812) 937-4476

Tokico America, Inc.
2808 Cregon Court
K-3
Torrance, CA 90505
(213) 328-7484

Towa Corporation of America
1711 S. Pennsylvania Avenue
Morrisville, PA 19067
(215) 295-8103

Unimation, Incorporated
Shelter Rock Lane
Danbury, CT 06810
(203) 744-1800

United States Robots
1000 Conshohocken Road
Conshohocken, PA 19428
(215) 825-8550

United Technologies
Automotive Group
Steelweld Unit
5200 Auto Club Drive
Dearborn, MI 48126
(313) 593-9500

Wear Control Technology, Inc.
189-15 Station Road
Flushing, NY 11358
(212) 762-4040

Westinghouse Electric Corporation
Industry Automation Division
400 Media Drive
Pittsburgh, PA 15205
(412) 856-7741

Yaskawa Electric American, Inc.
Motoman Division
305 Era Drive
Northbrook, IL 60062
(312) 564-0770

Postsecondary Programs

Broward Community College
Engineering Technology
3501 SW Davie Road
Ft. Lauderdale, FL 33314

Robotics Contact Person: Dr. Samuel L. Oppenheimer
(305) 475-6683

Community College of Denver - Red Rocks
Science and Technology
12600 W. 6th Avenue
Golden, CO 80401

Robotics Contact Person: P. E. Perkins/L. E. Deaver
(303) 988-6160 Ext. 388

College of DuPage
22nd Street & Lambert Road
Glen Ellyn, IL 60137

Robotics Contact Person: Dr. James B. McCord
(312) 858-2800

Gulf Coast Community College
Division - Technology
5230 W. Highway 98
Panama City, FL 32461

Robotics Contact Person: William Schilling
(904) 769-1551

Henry Ford Community College
Career and Occupational Studies
5101 Evergreen Road
Dearborn, MI 48128

Robotics Contact Person: Mr. John Nagohosian
(313) 271-0445

Macomb Community College
Mechanical Technology
14500 Twelve Mile Road
Warren, MI 48093

Robotics Contact Person: Laurence Ford
(313) 445-7455

C. S. Mott Community College
1401 East Court Street
Flint, MI 48053

Robotics Contact Person: John Ortiz
(313) 762-0387

Oakland Community College
Applied Technology Department
2900 Featherstone Road
Auburn Heights, MI 48016

Robotics Contact Person: Dr. Bill J. Rose/Edward Konopka
(313) 852-1000

Piedmont Technical College
Electronic Engineering Technology
P.O. Drawer 1467
Greenwood, SC 29648

Robotics Contact Person: Mr. James Rehg
(803) 223-8357

Schoolcraft College
Technology Department
18600 Haggarty Road
Livonia, MI 48152

Robotics Contact Person: Fernon P. Feenstra
(313) 591-6400 Ext. 530

Community and Technical College
University of Toledo
Engineering Technology
Toledo, OH 43606

Robotics Contact Person: Dr. C. Ziegler
(419) 537-3163

Washtenaw Community College
P.O. Box D-1
Ann Arbor, MI 48106

Robotics Contact Person: George Agin
(313) 973-3474

Carl Sandburg College
Galesburg, IL 61401

Robotics Contact Person: Don Crist
(309) 344-2518

Central Ohio Technical College
Engineering Division
University Drive
Newark, OH 43055

Robotics Contact Person: James F. Goodman
(614) 366-9250

DeKalb College
Electronics Dept.
495 Indian Creek Drive
Clarkston, GA 30021

Robotics Contact Person: Kenneth E. Kent
(404) 292-1520

Delta College
Technical Division
University Center, MI 48710

Robotics Contact Person: Don Holzbei
(517) 686-9442

Firelanas College, B.G.S.U.
901 Rye Beach Road
Huron, OH 44839

Robotics Contact Person: John Kovalchuck
(419) 433-5560 Ext. 279

Grand Rapids Junior College
Technology Division
143 Bostwick, N.E.
Grand Rapids, MI 49503

Robotics Contact Person: Don Boyer
(616) 456-4860

Howard Community College
Community Education Division
Little Patuxent Parkway
Columbia, MD 21044

Robotics Contact Person: Anne Hux
(301) 992-4823

Marshalltown Community College
Industrial Technology Dept.
3700 South Center
Marshalltown, IA 50158

Robotics Contact Person: Jeff Dodge
(515) 752-7106

Miami-Dade Community College
North Campus Electronics Dept.
11380 N.W. 27th Avenue
Miami, FL

Robotics Contact Person: Peter Maitland
(305) 685-4243

Moraine Park Technical Institute
Fond du Lac Campus
235 N. National Avenue
Fond du Lac, WI 54935

Robotics Contact Person: James Yu
(414) 922-8611

Moraine Valley Community College
10900 S. 88th Avenue
Palos Hills, IL 60465

Robotics Contact Person: Robert G. Backstrom
(312) 974-4300

Motlow State Community College
Industrial Technology
Tullahoma, TN 37388

Robotics Contact Person: Jasper Templeton
(615) 455-8511

North Dakota State School of Science
Technical Division
Wahpeton, ND 58075

Robotics Contact Person: Bernard Anderson
(701) 671-2278

St. Clair County Community College
323 Erie Street
Port Huron, MI 48060

Robotics Contact Person: Francis J. Mitchell
(313) 984-3881

Terra Technical College
Engineering Department
1220 Cedar Street
Fremont, OH 43420

Robotics Contact Person: Gordon Saan
(419) 334-3886

Triton College
2000 Fifth Avenue
River Grove, IL 60171

Robotics Contact Person: Neal Meredith
(312) 456-0300

Wallace State Community College
Technical College
P.O. Box 250
Hanceville, AL 35077

Robotics Contact Person: Rayburn Williams
(205) 352-6403

Waukesha County Technical Institute
800 Main Street
Pewaukee, WI 53072

Robotics Contact Person: Ron Eigenschink
(414) 548-5202

Vincennes University
Technology Division
Vincennes, IN 47591

Robotics Contact Person: Dean Eavey
(812) 885-4447 or 4448

Yavapai College
1100 E. Sheldon Street
Prescott, AZ 86301

Robotics Contact Person: Larry Strom
(602) 445-7300

SOURCE: Information provided through the courtesy of Robotics International of SME, One SME Drive, P.O. Box 930, Dearborn, Michigan 48128, Phone: 271-1500 Area Code 313, TWX 810-221-1232 SME DRBN

APPENDIX C

ROBOTIC TECHNICAL PAPERS

Technical Papers

MANAGEMENT RESISTANCE TO INDUSTRIAL ROBOTS Neal W. Clapp Block-Petrella-Weisbord	MS80-690
PLANNING AND IMPLEMENTATION OF ROBOT PROJECTS John A. Behuniak General Electric Company	MS80-691
RAM* FOR ROBOTS (*RELIABILITY, AVAILABILITY, MAINTAINABILITY) Brian W. Pollard Unimation, Inc.	MS80-692
ROBOTS ARE EASY . . . IT'S EVERYTHING ELSE THAT'S HARD David T. Cousineau General Electric Company	MS80-693
PROGRAMMABLE ROBOT - ROTARY TABLE SYSTEMS Kenneth J. Whaley & Francis J. Donohoe, Jr. B. J. Associates	MS80-695
UNIMATE APPLICATION AT CUMMINS ENGINE COMPANY William R. Riche & James G. Boerger, Jr. Cummins Engine Company	MS80-697
A THREE ROLL WRIST ROBOT Moshe Frank Cincinnati Milacron, Inc.	MS80-699
EVALUATION OF PERFORMANCE OF MACHINE VISION SYSTEMS C. A. Rosen & G. J. Gleason Machine Intelligence Corp.	MS80-700
ROBOTICS IN THE U.K. - AN OVERVIEW R. A. Cooke Trent Polytechnic	MS80-703
UPSET FORGING WITH INDUSTRIAL ROBOTS John Saladino General Electric Company	MS80-704
LOW TECHNOLOGY ROBOT PRESS LOADING. Thomas O. Blunt General Electric Company	MS80-705

ROBOT UTILIZATION IN AUTOMATIC HANDLING SYSTEMS AND TRANSFER MACHINES — MS80-708
Robert G. Fish
GMC/Hydra-matic Division

ROBOTIC DRILLING AND RIVETING USING COMPUTER VISION — MS80-712
Richard C. Movich
Lockheed-California Company

THE ROBOTIC DERIVETER - SYSTEMS CONCEPT — MS80-713
John M. Vranish
U.S. Navy

Technical Reports

TOUCH-SENSING TECHNOLOGY: A REVIEW — MSR80-03
Leon D. Harmon
Case Western Reserve University

PROCEEDINGS OF NBS/AIR FORCE ICAM WORKSHOP ON ROBOT INTERFACES — MSR80-06
Thomas Wheatley, Roger Nagel, & James Albus
National Bureau of Standards

SAFETY EQUIPMENT FOR INDUSTRIAL ROBOTS — MS80-714
Dr.-Ing. H. Worn
KUKA

A LOOK AT ROBOTICS INTERNATIONAL OF SME — MS80-715
Sandra L. Pfister
Unimation, Inc.

"OSHA'S Tinman" — MS76-160

"Control Strategies for Industrial Robots Systems" — MR76-616

"Designing Robots for Industrial Environments" — MR76-600

"Software Features for Intelligent Industrial Robots" — MR76-618

"The Evolution of a New Industrial Robot Controller - From User Specifications to Commercial Product" — MR76-607

"Computer Control of Robots - A Servo Survey" — MR76-617

"Orientation of Workpieces by Robots Using the Triangle Method" — MR76-612

"A Users Guide to Robot Applications" — MR76-601

"Extending Inspection Capability" — ME76DE016

"Let a Robot Help Inspection"	ME76DE024
"Analysis of First UTD Installation Failures"	MS77-735
"Applications of Industrial Robots With Visual Feedback"	MS77-748
"An Approach to Programmable Computer Vision for Robotics"	MS77-747
"Basics of Robotics"	MS77-734
"Development and Application of an Industrial Robot for Painting Industry"	FC77-629
"The Justification of an Industrial Robot"	FC77-630
"Machine Loading With Robotics"	MS77-739
"Moving Line Applications With a Computer Controlled Robot"	MS77-742
"Robot Applications in Aerospace Batch Manufacturing"	MS77-740
"Robot Decision Making"	MS77-751
"Robotics and CAD/CAM"	MS77-771
"Robots in Japan From an American Perspective"	MS77-754
"Robots—The Answer to Printing in the 1980s"	FC77-628
"Some Special Applications for ASEA Robots—Deburring of Metal Parts in Production"	MS77-736
"What Can Medium Technology Robots Do?"	MS77-737
"Workpiece Transportation by Robots Using Vision"	MS77-746
"Optimization of Metal Removal on Automatic Manipulators"	MS77-215
"The Remote Center Compliance System and Its Application to High Speed Robot Assembly"	AD77-718
"Using Compliance Instead of Sensory Feedback for High Speed Robot Assembly"	AD77-721
"An Advanced Assembly Robot"	MS77-755
"Control Concepts for Industrial Robots in an Automatic Factory"	MS77-745
"Can Robots Beat Inflation"	MS77-756
"Material Handling Advancements in the Manufacturing Process"	MS77-936

"Robotic Painting—The Automotive Potential"	MS77-738
"Applications of Low Cost Robots"	MS78-321
"Accelerating Robotics Technology Implementation in General Electric"	MS78-681
"APAS: Answer for Batch Assembly?"	ME78DE049
"Automated Investment Casting Shelling Process"	MS78-678
"Computer Aided Design and Manufacturing"	ME78JL040
"Grinding of Castings With Industrial Robots"	MS78-679
"Improving NC Productivity With Industrial Robots"	MS78-152
"Industrial Applications for Electrically Driven Robots"	MS78-319
"Industrial Robots in Manufacturing"	MS78-653
"Machine Loading and Unloading With Low-Cost Industrial Robots"	MS78-694
"Machine Loading Robots on a Planetary Pinion Machine Line"	MS78-676
"Machining and Machine Control With Robots"	MS78-692
"Part Transfer With a Medium Technology Report"	MS78-693
"Robot Automation - Today's Status"	MS78-316
"Robot Interface: Switch Closure and Beyond"	MS78-698
"Robot Painting of Microwave Oven Cavities and Other Job Shop Sheet Metal"	MS78-682
"The Robot System of Airesearch Manufacturing Company of California: A Case History"	MS78-691
"Robotic MIG Welding of Tubular Frames"	MS78-688
"Robots Assure Flexibility in the Integrated Automation of Kil's Sink Factory"	MS78-699
"Robots in Assembly"	MS78-684
"Robots in Hot Forging Operations"	MS78-695
"Robots in Paint Finishing"	MS78-317
"Robots—The Binding Link Between CAD/CAM"	MS78-484
"Utilization of a Robot System to Apply Sprayable Ablative Material on Solid Rocket Booster Components for the NASA Space Program"	MS78-680

"Three Laws for Robotocists: An Approach to Overcoming Worker and Management Resistance to Industrial Robots"	MS79-775
"A View of the United Automobile, Aerospace and Agricultural Implement Workers of America (UAW) Stand on Industrial Robots"	MS79-776
"Economic Analysis of Robot Applications"	MS79-777
"Safety, Training and Maintenance: Their Influence on the Success of Your Robot Application"	MS79-778
"Thoughts and Observations on the Application of Industrial Robots to the Production of Hot P/M Forgings"	MS79-779
"Robotics"	MS79-783
"Experiments in Part Acquisition Using Robot Vision"	MS79-784
"Automatic Dimensional Inspection Utilizing Robots"	MS79-785
"Remote Maintenance Development"	MS79-786
"Robots As An Extension to Skilled Labor"	MS79-788
"A Flexible Robot Arc Welding System"	MS79-790
"Welding With Traversing Robots: A New Concept in Line Tracking"	MS79-791
"Robotics Research and Reality in Aerospace"	MS79-792
"Experiences in Applying Robots in Light Industry, and Future Needs"	MS79-793
"An Electric, Continuous Path Portable Robot for Arc Welding"	MS79-794
"Spray Painting With Robots"	MS79-796
"The Remote Axis Admittance - A Key to Robot Assembly"	MS79-798
"Use of Sensory Information for Improved Robot Learning"	MS79-799
"A Robot Task Using Visual Tracking"	MS79-800
"Robot Controlled Mold-Making System"	MS79-780
"Robot Flexibility Allows Transfer to New Job"	MS79-781

Technical Papers are available from the
Society of Manufacturing Engineers
One SME Drive
P.O. Box 930
Dearborn, MI 48128

APPENDIX D

TASK SURVEY RESOURCES

The task inventory survey approach to curriculum development is one of several that can provide accurate and reliable information and data about the tasks and skill requirements of an occupation. The procedures involved in the approach are relatively simple and can be modified to meet local needs. A list of the tasks that are performed in an occupation is developed based on input from a few technical experts, reviews of technical manuals, and observations of workers' performance on the job.

One or more rating scales may be used to collect information about the frequency of task performance, task criticality, task importance, difficulty, training location, or other criteria that are useful in selecting curricular content. The task list with desired response scales is duplicated and distributed to a sample of workers and/or supervisors employed in the target occupation who rate each task. The results are tabulated and analyzed to determine the tasks and related skills and knowledge that are to be included in the training program.

The following task inventory identifies many of the tasks that a robot technician might be required to perform when installing, operating, troubleshooting, repairing or maintaining robots and related equipment. The inventory is provided for use in collecting job performance information.

Industrial Equipment Technician Job Tasks

1. Satisfy the physical requirements of the job.
2. Mathematically plan and analyze work.
3. Render technical assistance to craftsperson.
4. Use properly the available hand and power tools associated with the electromechanical field.
5. Use techniques of soldering, welding, and other skills associated with the field.
6. Operate precision measuring test equipment.
7. Identify common use hardware and equipment.
8. Interpret, analyze, and transmit facts and ideas graphically, orally, and in writing.
9. Prepare appropriate technical reports.
10. Read and interpret electromechanical blueprints, drawings, schematics, graphs, line diagrams, and bulletins.
11. Select, compile, and use technical information from current references.
12. Install electromechanical equipment according to existing codes.
13. Determine the most economical and efficient materials and methods of installation.
14. Test installations using the appropriate equipment and procedures.
15. Design and construct basic electromechanical systems.
16. Perform instrumental tests on mechanical, hydraulic, pneumatic, electrical, or electronic components of industrial robot equipment.
17. Use appropriate tools and equipment to disassemble and repair electromechanical equipment.

18. Replace defective parts or systems.
19. Perform routine preventive maintenance on electromechanical equipment and develop appropriate maintenance program to keep equipment operable and efficient.
20. Recommend changes for improvement of existing systems.
21. Assist in determining materials, supplies, tools, and equipment needs for a job.
22. Assist in ordering job needs and estimating costs using approved practices.
23. Modify existing systems.
24. Assess and recommend modernization.
25. Assess and recommend needs for expansion of facilities.
26. Call in consultants as required.
27. Keep current on new developments in technology.
28. Provide required data for cost accounting systems.
29. Assist in maintaining inventory control.
30. Schedule equipment and materials for efficient use.
31. Establish procedures for the most economical use of employees under his/her control.
32. Keep fully informed of all safety precautions and proper procedures pertaining to his/her work.
33. Plan a safety program for each job.
34. Administer first aid.
35. Demonstrate effective relationships with customers and suppliers.
36. Maintain effective relations with superiors, coworkers, subordinates, inspection personnel, and engineers.

SOURCE. The Instructional Materials Laboratory, The Ohio State University, 1885 Neil Avenue, Columbus, Ohio 43210

APPENDIX E

ROBOTIC TRAINING—A COMPREHENSIVE PLAN

The following discussion of robotics training was prepared by Lloyd R. (Dick) Carrico, of Cincinnati Milacron Company. Mr. Carrico presents an overview of the need for a comprehensive training and implementation plan when robots are to be introduced. In addressing several specific training concerns, Mr. Carrico provides some insights to the type of training services that postsecondary colleges might be asked to provide.

The Problem

Until recently, the concept of educating the work force in a facility receiving industrial robots has been to train the entire work force—in most cases, sixty people or more. Although the intentions were honorable, this concept unfortunately fell far short of the goal of effective training for several reasons.

First, in several cases there were only a minimal number of robots with the majority of the work force not having the opportunity to work with them. Second, a large percentage of trained personnel was assigned to other areas of more importance, resulting in a very limited number of persons being trained to work with industrial robots. Third, it was assumed that the engineering and maintenance staffs could readily relate to the robotics technology as they had done in the past with other forms of automation. This proved to be a fallacy. Fourth, although a few facilities had the experience of working with one or two industrial robots, they found that their training was inadequate for a varied, large number of robots.

For these reasons, the implementation of a robotics application proved to be lengthy, problematical and very costly. A more objective look at what is specifically needed in the area of robotics training is necessary.

The Solution

What has been overlooked in the case of a robotics system—and as a result has caused a costly and lengthy payback time—is the need for adequately trained personnel to implement and maintain the system. Management has become acutely aware of this fact and its possible solutions.

A thorough "before, during and after" approach to training is needed to guarantee a profitable return and a safe on-going investment. When considering this "before, during and after" approach to training needs and requirements, it must be remembered that there are two categories of personnel that need to be trained: engineering and maintenance. With both categories of personnel, it is imperative that management recognizes the need and shows interest in the continuing process of training.

Training Requirements before Implementation

Prior to the implementation of a robotics system, there is a need to indoctrinate and familiarize personnel with a system's capabilities. In addition, this familiarization is to ensure that the system is received with a positive attitude by all personnel in the facility. To effectively carry out this familiarization, a select person or group should be asked by management to work with the vendors of the equipment to gain the required knowledge. They should attempt appropriate training courses at the vendor's location and work with the vendor's personnel in setting up indoctrination seminars. These seminars should first be presented to management personnel to gain their added support and faith in their investment. They should cover the capabilities of the robotics system in relation to its application in the facility, the advantages of the system, and the possibilities of utilizing the system in future applications.

A second series of seminars should be presented to the engineering staffs, since these are the personnel involved in directly implementing the robotics system. They will require both the information given to management and more specific information, such as interfacing characteristics. Also, during this familiarization phase, other personnel in the facility should be indoctrinated—the "operator" and "maintenance" personnel who will be required to work with the robotics system on a daily basis. To eliminate apprehension of accepting this new technology, these personnel will need to know as specifically as possible what the robotics system is, when it will be there, and most importantly, what their role will be in reference to it.

The most important factor before the implementation of a robotics system is "skilled trades training." The rapid impact of robotics technology has shown that the technical knowledge level of the skilled tradesman is in most cases insufficient. For example, the plant electrician may have been working with control transformers, relays, limit switches and weld transformers, but with the implementation of robotics, he is now required to maintain controls, computers, microprocessors and the programmable controllers. In most cases he will not be able to effectively perform this new job.

An immediate solution to this problem is to replace the old work force with those already trained in new technology. This is not totally effective because of a loss in the present level of knowledge relating to applications and processes gained over the years. Also, the availability of personnel knowledgeable in today's technologies is limited. Thus, it is simply not cost-efficient to replace the present work force. Therefore, to efficiently utilize their investment in equipment and manpower for today's technology, management must initiate and support skilled trades training.

This training should be under the direction of "Technical Training Coordinators" and should be designed to elevate personnel to today's technology through various levels of training. The first level is basic skills: basic electricity (both AC and DC), basic electronics, basic hydraulics, basic pneumatics and basic mechanical maintenance. Once this level is achieved, specific courses in oscilloscope operation, and electric/electronic circuits (drives amplifiers, servo systems, etc.) should be considered. The skilled tradesman should then be instructed in basic theory relating to robotics, programmable controllers, and microprocessors. This initial specific training should be for both engineering personnel and the skilled tradesman; engineering personnel should be trained in the aspects of programming (teaching) the robotics system, the skilled tradesmen in their respective areas of maintenance (electrical, electronics, hydraulics, mechanical, and so on).

To facilitate optimum training, the trainees should meet specific prerequisites. For the skilled tradesman, this would be the successful completion of the skilled trades training previously mentioned. The prerequisites for the engineering personnel would be the industrial, production and/or process engineering background needed for application.

Training Requirements during Implementation

Realistically, it is not feasible to train all personnel prior to a robotics system being implemented. Therefore, care should be taken to select key personnel and make certain that they are trained prior to the installation.

To enhance and support the training, these key personnel should be assigned to work with the vendor's representatives to gain firsthand experience. This will enable them to readily relate to the unique characteristics associated with that system.

Also, during implementation, management should ensure that the skilled trades training is continuing along with the training of engineering personnel so as to have a knowledgeable work force available to add to the previously trained force or to replace the previously trained work force as it is depleted through attrition.

To ensure that personnel are knowledgeable in all aspects of the robotics system and its peripherals, "systems" training courses covering the the entire process and the interfacing and synchronization of all equipment need to be conducted. To provide additional expertise in the robotics system, selected personnel should be trained in "Advanced Robotic/Advanced Control" courses. This will provide in-house technical specialists to assist in solving the more complex problems that may arise.

Training Requirements after Implementation

After implementation of a robotics system, it is necessary to recognize the need to continually train personnel. Continued training after implementation is just as important, if not more important, than initial training.

Due to the high reliability of today's equipment, in some cases as high as 98 percent, trained personnel tend to become less efficient as time goes on because they are not using the skills and knowledge gained through prior training. To maintain peak efficiency of the skilled tradesman, learned skills must be exercised and refresher seminars and applications sessions must be conducted.

These seminars should not be designed to repeat previous training, but rather to emphasize the areas involving the specific skills such as preventive maintenance, alignment of axis control systems, functional descriptions of specific components and so on. The application sessions (or hands-on exercises) will assist personnel to maintain skills at peak efficiency. The hands-on sessions can be performed on machines during nonproduction times or on machines purchased for training purposes.

Engineering personnel must also undergo refresher training to prepare for new applications and keep up to date on programming (teaching) techniques and applications.

In both cases, this refresher training can be accomplished through the use of support programs such as sound/slide or video tape, and the availability and effective use of the operating and service documentation associated with the robotic system.

Summary

In conclusion, it should be remembered that training on robotics systems is not just a one-time initial training session. Because of the rapid expansion of the robotics industry, the supply of knowledgeable, qualified personnel is minimal. Therefore, management must ensure that the existing work force is continually educated to meet the demands of the new technologies.

With management's interest and direct support of establishing a thorough and continuing approach to training before, during and after the implementation of their robotics systems, a profitable return on an investment in both equipment and manpower can be guaranteed.

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