DOCUMENT RESUME

ED 240 279 CE 038 086

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TITLE Competencies Identification for Robotics Training.
PUB DATE 5 Dec 83
NOTE 25p.; Paper presented at the American Vocational Association Convention (Anaheim, CA, December 5, 1983). Broken print may affect legibility.
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Automation; *Job Analysis; *Job Skills; *Manufacturing; Manufacturing Industry; Occupational Information; Paraprofessional Personnel; *Robotics; *Technical Education; Trade and Industrial Education; Vocational Education

ABSTRACT

A study focused on the task of identifying competencies for robotics training. The level of robotics training was limited to that of robot technicians. Study objectives were to obtain a list of occupational competencies; to rank their order of importance; and to compare opinions from robot manufacturers, robot users, and robotics educators concerning the degree of importance of the competencies identified. Responses to mailed questionnaires identified 94 competencies, 11 of which were deleted because respondents considered them less important. The remaining 83 competencies were categorized into basic skills and five job functions: operation, application, programming, installation, and maintenance for robot technicians. A coefficient of agreement statistics was used as the evaluation criterion for determining the degree of importance of competencies identified. The results indicated a very high and significant degree of agreement (A=0.93) among manufacturers, users, and educators on the importance of all competencies. Maintenance was perceived as by far the most important job function, followed by operation. Programming and installation were tied for third place. Application was least important. (Sixteen pages of exhibits, including data tables, are appended.) (YLB)

COMPETENCIES IDENTIFICATION FOR ROBOTICS TRAINING

Paper Presented at

The 1983 AVA Annual Convention

Anaheim, California

December 5, 1983

By

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This presentation is based on a research study funded by Ball State University in the Summer of 1983. The presentation is divided into four sections - Background, Problem, Methods, and Findings. They are presented in orders.

BACKGROUND

It is helpful, in the beginning, to say several words about the motivations and background of this study. Literature suggests that technological change is the most important factor for changes in occupational structure (Rothwell and Zegveld, 1979). This observation has recently been examined emperically in the context of manufacturing sector. Results indicate that certain technological change in manufacturing processes will call for new skill requirements and consequently, will result in new occupations (Tang, 1981). This is consistent with the result of a recent Delphi study in which such new occupations as robot technicians and programmers replacing old machine operators due to automation is suggested (Smith and Wilson, 1982).

This change has profound effects on the labor market in two dimensions. Quantitatively speaking, three out of eight million machine workers may theoretically be replaced by sensor-based robots by the end of this century (Ayres and Miller, 1982). More recently, Hunt and Hunt (1983) in the Upjohn Institute suggest that by 1990, there will be 32000 to 64000 jobs created related to robotics. Out of these created jobs, approximately 12000 to 25000 robotics technicians and 4600 to 9300 robotics engineers are suggested. These employment projections are shown in Exhibit 1.

Qualitatively speaking, the skill requirements for workers to man the machines are greatly different from the traditional ones. As robots become more sophisticated, the necessity of integrating them into autorated production system alters the job contents for workers. Their jobs may change from traditional operative to monitoring or programming type of work. However, the exact nature of the changes is still unknown at this point. This certainly has serious implications to educational and training community which prepares graduates for the future work force.

Despite the awareness of new skill requirements in robotics is shared by industries and educational institutions, and despite courses in robotics are offered at both engineer and technician level, little has been done to design training programs in robotics based on competency-based approach.

Though the concept of Competency-Based Education (CBE) is hardly new, it is still the forefront in education. It is very popular and also proven effective for vocational and technical education curriculum development due mainly to its close reflection to essential job performance required for an occupation (Blank, 1980; Boulmetis, 1981). Here job performance refers to an individual's ability to perform given tasks under specified conditions at proficiency level acceptable to certain criteria. A marriage between CBE and robotics training will likely result in better learning outcomes for students. Here I like to say some words about the CBE development processes.

Developing CBE curriculum in general consists of three phases - research, development and testing, and implementation

and testing. They are i[illegible]ted in Exhibit 2. The research phase starts from needs as[illegible]ent, competency identification and verification, objectives dev[illegible]ment and sequencing, to competency assessment. The develop[illegible]t and testing phase consists of instructional modules design, entry level pre/post tests development, instructional stragety and media development, field testing, and revision of modules. The implementation and evaluation phase consists of learner assessment, instruction implementation, learner evaluation, and instructional materials revision. The results of the last phase are then fed back to competency identification and verification to complete a continuous cycle.

Under the CBE framework, the most critical step in the process is competency identification and verification. The outcomes of this step dictate the content validity of the curriculum to be developed.

The major focus of the study is exactly to accomplish the task of identifying competencies for robotics training. Here the level of robotics training is limited to that of robot technicians. Before getting into the objectives of the study, the terms of industrial robots and robot technicians should first be defined. They are shown in Exhibit 3 and 4 respectively. The definition for industrial robot, given by the Robotics Institute of America (RIA), is to exclude those pick-and-place devices being considered robots. The definition for robot technicians is broad enough to include most job functions currently undertaken entirely or partially by individuals with such a job title.

PROBLEM

The objectives of the study were twofold. The first one was to obtain a list of occupational competencies for robot technicians and their rank order of importance. The second one was to compare opinions from robot manufacturers, robot users, and robotics educators concerning the degree of importance of the competencies identified.

It was hoped that, upon the completion of this study, an inventory of competencies for robot technicians in different job functions would be in place. This would lay the foundation for design and implementation of a CBE program in robotics training.

METHODS

Prian (1981) indicated that no single best method is available for competency identification. Practicality dictates the selection. For robot technicians, a large number of mental activities are imbedded in the occupation which makes observation virtually impossible as the means to obtain competency information. Interview and jury of experts requires large resources commitment which was prohibited at the outset of the study. At last, questionnaire approach was adopted because it was the most cost-effective way to approach the problem.

Three sampling frames ,with respect to robot manufacturers, robot users, and robotics educators, were obtained from either available data or private sources. No probability sampling was made due mainly to small number of sampling units in each frame.

The rates of usable responses for robot manufacturers, robot users, and robotics educators were 52%, 54%, and 33% respectively

after two mailings. They are summarized in Exhibit 6. Owing to low usable rates, a non-respondents analysis was done to compare response patterns between respondents and non-respondents. The findings will be discussed in the next section.

FINDINGS

The major objective of this study was to obtain a list of rank-ordered competencies for robot technicians based upon the inputs from robot manufacturers, robot users, and robotics educators. There were 94 competencies identified in the original list. Eleven of them were deleted because they were considered less important by respondents. The remaining 83 competencies were categorized into basic skills and five job functions : operation, application, programming, installation, and maintenance for robot technicians. The rank orders of importance of them are shown in Exhibit 7.

The second objective of this study was to compare opinions from robot manufacturers, robot users, and robotics educators concerning the degree of importance of competencies identified. A coefficient of agreement statistics suggested by Lu (1971) was used as the evalution criterion. The results indicated that a very high and significant degree of agreement ($A = 0.93$) existed among manufacturers, users, and educators on the importance of all competencies for robot technicians. This is shown in Exhibit 8. If further inquiry on the agreements among the three groups with respect to six competency categories was made, the coefficients of agreement, in each case, were also high and significantly different from zero as shown in Exhibit 9. However, the

within group agreement statistics weren't as good as those of between groups. Robot manufacturers themselves had higher coefficient of agreement than those of robot users and educators This could be explained by the fact that robot manuafcturers are usually more homogenenous in their background on requirements for robot technicians than those of users and educators. The data are shown in Exhibit 10.

In addition to the objectives described above, the order of importance of job functions for robot technicians was also investigated. Robot technician was defined in the study as an occupation with job functions of operating, applying, programming, installing, and maintaining industrial robots in manufacturing settings. As indicated in Exhibit 11, maintenance was perceived by far the most important job function for robot technicians. Following in order was operation. Programming and installation were tied in the third place with application being the least important one.

It was suggested, during the course of the study, by a couple of respondents that application of industrial robots in the field has generally been done by engineers instead of by technicians. This comment coincided with the data. Though the author contended that some of the application competencies are basic to the knowledge of robot technicians, it seemed, from the responses, that the job function of application of industrial robots could be considered least important, if not excluded, from the work spectrum for robot technicians. More studies will be needed to settle this point.

PFFERENCFS

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EXHIBIT 1. EMPLOYMENT PROJECTIONS FOR ROBOT RELATED OCCUPATIONS

OCCUPATION	JOBS CREATED BY 1990
Robot Engineers	4600 - 9300
Robot Technicians	12000 - 25000
Others	15400 - 29700
Total	32000 - 64000

EXHIBIT 2. Systematic Processes for CBE Curriculum Development

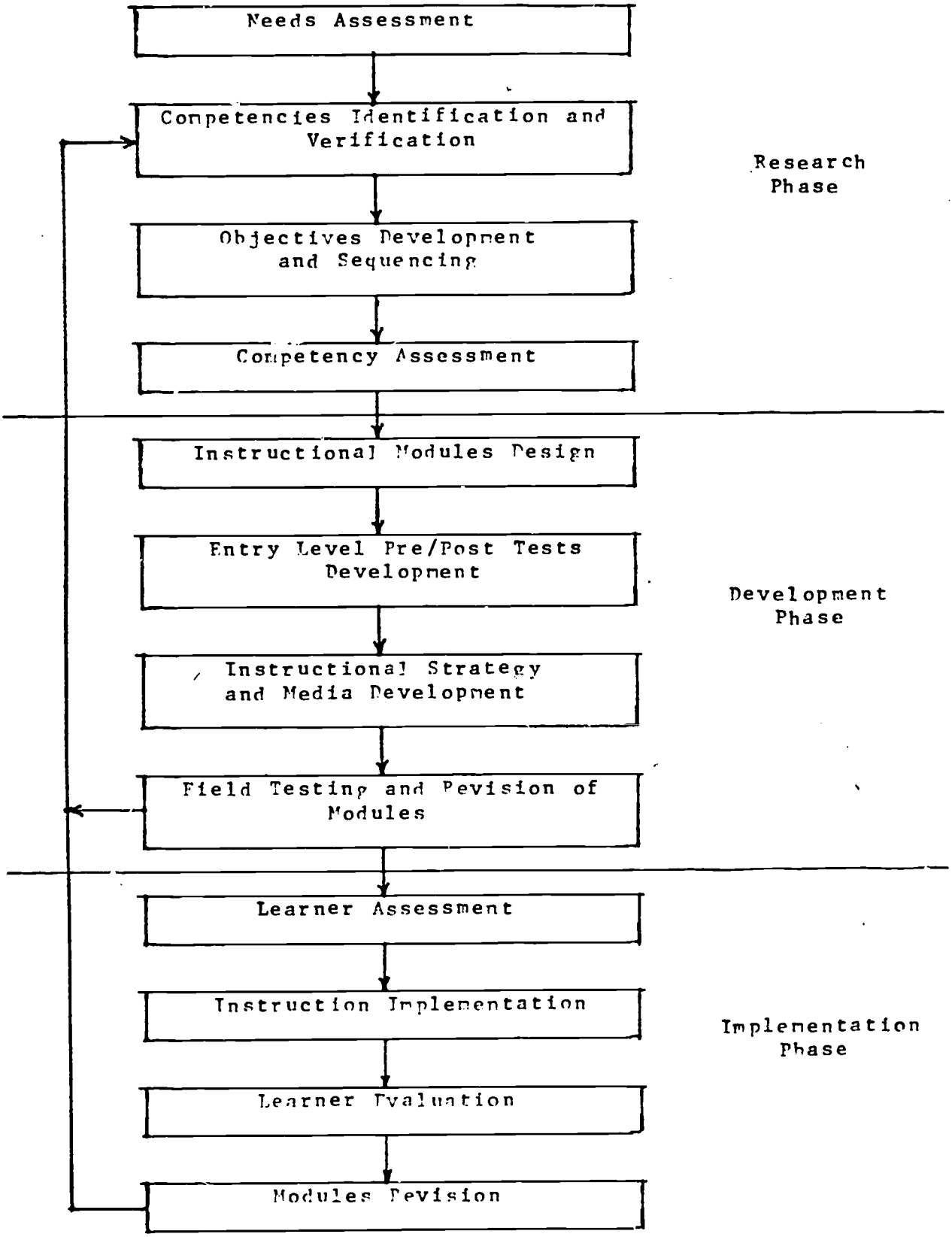

EXHIBIT 3. DEFINITION OF INDUSTRIAL ROBOT

An industrial robot is a reprogrammable multi-functional manipulator designed to move material, parts, or specialized devices, through variable programmed motions to accomplish a variety of tasks.

EXHIBIT 4. DEFINITION OF ROBOT TECHNICIAN

An occupational title for those who are performing their job functions in operation, application, programming, installation and maintenance of industrial robots in manufacturing settings.

EXHIBIT 5. OBJECTIVES OF THE STUDY

(1) Obtain a list of occupational competencies for robot technicians and their rank order of importance

(2) Compare opinions from robot manufacturers, robot users, and robotics educators concerning the degree of importance of the competencies identified

EXHIBIT 6. RESPONSE RATES FOR THE STUDY

	ROBOT MANUFACTURERS		ROBOT USERS		ROBOTICS EDUCATORS	
	#	%	#	%	#	%
FIRST MAILING	9	39%	34	37%	23	30%
SECOND MAILING	13	57%	53	58%	33	43%
USABLE RESPONSES	12	52%	50	54%	25	33%

EXHIBIT 7. OVERALL RANKINGS ON BASIC SKILLS COMPETENCIES

BASIC SKILLS COMPETENCIES	RANK
Maintain good interpersonal relations	1
Demonstrate effective oral communications & presentations	2
Demonstrate effective locations of needed information from a manufacturer-supplied manual	3
Demonstrate good technical reports writing skills	4
Perform basic algebraic operations	5
Perform conversions of measurement units	5
Demonstrate mechanical drawings or industrial drafting fundamentals	7
Perform basic trigonometric operations	7

EXHIBIT 7. OVERALL RANKING ON OPERATION COMPETENCIES

OPERATION COMPETENCIES	RANK
Demonstrate understanding of electrical fundamentals	1
Demonstrate understandings of electronics fundamentals	1
Identify hydraulic, pneumatic, and electric actuators in robots and describe how each one works	3
Demonstrate understanding of hydraulic and electric servo systems used in robot	3
Demonstrate understanding of mechanics fundamentals	5
Demonstrate understanding of microcomputer fundamentals	6
Demonstrate understanding of relay control, solid state control, sequence control, counter and timer control	6
Demonstrate understanding of pneumatics fundamentals	8
Identify transducers, detectors, contact & non-contact sensors used in robot system	8
Demonstrate understanding of hydraulics fundamentals	10
Demonstrate understanding of mechanical structure of a robot	10
Demonstrate understanding of linkage & drive train of a robot	12
Demonstrate understanding of printed circuit board	13
Classify robots based on their control	14
Perform a robot task analysis	14
Demonstrate understanding of kinematics of a robot	16

Configure a programmable controller for robot control	16
Match off-the-shelf end effectors to the requirements of various manufacturing operations	16
Describe machine vision system	16
Classify robots based on their manipulator's coordinates	20
Classify robots based on their path motions	20

EXHIBIT 7. OVERALL RANKING ON APPLICATION COMPETENCIES

APPLICATION COMPETENCIES	RANK
Select appropriate end effectors for certain manufacturing operations	1
Conduct a feasibility study of applying robot for a manufacturing operation	2
Evaluate strong and weak points of current commercially available robots for a manufacturing process	2
Analyze robot task requirements of a manufacturing operation	2
Analyze robot sensing requirements for certain manufacturing operations & select appropriate sensors	2
Describe potential applications of current commercially available robots	6
Explain such manuafcturing processes as arc welding, resistance welding, grinding & finishing, painting & coating, material handling, assembly, and machine tool operation	7
Explain flexible automation processes	7
Promote a robot application project within a manufacturing setting	9

EXHIBIT 7. OVERALL RANKING OF PROGRAMMING COMPETENCIES

PROGRAMMING COMPETENCIES	RANK
Perform on-line teach programming, repeat checking, and modifying of robot motions	1
Perform programs documentation based on uniform definitions & styles adopted by the company	2
Program ladder diagrams for various industrial control applications	3
Write & debug computer programs in at least one of the following high level languages : BASIC, FORTRAN, PASCAL	4
Distinguish the levels of robot programming languages for current commercially available robots	5
Describe hardward & software support requirements for major commercial robot languages	5
Perform step drum programming for simple robots	7

EXHIBIT 7. OVERALL RATING ON INSTALLATION COMPETENCIES

INSTALLATION COMPETENCIES	RANK
Try out and debug a robot system	1
Perform start-up and shut down procedure for a robot system	2
Ascertain errors in layout, design, and logic wiring contained in the blueprint and report to the supervisor	3
Specify safety considerations for personnel, work area, operation, and maintenance	4
Perform incoming inspection on industrial robots bought from vendors	5
Test wiring of each sub-assembly of a robot system and the robot system as a whole	5
Plan robot installation procedures and methods to assure efficient and timely progress	7
Select location, specify mounting requirements, and organize a service area for robot to be installed	7
Plan, layout, wire, and assemble complex electrical and electronic systems in accordance with engineering specification and schematics	7
Install programmable controller and its input/output devices	7

EXHIBIT 7. OVERALL RANKING ON MAINTENANCE COMPETENCIES

MAINTENANCE COMPETENCIES	RANK
Follow troubleshooting procedures recommended by manufacturer to diagnose, isolate, and repair components of a robot system	1
Identify major components of a robot based on prints	2
Analyze operating difficulties of installed robots and perform necessary adjustments or recommend purchase of repair parts	2
Operate electrical, electronic, hydraulic, and pneumatic test equipment	2
Perform field testing of a robot and check to assure that performance is in accordance with specifications	2
Perform electrical adjustments on servo power amplifier board	2
Perform zeroing of encoders on a robot	2
Troubleshoot robot controller at the board level (board nulfunction)	2
Perform removal or replacement of hydraulic components on a robot	2
Perform mechanical adjustments on chain tension, alignment of minor axis, and backlash	10
Perform servo valve nulling operation on a robot	10
Perform removal or replacement of pneumatic components on a robot	10
Troubleshoot an electronic power supply	10
Keep maintenance records & parts inventories, and order parts	14
Adjust pneumatic valves & test them to the specifications	14

Troubleshoot fault operations in programmable controller	14
Schedule preventive maintenance on a robot system	17
Select proper lubrication for various mechanical parts (gear box, oilite bearings, plastic bearings, etc.) under different pressure and temperature conditions	17
Perform removal or replacement of electrical components on a robot	17
Troubleshoot a hydraulic power supply	17
Perform routine check on hydraulic system of a robot	21
Identify and work with different fastening devices, such as screws & nuts, pins & keys, rings, etc.	21
Adjust hydraulic valves & test them to the specifications	21
Perform routine hand drive train maintenance	24
Perform electronic components testing to determine the acceptance of the components	24
Demonstrate correct & effective procedures to use various hand & power tools	26
Schedule services based on best advantage in priority needs and in traveling costs	26
Estimate service costs for customers	28

EXHIBIT 8

AGREEMENT STATISTICS BETWEEN MANUFACTURERS, USERS, AND EDUCATORS ON OVERALL COMPETENCIES FOR ROBOT TECHNICIANS

	A	θ	df	θxdf
Overall Competencies	0.93	0.07	15	1.05 *

* Significant at 0.05 level

EXHIBIT 9

AGREEMENT STATISTICS BETWEEN MANUFACTURERS, USERS, AND EDUCATORS WITH RESPECT TO SIX COMPETENCY CATEGORIES

CATEGORY	A	θ	df	θxdf
Basic Skills	0.69	0.31	21	6.51 *
Operation	0.73	0.27	60	16.20 *
Application	0.83	0.17	36	6.12 *
Programming	0.90	0.10	18	1.80 *
Installation	0.83	0.17	42	7.14 *
Maintenance	0.88	0.12	87	10.44 *

* Significant at 0.05 level

EXHIBIT 10

AGREEMENT STATISTICS WITHIN MANUFACTURERS, USERS, AND EDUCATORS ON OVERALL COMPETENCIES FOR ROBOT TECHNICIANS

GROUP	A	θ	DF	θxdf
Manufacturers	0.54	0.46	59	27.14 *
Users	0.48	0.52	247	128.44 *
Educators	0.44	0.56	117	65.52 *

* Significant at 0.05 level

EXHIBIT 11

RANKING OF JOB FUNCTIONS FOR
ROBOT TECHNICIANS

JOB FUNCTION	RANKING			
	MFTRS	USER	EDUCATORS	OVERALL
Maintenance	1	1	1	1
Operation	3	2	2	2
Programming	3	3	3	3
Installation	2	5	3	3
Application	5	4	5	5