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ABSTRACT

This 18-month pilot project, which ran from October 1, 1987 to March 31, 1989, developed a prototype robotic arm for educational use by students with severe orthopedic disabilities in the Columbus (Ohio) Public Schools. The developmental effort was intended first, to provide direct access to currently available instructional materials and, second, to provide a new type of learning activity to foster these students' cognitive, affective, and psychomotor development. During the course of the project, seven children with severe orthopedic disabilities learned how to use a robotic arm to pick up, place, examine, and otherwise manipulate regular educational and household items in instructional activities. The project also produced a training methodology for educational robotic environments and investigated psychological and logistical impacts of a robotically aided educational environment. It identified issues involving accessibility, software design, and curriculum integration. Appendices include samples of data collection instruments and the following articles: "Software-based Access and Control of Robotic Manipulators for Severely Physically Disabled Students" (Richard D. Howell and Kenneth E. Hay); "Robot Technology: Implications for Education" (Paul E. Post, et al.); "Designing an Educational Computer Game: Guidelines That Work" (Audree Reynolds and Jeanette V. Martin); and "Design Issues in the Use of Robots as Cognitive Enhancement Aids for Disabled Individuals" (Richard D. Howell et al.). (DB)

THE OHIO STATE UNIVERSITY

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PART I: PROJECT IDENTIFICATION

Date of Report: 11/29/89

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Period of Report: October 1, 1987 - March 31, 1989

Grantee Name and Title of Project: Richard Howell, Ph.D., " A Prototype Robotic Arm for use by Severely Orthopedically Handicapped Students".

Certification: I certify that to the best of my knowledge and belief this report (consisting of this and subsequent pages and attachments) is correct and complete in all respects, except as may be specifically noted herein.

Richard D. Howell, Ph.D.	Richard Howell
Principal Investigator	Principal Investigator

ABSTRACT

This pilot project sought to develop and implement a prototype robotic arm for educational use by severely orthopedically handicapped students in the Columbus Public Schools. The purpose of the developmental effort was twofold: first, to provide direct access to instructional materials already available in the schools; and secondly, to provide a new type of learning activity that benefits the orthopedically handicapped learner in terms of their cognitive, affective and psychomotor development. The anticipated overall outcome of the use of this device and accompanying curricular materials is to increase the personal independence of the users within a normal classroom environment.

During the course of the design and development of a prototype robotic system for educational use, several issues have surfaced that constitute serious considerations in the process. Of particular importance are issues involving accessibility, software design, and curriculum integration. Performance information from previous investigations has shown that learning to use robots can be easily accomplished and that the consequent learning is remarkably resistant to decay over time. This project is ongoing at the present time and has resulted in the funding of three external proposals that will allow it to continue, albeit in a reduced capacity, through March, 1989. The project team has made substantive progress toward solving larger hardware issues and has engaged in pioneering efforts in the development of new controller software for using assistive devices. Finally, much progress has been made toward the development of a set of instructional activities that facilitate the use of robots by physically disabled students.

Introduction

This report summarizes the research and development project undertaken by The Ohio State University under the auspices of an18-month grant from the Office of Special Education, U.S. Department of Education. An integrated team undertook this project to investigate the overall feasibility, educational impact, and marketability of a robotic technology for use by severely orthopedically handicapped students in an educational setting. A major focus of the research funded by the grant addressed the challenge of providing instructional experiences for members of the physically handicapped population so that the gap between the experiences of handicapped students with instructional materials, and the experiences of normal school children with similar materials could be narrowed. The robotic arm, controlled by the handicapped student, allows them to gain access and benefit from instructional materials that regular school children use daily without inhibition.

The Educational Robotics Laboratory of The Ohio State University established a robotically-aided educational environment in 1988 at Colerain Elementary School, Columbus Public Schoools in Columbus, Ohio. Colerain Elementary School is one of the few schools in Ohio specifically designed and constructed students who are orthopedically handicapped. The school serves both non-handicapped students from the neighborhood and handicapped students from throughout the Franklin County area in grades kindergarten through third grade.

Over the eighteen months of the project, seven severely orthopedically handicapped children learned how to use a robotic arm to pick up, place, examine and otherwise manipulate regular educational and household items in instructional activities. Previous to this experience, these children had had little, if any, purposeful manipulation of objects -- a daily activity that most school children take for granted.

Research designed and directed by the project team focused on: 1) training methodology, 2) the impact on the cognitive, psychomotor and affective development of the participating students, and 3) factors that would influence successful implementation and use. Methods of data collection included field observations, interviews of staff, and repeated measures of visual/spatial skills, motor control, and cognitive mapping.

During the first nine months of the project, a Prototype I System consisting of a Rhino XR-2 Robot interfaced with an Apple IIe computer system and a Prentke-Romich 5-Slot Switch device was used. Because of increased capacity, mechanical dependability, and decreasing hardware costs, the Rhino was replaced by a Prototype II system consisting of a UMI/RTX robotic arm and an IBM-PC AT computer system. The Prototype I system was developed on the premise that it was the least expensive robotic system available that seemed feasibly applicable in a classroom setting. Capability, and especially dependability, increased significantly with the implementation of the RTX robotic system.

Over the course of the 18 month project, the participating children learned to use the robot and then used the robot to learn. The project also produced a training methodology to serve as a recommended course of action for educational robotic environments replicated in other settings. Finally, systematic investigation of the psychological and logistical impact of a robotically-aided educational environment yielded insight into the factors that determine acceptance and use of new technology.

PROJECT OVERVIEW

Phase I: Design and Development of the Prototype

The activities of this phase focused upon the design, development, and initial laboratory testing of the prototype robotic arm. As mentioned earlier, two distinct prototypes were developed in this phase, with initial field testing invalidating the first prototype, and the second prototype being advanced for more substantive applications in the science education context.

Phase II: Prototype Field Test and Evaluation

This phase incorporated the majority of activities for the second half of the project period and included a number of interrelated activities:

1. Conduct research on the cognitive, affective, and psychomotor impact of a robotically-aided educational environment.

2. Determine which instructional materials and tools are amenable for use by severely orthopedically handicapped students employing the robotic arm.

3. Investigate the factors that affect the feasibility and implementationa of robotic technology in an educational setting.

4. Analyze and synthesize information resulting from evaluations of educational and engineering aspects of the robotic arm.

The information collected as a result of these activities provided the basis for a number of research articles, international and national presentations, and further research question formulation which continues to this time. The research methods, results, and recommmendations from the Phase II effort are detailed in the Section titled, "Research Methodology."

Phase III: Marketing and Distribution Plan

The information developed in this final phase of the project consisted of a proposed plan for a marketing and distribution plan for the robotic device if it were amenable to mass production. The plan developed predicted that at least two more years of field-based research and development activities were necessary in order to gain the reliability and confidence necessary to bring the robot and materials to market.

Research Methodology

Research generated during this project has focused on those factors that inhibit or enhance utilization of robotic technology in classrooms for the severely orthopedically handicapped. Specific research emphases included the training methodology, implementation factors, and psychological impact of a robotically-aided learning environments.

The Educational Robotics Laboratory offered a window of opportunity for research into a unique situation: the implementation of robotic technology in an educational serting. It was the opinion of the Research Team that the initiation of a new research agenda such as a robotically-aided educational environment called for multiple perspective taking in the development of the agenda. Research methodology consequently incorporated a mixture of quasi-experimental and observational research approaches. The combines use of quantitative research methods (emerging from an experimental perspective) and qualitative research methods (emerging from a naturalistic perspective) promised to provide a rich picture of this unique environment. The complementarity of methods enabled the collection and analysis of integrated and triangulated data. In this manner, the combinations of methodology allowed each method to reveal its own uniques perspective of the robotic activities and impact.

From a phenomenological perspective utilizing naturalistic inquiry methods, the primary research goal was to describe and interpret the interactions of the student, robot, trainer, and materials in the educational robotics environment. The method for examining the phenomena in the robotic classroom was field observation. Before entering the field, the preliminary research question was, "What is the nature of the interactions between the student, robot, trainer, and materials when engaged in a series of educational and recreational activites?".

An experimental perspective was taken, however, to investigate specific questions related to the cognitive, affective, and educational effects associated with severely orthopedically handicapped children using robots in educational and recreational tasks. The research question originally posed was "What are the specific relationships between using the robotic arm and the cognitive and psychomotor skill development of severely orthopedically disabled students?"

First Year Research - Prototype One

The first year of research took place from February 1988 until May 1988. The Prototype 1 system (the Rhino Robot) was used during these initial field trials. The purpose of this first round of research was exploratory in nature. The first iteration of research gave the research team an opportunity to look at applicability and suitability of different research instruments, techniques, and research questions. The outcome of the 1988 winter and spring effort was intended to provide grounding for more definitive question formulation and improved methodological strategies for the second year of inquiry that would begin in the Fall of 1988.

The amount of time that the students had with the robot was impressive for a prototype system. Thirty days of training and instruction were delivered over a sixteen week period (spanning from February 8, 1988 through May 25, 1988). In that time ;the students collectively had approximately 75 hours of robot-based training and instruction. At thirty minutes per session, a maximum of fifteen hours of contact with the robot was offered to each student.

The research efforts of Year One resulted in a more refined approach for the research to be conducted in the fall. The recommendations for follow-on research included:

1. The Space Visualization Test was to be used again since it appeared to be appropriate and applicable.

2. A comparison group of 3-4 students was to be used to control for maturation and experience. This procedure was approved by the principal of Colerain Elementary.

3. The action coding, while informational, overwhelmed the research team with coding responsibilities and data. A dribble file for tracking key strokes was to incorporated into the control software. If personnel are available for data analysis, then analysis of the contents of the file could be conducted.

4. The videotaping was also overwhelming the team with data. Videotaping was consequently planned for intermittent sessions. The video could be used for data verification (via triangulation) and for dissemination of research activity.

5. Field observations had to be conducted by a single observer. Every effort was to be made in order to obtain a graduate student who could do the observations as part of an independent study.

Second Year Research- Prototype Two

In the second year of research, the focus of the investigation continued to be on those factors that inhibit or enhance utilization of robotic technology in classrooms for the severely orthopedically handicapped child. Specific research emphases were training methodology, implementation factors, and psychological impact.

The instruments and techniques for collecting and analyzing data were modified to reflect the experience gained from the previous research activities. Data gathering was refined to include:

1. Space Visualization Test from the Southern California Sensory Integration Tests

2. Motor Control/Cognitive Mapping Test

3. Single Input Control Assessment from the High MacMillan Medical Center and distributed by the Easter Seal Communication Institute

Field Observations

The Ohio State University team planned to continue the research beyond the OSE grant period, so research was conducted through March 1989, but planned to continue through May 1989. Research for Year Two is therefore research in-progress, and data reported in this report reflects the research effort through the project deadline of March 1989.

Three students participated in the Robotics Laboratory the second year: Amos (his second year), Trent, and Sara (student names have been changed). The observer's rich descriptions of the children provide a picture of their personalities. Amos has cerebral palsy (CP), which primarily affects motor responses. Amos has too much muscle tone, therefore, his muscles contract. During Spring 1989 he underwent surgery to partially correct this condition. The owner of a bright yellow wheelchair with multi-colored spokes, Amos is a "veteran" of the robot project. " 'Yea!' he says when he gets in front of the robot desk."

Fair headed and enthusiastic, Trent was essentially non-verbal. Trent's main communication problem was his impulsivity. He was all too eager to nod his head in agreement regardless of the question or the task. Sara, eight years old, is CP-mixed. She has continuous movement and has fluctuating muscle tone. She is a very pleasant child; she likes being around people. Any succcess over making the robot complete a task would invariably bring on a wide grin.

Three other children were used as points of comparison for the repeated measures tests of the second year. These children were Madge, Andrea, and Mark.

Repeated Measures

The Space Visualization Test was again used to help identify change in the ability to do mental rotations as a result of plannin and carrying out movements of the robotic arm. The participating students had been pre-teseted as evedenced by Figure 1, but the reults of the pre-tests of the comparison group have not yet been reported by the OT who conducted the testing.

	Accuracy		Time	Accuracy Adjusted for Time
Amos	T1	16	63	12
Trent	T1	8	14	8
Sara	T1	14	90	8

Figure 1. Space Visualization Test - Year Two

Amos was in the program during the first year, and his space visualization score on this pre-test was lower than his space visualization score on the post test in 1988. His post test score in May 1989 will give more indication of retention or decay of mental rotation ability. The trainers have remarked about Trent's impulsiveness, and his low time and low score indicate a speed accuracy trade-off. The post test should reflect the lessening of his impulsiveness that has been evident in recent weeks. Sara's score will provide more information when coupled with the post test scores. Needless to say, the pre and post tests of the comparison group will be critical for proper interpretation of the students' space visualization performance.

Two issues dealing with the transparency of the technology (the extent to which the technology is not apparent to the user during use, i.e. the telephone): ease of using the 5-Slot Switch and cognitive mapping of the computer menu that students refer to when controlling the robot. It is hoped that pressing switches on the 5-Slot Switch would become easier over time. It is also assumed that the menu (see Figure 2) would become mapped in the user's mind so that reference to the menu and choice of corresponding switches would reach a point of automaticity.

The menu provides selection options for the student in controlling the robot. There are options for selecting individual motors of the arm (there are six degrees of movement), pre-programmed positions, axes, increments and decrements of movements, and proceeding with selections (GO). Each column of the menu corresponds to a switch on the 5-Slot Switch.

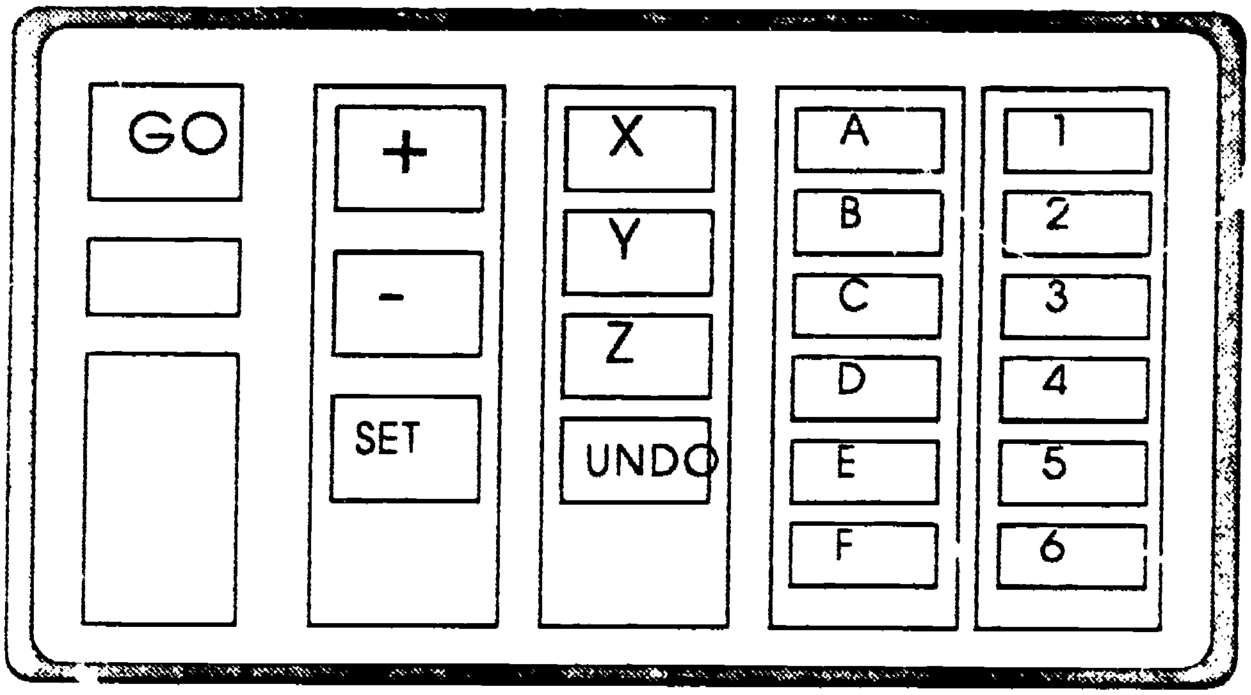


Figure 2. Software Robot Control Menu

The motor control/cognitive mapping test was constructed to address issues concerning ease-of-use and automaticity of screen display features. The test, administered approximately every six weeks, has three treatments: 1) monitor directly in front of 5-Slot Switch: stimulus is presented from the menu on the monitor, 2) monitor to the left of the 5-Slot Switch; stimulus is again presented from the monitor, and 3) monitor to the left of the 5-Slot Switch but the stimulus is an actual menu item that is presented on the right using randomly chosen cards. Each treatment requires progressively more difficult spatial processing but maintains the same motor effort. (See Figure 3).

Two measures are taken in all three treatments: 1) accuracy in pressing a switch on the 5-Slot Switch that corresponds to a menu item on the computer monitor, and 2) time between the appearance of the stimulus and the press of the switch. Treatment Three will eventually reflect the development of cognitive mapping of the menu. The student looks to the card for the stimulus (right), looks to the computer monitor (left) for the menu column that the stimulus is in, and then presses the switch (front) that corresponds to the column of the stimulus. This arrangement simulates the robot, monitor, and 5-Slot Switch working space. As the menu becomes more mapped in the students' minds, the students won't need to look at the monitor for the corresponding column. The hypothesis is that time for completion in Treatment Three will decrease more dramatically across time than in the other two treatments. The development of cognitive mapping will serve as an indication that the technology is becoming more transparent with use of the robot.

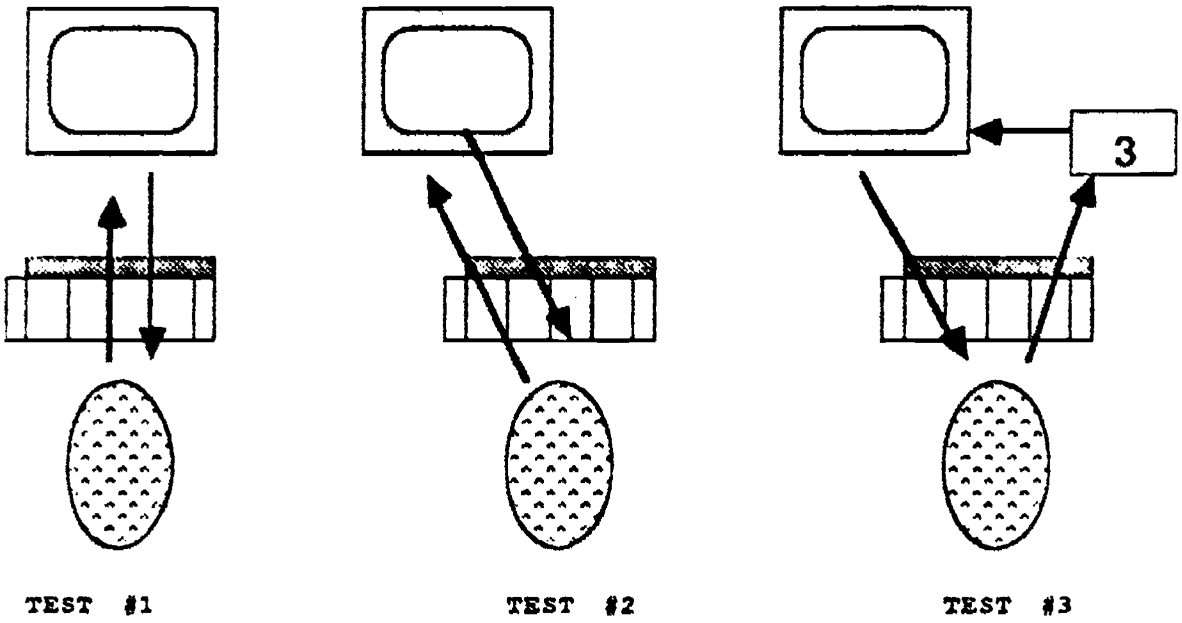


Figure 3. Motor Control/Cognitive Mapping Test Layout

An example of the type of data being gathered in the motor control and cognitive mapping test is demonstrated by Trent's results in two different sessions on Figure 4.

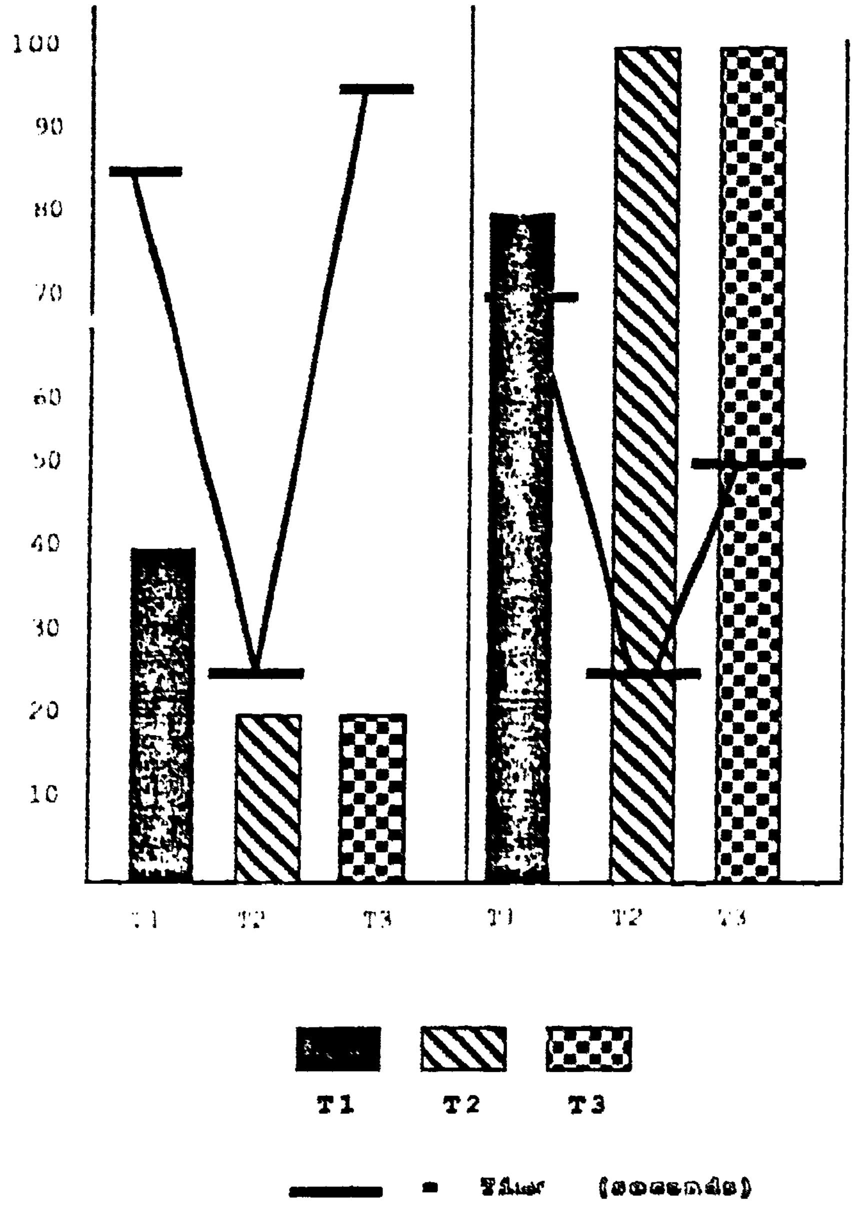


Figure 4. Motor Control/Cognitive Mapping: Trent

The Single Input Control Assessment (SICA) is another research tool of the project. Under the assumption that the most effective input device is one that permits the fastest and most reliable response to a visual stimulus, the SICA was designed to assess the speed and reliability of various input devices. For purposes of this research, the SICA is being used to assess the speed and accuracy of the child's response using the switch-based input device. An Apple computer and an input device was used for administering the test.

There are two subTasks which make up the SICA. The purpose of the Response Task is to measure the time it takes the student to respond to a visual stimulus by activating the input device, and also to measure the length of time that the interface is activated or held. The data collected included: 1) response time to each stimulus, 2) holding time of each activation, and 3) number of prehits, or the times that the input device was activated prior to the stimulus appearing. The purpose of the Autoscan Task is to test the student's ability to use an automatic linear scanning strategy. The task consists of repeated trials of selecting a target from 5 items. The cursor consists of a "rocketship" that scans below and across the line. The data collected during this task consisted of the number of accurate "hits".

An example using Trent (see Figure 5) shows some improvement, but the autoscan results indicate an inverse relationship. The results of the second test of the comparison group had not been turned in yet at the time of this writing. Again, a better picture of the significance of the Single Input Control Assessment will appear when the repeated measures are completed and analyzed.

(See Figure 5. Single Input Control Assessment, next page)

With such a small number of students, and given the unique handicapping condition of each student, collecting consistent data was difficult. For example, Amos required surgery and was out of school for several weeks during the beginning of the project. Other students have been either ill or busy on some days of the tests. The strategy was to collect a variety of data as consistently as possible and attempt to draw conclusions from the puzzle in spite of the inevitable missing pieces.

Field Based Research

The field based research provides another perspective of the dynamic and complex phenomenon involved in the development and use of a robotically-aided educational environment. The primary goal of the observational research has been to describe and interpret the interactions of the student, the robot, the trainer, and materials in the educational robotics classroom. The preliminary research question in Year One of the project had been: "What is the nature of the interactions between the student, robot, trainers, and materials when engaged in a series of educational and recreational activities?"

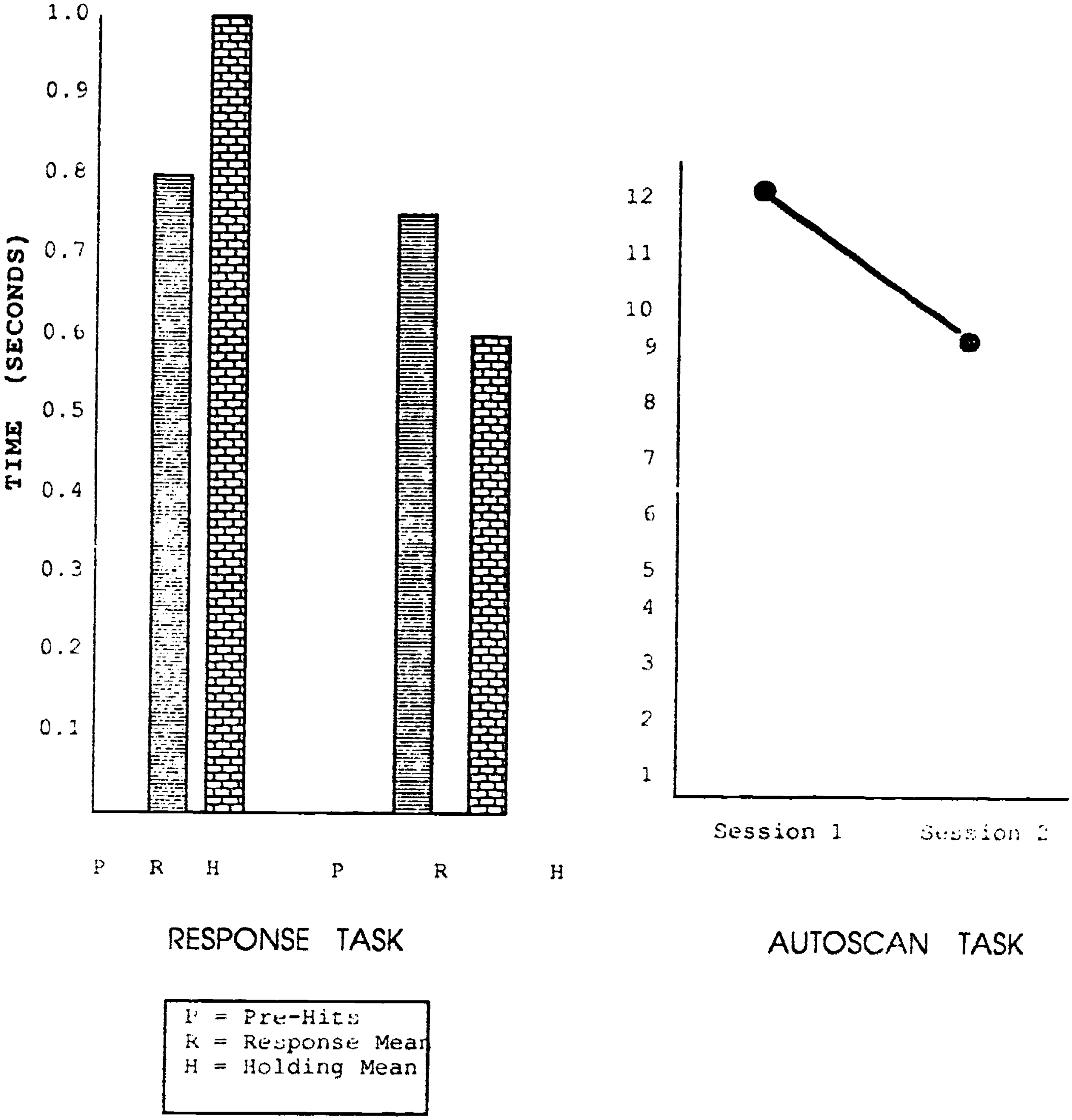
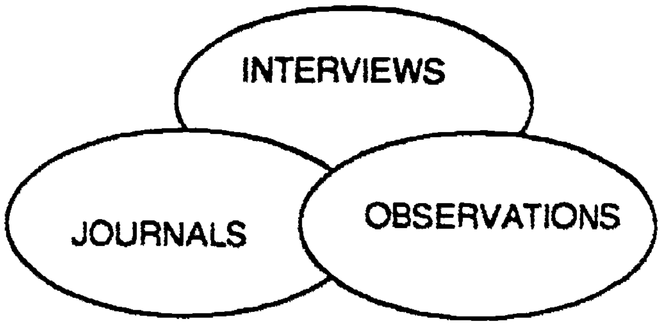


Figure 5. Single Input Control Assessment: Trent

By the second year, the question had been refined and emerging themes had been identified. The research quesion then became: "What social, educational, and technological factors influence the adoption of robot technology in the education of severly orthopedically handicapped children?

Figure 6 gives the research focus for the second year of research effort and illustrates how the initial research activities helped in the identification of the emerging themes: training methodology, transparency of technology transfer, curricular applications. These themes served as the foundation for the current investigation by: 1) providing issues that could be explored and 2) eliciting testable questions.



EMERGING THEMES

- Training Methodology
- Transparency of Technology
- Student Factors
- Teacher/Trainer Characteristics
- Technology Transfer
- Curricular Applications

Figure 6. Research Focus -- Second Year

Method

Three children were observed twice a week during each of their 20-30 minute sessions. Working sessions ocurred from January 1989 to May 1989. These working sessions generally involved set-up of equipment and adaptive devices, a training task and, if time allowed, a short period of free play or games. After a sufficient period of training, the children participated in science education activites. Having learned to use the robot control software allowed the children to begin using the robot to learn.

The research protocols, including the contact summary sheet, guided the observer in the procedures and responsibilities of field observation. Field notes were reviewed so that target questions for subsequent visits could be prepared, codes could be developed and refined, and emerging themes identified. The model used for development of some of the tools and procedures of data analysis was an outstanding sourcebook by Matthew B. Miles and A. Michael Huberman called Qualitative Data Analysis (Sage Publications, 1984).

The observer was responsible for taking the field notes during the observations, transcribing the notes to a computer file, and assisting in the formulation of target questions prior to each observation. Later in the project, when intercoder reliability was established, the observer then became responsible for coding the field notes.

The observer was an elementary school teacher who was on sabbatical while completing a Master's in Instructional Design and Technology at The Ohio State University. Enthusiastic and well prepared, the observer made a visit to the school prior to the observations. The objectives for this visit were to: 1) establish a working rapport with the occupational therapists (referred to hereafter as the trainers), 2) familiarize herself with the school's physical plant, general routines and the actual room where she would be doing the observations, and 3) gain general information about the children and the project, from the trainer's point of view.

For each visit, the observer would sit in the room in a location that was unobtrusive but also allowing good visual access to the children's interactions with the robot and the trainer. The notes taken for every session would later be transcribed into a computer file, and a contact summary sheet would be filled out for each (see Appendix A).

The sampling of data came from four sources: setting, people, events, and processes. Figure 7 illustrates the specific elements of those sources. Renee used any of these sources to question or support emerging themes.

SETTING	PEOPLE	EVENTS	PROCESSES
Colerain Elementary School	* Occupational Therapists * Students * Principal * Team Leaders * Teachers * Project Leader * observer	Training Activities Science Activities Interviews Meetings	Training for use of robot. Learning with the robot. Play Communication Software Engineering Hardware Engineering Organization

Figure 7. Sampling Framework

The raw data, transcribed into computer text files was then coded. Coding, a crucial phase of data analysis and interpretation, served as a means for categorizing and organizing relevant data. Codes for the data fell into several categories: descriptive, interpretive, or explanatory. The initial round of coding was necessarily descriptive, that is, attributing a descriptive category to a segment of test. This type of coding was first conducted at a macro level. For instance, the code "TR" for training issues would be assigned to the following sentence: "Jan re-explains switches in relation to columns on the screen." As codes are refined and themes are modified, coding takes on more levels, (e.g. TR:ME/SH or "training methodology, shift from planned instruction"). The interpretive coding delves more deeply into hypothesis testing, (i.e. "Is there consistency in the junctures at which a shift in the training plan occurs?"). Finally, coding at the explanatory level focuses upon patterns, themes, or causal links. At the time of this report, coding was just beginning to occur at that level (see Appendix B).

The development of codes for data analysis is an iterative process that uses the field observations to define and refine the codes. The method for developing codes for data analysis is best illustrated by Figure 8, the "Methodology for Field Research". Figure 8 demonstrates the interrelationship of the field observations and code development. Preliminary codes were gradually developed in the first year of research. The resultant research framework guided the second year of field observations, during which codes were generated or refined.

(See Figure 8. Methodology for Field Research, next page)

Credibility of the data analysis was crucial in this phase of research so procedures for establishing intercoder and intracoder reliability were initiated. Intercoder reliability, the consistency with which several coders assign codes to like chunks of data, helps to determine the replicability of the analysis. Four sessions of field notes were distributed for analysis by three research team members. The unit of analysis was a line, and a number was sequentially assigned to every line of the sample notes. Given a list of codes (Appendix E), each team member was directed via an instruction sheet to acquaint him/herself with the codes and to ask any questions as to meaning of the codes. The team members were instructed to read a paragraph at a time and then assign a code to every line in that paragraph. The coders continued in this fashion until the notes were completely coded.

Comparing two sets at a time, the number of agreements was divided by the number of agreements plus disagreements (r = agreements/agreements + disagreements). After the r factors were calculated, the team members attempted to reach consensus on the meaning of the codes that elicited disagreement. Coders were invited to suggest different or modified codes. This process was to take place as many times as necessary to reach a reliability factor of .8 . The first iteration produced a predictably low reliability factor (.6), but subsequent trials produced a reliability factor of .83; thus substantially increasing the validity and credibility of the codes.

Intracoder reliability, the consistency with which the individual coder assigns codes, was also part of the reliability testing procedures. Establishing intracoder reliability sensitizes the coder to his or her own mental constructions of the codes and helps solidify those constructions. To establish intracoder reliability, the coders were given two sets of the same field notes to code, separately, two days apart. Reliability was calculated by comparing the two sets, again, dividing the number of agreements by the number of

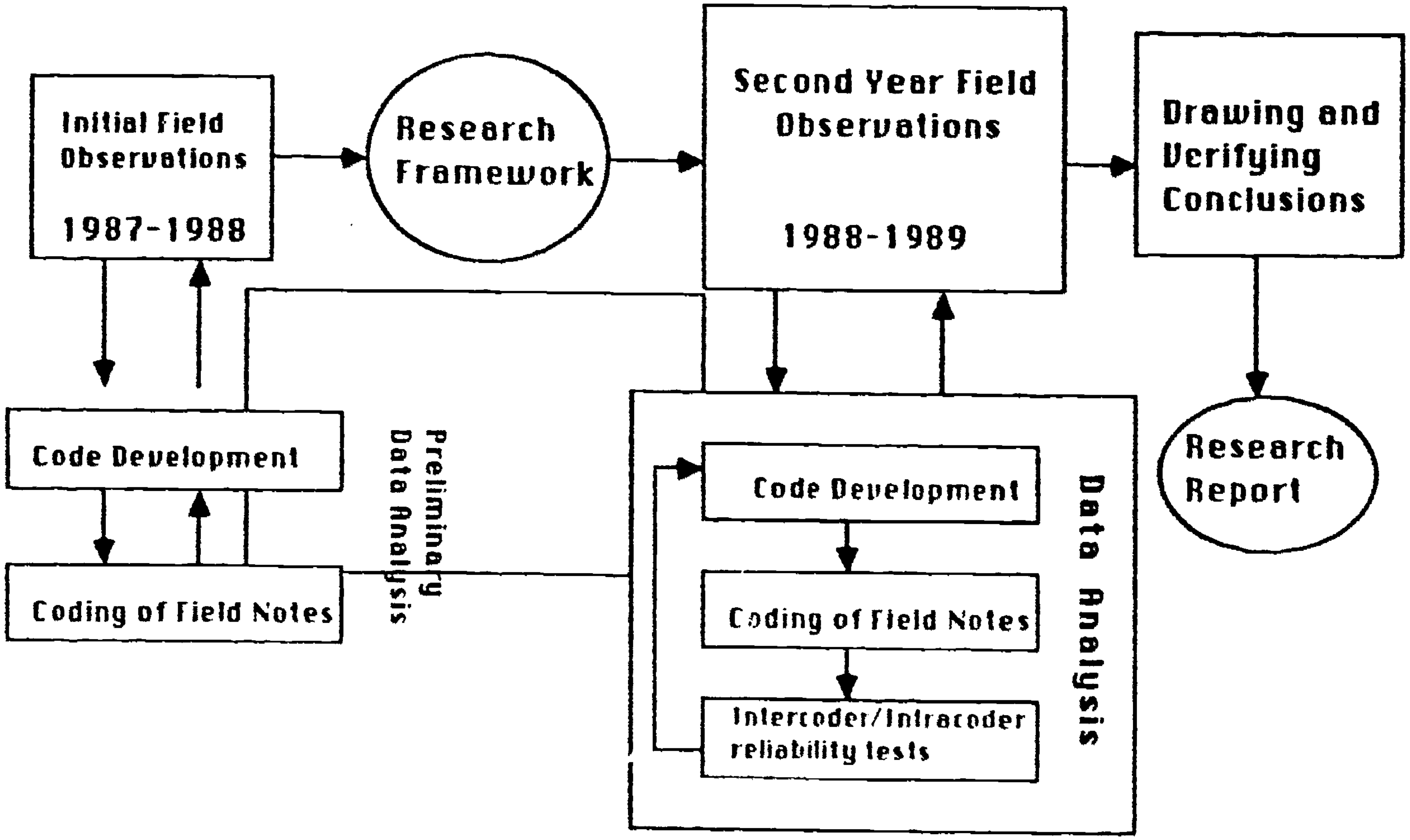


Figure 8. Methodology for Field Research

agreement plus disagreements. The goal for intracoder reliability was 90%.

Results

At the time of this report, the codes fell into twelve categories. These categories reflected or supported the themes that were being examined in the field.

(See Figure 9. Factors in Innovation Adoption, next page)

* **Transparency of technology**: the degree to which the technology is not apparent during use.

* **Metaphors**: metaphorical statements indicating the person's perception of the robot or activities.

* **Training** (external factors): the methods and materials that are provided the student.

* **Learning** (internal factors): behavioral and cognitive responses and processing.

* **Affective Domain**: attitudes, emotions, state of well-being.

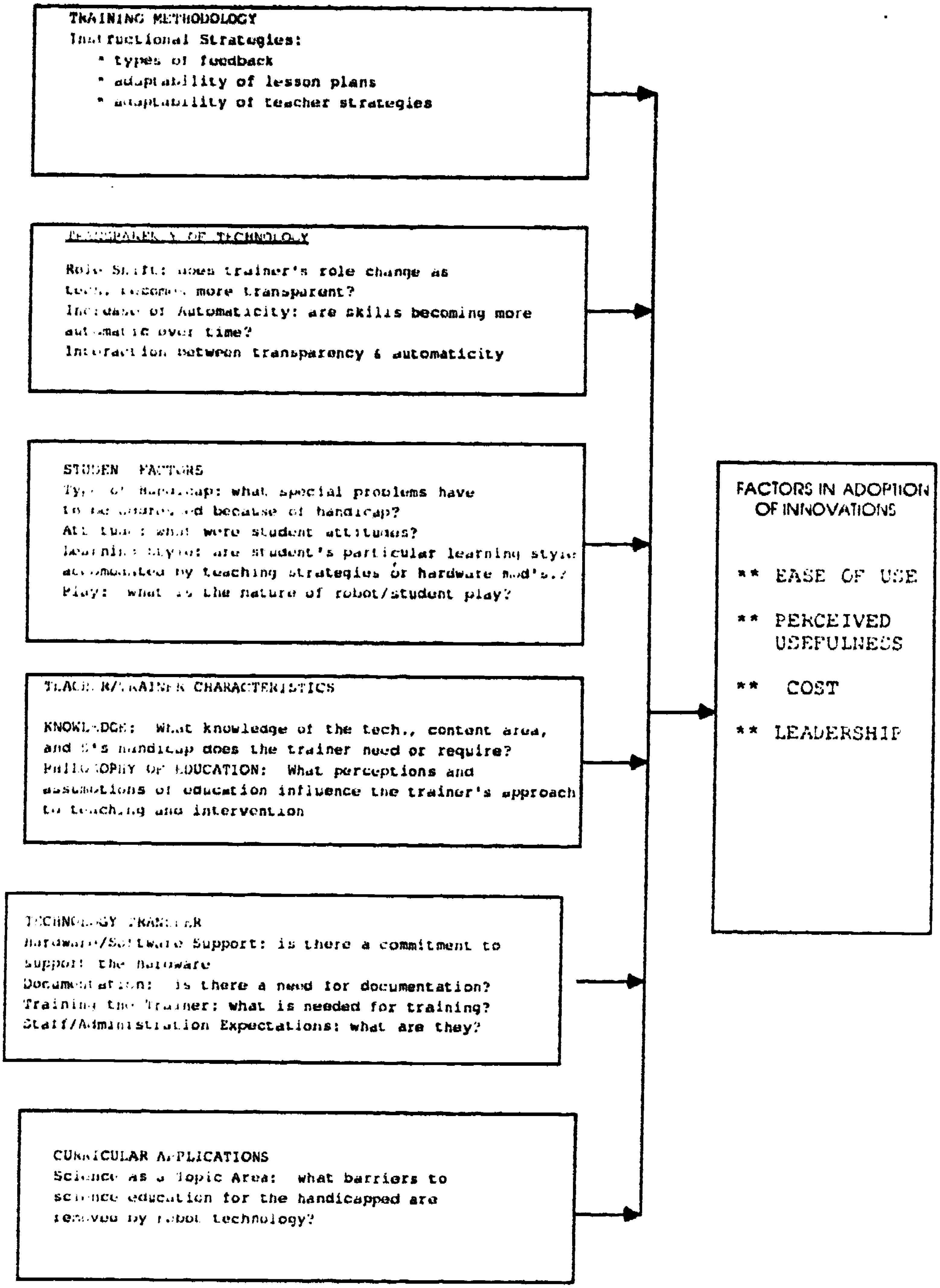
* **Observer**: reactive and reflexive impact of observer (how the activity is influenced by the observer's presence and how the observer is influenced by the activity.

* **Technology transfer**: design, development and implementation issues that influence the adoption of the technology by the school staff.

* **Curricular applications**: factors that describe the usability and impact of this technology as a tool in facilitatating the delivery of the curriculum.

* **Trainer characteristics:** characteristics that facilitate or impede learning and technology transfer.

* **Student factors**: descriptive factors about the student.



TRAINING METHODOLOGY
Instructional Strategies:
- types of feedback
- adaptability of lesson plans
- adaptability of teacher strategies

TRANSPARENCY OF TECHNOLOGY

Role Shift: does trainer's role change as tech. becomes more transparent?
Increase of Automaticity: are skills becoming more automatic over time?
Interaction between transparency & automaticity

STUDENT FACTORS
Type of Handicap: what special problems have to be addressed because of handicap?
Attitudes: what were student attitudes?
Learning Styles: are student's particular learning styles accommodated by teaching strategies or hardware mod's.?
Play: what is the nature of robot/student play?

TEACHER/TRAINER CHARACTERISTICS

KNOWLEDGE: What knowledge of the tech., content area, and S's handicap does the trainer need or require?
PHILOSOPHY OF EDUCATION: What perceptions and assumptions of education influence the trainer's approach to teaching and intervention

TECHNOLOGY TRANSFER
Hardware/Software Support: is there a commitment to support the hardware
Documentation: is there a need for documentation?
Training the Trainer: what is needed for training?
Staff/Administration Expectations: what are they?

CURRICULAR APPLICATIONS
Science as a Topic Area: what barriers to science education for the handicapped are removed by robot technology?

FACTORS IN ADOPTION OF INNOVATIONS

** EASE OF USE

** PERCEIVED USEFULNESS

** COST

** LEADERSHIP

These categories of data that were being investigated supported as well as challenged the conceptual framework for the field observations (see Figure 9). Training methodology, of course, was a major concern of the project since successful implementation depended upon determining effective ways of training trainers and student users to use the technology. Instructional strategies, instructional aids, and types of feedback are examples of issues being examined under the category of training methodology.

Investigating the transparency of the technology began to yield an interesting interaction between transparency and automaticity and between transparency and trainer role. As automaticity increased (e.g. the child didn't have to look at the monitor as often for determining which switch to press because the "GO" position was memorized.). In these cases, the technology became more second nature to the student, more "transparent". The trainer's role also seemed to shift from instructor to facilitator as the robot became more familiar to the child.

The student factors at this time were proposed to address the especially human element of using this technology. Who are these children? How are they affected by this experience? How do they play and learn with this technology? Note, however, that the coding took a different turn. Factual information about the children, learning styles, and affective issues were separated. Further investigation will solidify the categories and inter- relatedness.

Teacher/trainer characteristics address the knowledge required by the trainer in order to direct and facilitate the learning of the child in the robotically-aided educational environment. Furthermore, some assumptions or constructions of education influence the trainer's approach to teaching and coaching.

Technology transfer is an issue that is crucial to any new technology that is to be perceived as useful and consequently adopted. In this study, we were beginning to look at the importance of the hardware software development team in the implementation of robot technology in the classroom. In addition, we were investigating the role of documentation and staff/administrative expectations in the acceptance of the robot.

By Spring of1989, the children were beginning to use the robot to explore the phenomena of science. Science was chosen as the curricular area because the nature of the subject requires manipulation and examination processes that are nearly impossible for these children to do on their own. (see Appendix C for a sample science lesson plan). Through providing science experiences we were asking the question, among others, "What barriers to science education for the orthopedically handicapped are removed by robot technology?"

The different themes address major factors in the adoption of innovations such as the robot for educational purposes: ease of use, perceived usefulness, cost, and leadership. These four factors deal with human learning and teaching needs, logistics of implementation, and vision.

Conclusions

The data emerging from the field research demonstrate the richness and complexity of the phenomena being observed in the robotically aided educational environment established by The Ohio State University. Since the activities of the robotic laboratory at Colerain School extend beyond the contractual period determined by the U.S. Department of Education, this report describes research in progress that will be completed by the team of researchers at Ohio State. Only tentative conclusions can be attempted if at all, because of the incompleteness of the data analysis. Although no conclusions can be put forth which definitively assert the benefits of the robotic system as an assistive device, there is sufficient proof to warrant its continued investigation with students. The discoveries thus far show that severely handicapped students can make progress and can develop a sense of control over their immediate environments using the robot as a manipulative tool.

APPENDICES: FINAL REPORT

Appendix A

Samples of Data Collection Instruments

Date: __________ Coder: __________

Student: __________

:Trainer __________

Task Series: __________

Description: __________

Time begin ______ Time end ______ Total time ______

Total # moves to complete task______

Page ___ of ___

Coding:

W = Wrong select

V = Verbal assistance

P = Physical assistance

D = Demonstrate

NOTES

Blu																	
Orn																	
Pur																	
Grn																	
Wht																	
Blk																	
X																	
Y																	
Z																	
A																	
B																	
C																	
D																	
E																	
F																	
+																	
-																	
UNDO																	
GO																	
Tally																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

ACTIONS

Field Observation Notes

Date: ______________________________ Page ___ of ___

Observer: ______________________________

Student Observed: ______________________________

General description of intended activity:

Target questions for this observation:

Frame #'s	Codes	NOTES

Field Observation Notes

Page ___ of ___

Date: ____________________

Student : ________________________________

Frame #'s	Codes	NOTES

Contact Summary Form

Contact date: Today's date:

Student: Observer:

1. What were the main issues or themes that struck you in this contact?

2. Summarize the information you got (or failed to get) on each of the target questions.

<u>Target Question</u>	<u>Information</u>

3. What target questions will be addressed next contact? Assign codes for new questions.

Appendix B

List of Codes - June, 1988

CURRENT CODES FOR DATA REDUCTION
June 1, 1988

AC: acceptance
AC - pr: parents
AC - te: teachers
AC - ch: children
AC - tr: trainer
AC - ot: occupational therapists

AF: affective, attitude

AN: anthropomorphism of robot

AT:student attention
AT-mn: attending to monitor
AT-rb: attending to robot
AT-tr: attending to trainer
AT-sw: attending to switch
AT-ds: miscellaneous distractors

BN: benefits

DV: divergence from task at hand to something the student wants to try. What happens just before the lost of attention that triggers the student's need to go off in another direction? This can lead to some inquiry into hypothesis testing.

GE: generalizability to other activites

LS. learning style of child

OT: issues relating to the occupational therapists
OT - int: OT interference e.g. need for, incident of, requested

PL: play issues

SC: science activities

SP: spatial learning, mislearning, problems

ST: student strategy

TI: issues relating to the technology
TI - in: inhibitors to the transparency of the hardware and software. For instance, strong external motivation is sometimes required to overcome the tediousness of the task. The technology is evidently not transparent enough. These inhibitors cause the student to focus on the technology instead of the task.

TR: those issues relating to trainers. Initially considered are training techniques such as corrective feedback, perspective of student progress, background (and influence of), and vocabulary used to communicate directions and concepts to students.
TR - fe: feedback
TR - fe.cr: corrective feedback
TR - fe.ex: explanatory feedback
TR - fe.dir: directive feedback
TR - vo: vocabulary
TR - tm: training methodology

UP: understanding of self or other people. Does use of robot increase/change knowledge or perspective?
UP - em: emotional linkage to OT. When does robot enhance/change that linkage?
UP - st: insights gained by project staff
UP - ch: insights gained by children

Appendix C

Sample Lesson Plan Format

Title:

General Description

The student will

The robot will

The trainer will

Goals of the Activity

Cognitive:

Affective:

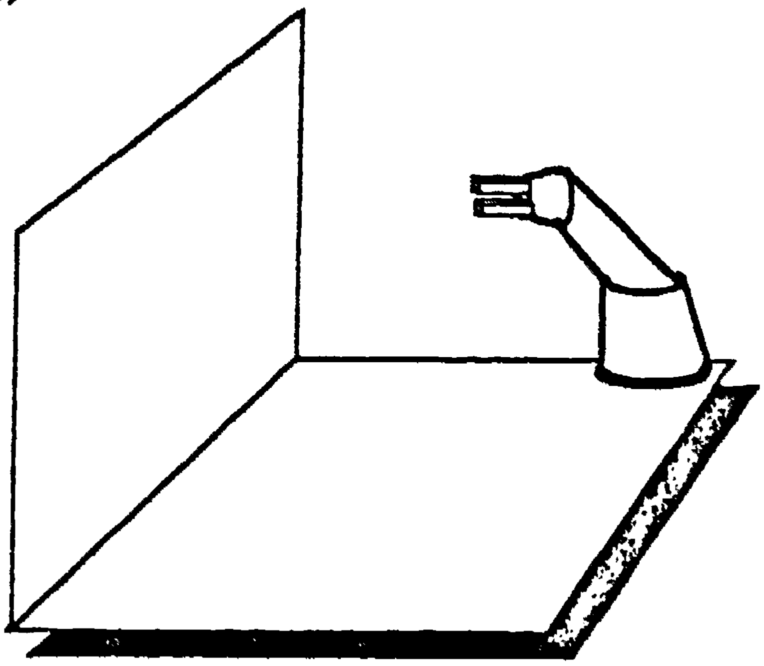
Scientific Process(es) Encouraged:

Objectives of the Activity

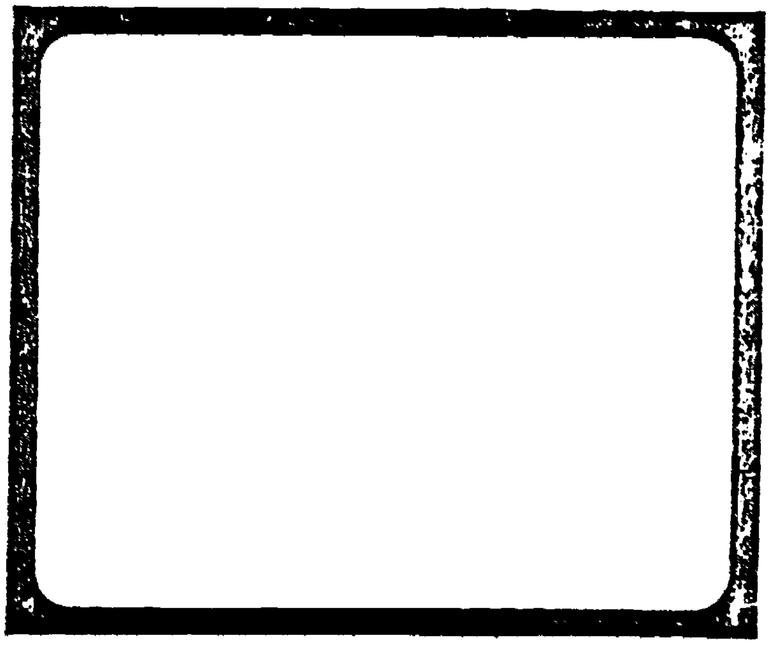
Materials

Quantity	Size	Item Description	Comments (including modificatio))

Set-Up (Conditions of the Environment)



Software Modifications



Activity Descriptions (in sequence)

Estimated Tim

Training/Instruction Notes (Implementation Strategies)

Evaluation Criteria (including Observational Cues)

Software-based Access and Control of Robotic Manipulators for Severely Physically Disabled Students

by
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July, 1989

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ABSTRACT

The design of robot control software for use in rehabilitative and educational interventions with disabled persons is a new research and development endeavor. A three-year research and development project at the Educational Robotics Laboratory, The Ohio State University (ERL/OSU) has initiated work on educational applications of robotic devices for physically disabled students in an elementary school setting. This article focuses upon some of the key considerations and issues that face designers of robot control software for persons with limited control and communication abilities. While the focus of the effort has been upon applications appropriate for severely physically disabled students, some of the considerations may be applicable and useful for other students in elementary settings.

Introduction

The path that leads to the development of a functional software program allowing easy access and control of a robot by physically disabled students has proven occasionally circuitous and constantly challenging. The rationale for development of the adapted robotic system arose from a specific need; in this case, the severe manipulation and control deficits evidenced by many physically disabled students. Within the framework of a larger research initiative aimed at developing and evaluating the impact of a prototype educational robotic environment, a software program was created which provides an effective robot control interface for use by children with minimal physical control abilities. This article will discuss the process by which design decisions were made in the development of this robot control software program.

The design process revealed the need for a set of features that exemplified specific software design considerations which accommodated the identified needs of the disabled student users. In addition, a number of major design issues have arisen concerning the control and interface options available, and the restrictions inherent with contemporary robotic devices when they are used as tools in educational settings by disabled learners. This article will investigate these sets of considerations and issues by presenting a brief overview of the decisions and rationales that were eventually incorporated into the current version of the robot control software. Finally, a perspective is given on the design process that demonstrates conceptual elegance in an easily accessible and understandable control interface, while simultaneously maintaining simplicity of screen display features and input requirements.

The Problem

One of the primary barriers that prevents the severely physically disabled student from successful academic interactions in mainstream educational settings is an inability to exert physical control over their external environment. The lack of physical control constitutes a significant barrier to academic success especially when coupled with other problems such as communication disorders and related medical problems. Accompanying the reality of diminished control are feelings of helplessness and the frustration of having to rely on caretakers in order to effect even the slightest changes to their outer environment. It was in response to this milieu that attempts were begun to develop a robotic aid that would partially compensate for the loss of manipulative control and perhaps find a useful niche as an assistive device within a public school setting. The intensive planning, design and development activities have elicited two critical concerns involving the **Access** and **Control** of robots which seem to largely determine the success or failure of robotically-aided educational interventions with disabled children. **Access** deals with the appropriateness of the hardware interface(s) and the interface strategies incorporated into the screen designs. **Control** deals with the ways in which a student's desired actions are transformed into purposeful manipulations, given the robot's movement potential within the environment. Control can originate from either the student or the computer, and is a major consideration in all technology-based educational systems. These dual concerns are revisited throughout this article and may be seen as central considerations to the development of such systems. Norman (1986) describes the tension that exists between the types and levels of control ascribed to either the human or computer as:

> Tools that are too primitive (or too human controlled), no matter how much their power, are difficult to work with. The primitive commands of a Turing machine are of sufficient power to do any task doable on a computer, but who would ever want to program any real task with them?
>
> . . . On the other hand, tools that are at too high a level (or too computer controlled) are too specialized. An applepeeler is well matched to its purpose, but it has a restricted set of uses. Spelling checkers are powerful tools, but of little aid outside their domain. Specialized tools are invaluable when they match the level and intentions of the user, frustrating when they do not. (p. 53-54)

A CONTEXTUAL FRAMEWORK

It will be useful to provide a context for discussing the design and development of control software for robotic systems so that they are accessible and useful to severely physically disabled students. This framework will include a brief review of the history of educational and rehabilitation robotics, a description of the target population, and a description of the robotics environment that has been designed at the Educational Robotics Laboratory at the Ohio State University (ERL/OSU). When appropriate, examples from the work of this and other rehabilitation robotics projects will be used to illustrate concepts or processes.

Historical Background

Advances in the development and use of robotic devices have demonstrated their potential as prosthetic aids which can compensate for physical, sensory, and cognitive impediments (Hoseit, Liu & Cook, 1986; Seamone & Schmeisser, 1986; Leifer, 1983). Robotic devices promise to someday gain stature as powerful assistive devices, increasing the personal independence and vocational access for severely physically disabled individuals (Anderson, 1986). Recent work done in several different research sites in the country have resulted in the commercialization of one professional robotic workstation for the disabled (PRAB Command), with two other workstations in the final stages of field testing previous to commercialization. Other robotics projects throughout the world include pioneering work in a wheelchair-mounted robotic manipulator (Kwee, 1986); a robot "guide dog" developed by Tachi (1982) of the Technology Research Association of Medical and Welfare Apparatus (TRAMWA) of Japan, that guides a blind walker according to a microcomputer-based land map; and the "COSGORTH" (Cognitive Orthothics) applications environment developed to guide a mobile robotic nursing assistant (Levine, et al. 1989). The widespread research and development activities indicate that the movement of this technology from the laboratory into society is forthcoming with the relevant questions centering around the effectiveness, utility, cost and desirability of specific robotic applications.

Software development for rehabilitation or educational robotic systems have generally followed one of two paths: as dedicated applications software, or as generic robot control languages that are transportable, highly flexible, and have potential to become standardized. The primary emphasis for many projects has been to develop software for vocational applications with several projects investigating aspects of voice-activated robot control software, including natural language processing (Michalowski, 1989; Amori, 1988), and interactive voice editing features (Horowitz, 1989). Among the attempts at developing a generic robot control language, CALVIN was the first reported attempt at a language specific to rehabilitation settings (Gilbert, Minneman, & Pham, 1987). The language was developed in an attempt to create a set of generic procedures which would have widespread utility in robotically-aided settings in addition to being transportable to a variety of different robotic manipulators. Unfortunately, CALVIN was never developed completely and its future is unknown at this time. The other generic control language is a program designed by Gosine, Harwin and Jackson (1989) called the "Cambridge University Robot Language" (CURL). CURL has recently undergone a series of field tests with disabled students within instructional settings using a variety of educationally-based activities. CURL's performance has shown it to be a reliable, flexible robot control program, with the authors planning to integrate it into a vocational workstation and to continue development of its visual sensing capabilities. These investigations indicate a diverse and vibrant research agenda aimed at developing more effective and flexible software-based control over a variety of robotic tools.

Population Parameters

The target population is composed of students exhibiting developmental disabilities caused by neuromuscular dysfunctions resulting in severe communicative and physical handicaps. Orthopedically impaired students represent a very heterogeneous group of the physically disabled, including persons with: cerebral palsy, muscular dystrophy, poliomyelitis, arthritis, osteomyelitis, congenital heart defects, absence of arms or legs, hemophelia, diabetes, and spina bifida. The severely physically disabled population in the U.S. is estimated to range between 5 million (Household Economic Studies, 1986) and 7.5 million individuals with approximately one million orthopedically handicapped children being included within this group (National Health Interview Survey, 1985). The age range for students used to test the ERL/OSU software program was nine through eleven years of age. Students had to have adequate physical control to activate a switch input device and enough expressive ability to communicate their desires verbally or via a communication board or other augmentative communication device.

A common deficit evidenced by this population, and discussed by a number of learning theorists, is the importance of early motor learning in normal cognitive development (Kephart, 1971; Piaget, 1976; Bruner, 1964). Since movement is one of the first overt and observable responses of the child, it is logical to view psychomotor learning as an important aspect of cognitive development. In some cases, it has been asserted that normal cognitive development is impossible without early physical exploration (Kephart, 1971). The implicit outcome of such a deficit would be a wide range of mental handicapping conditions in addition to the physical disabilities if these theories were consistent. But the integration of severely orthopedically disabled children into public education by virtue of the "Education for all Handicapped Children Act" (PL 94-142) has clearly demonstrated that many of these children can be successful learners when given the appropriate educational and therapeutic interventions (Hofman & Ricker, 1979) . Support for this observation is given by Flavell (1977) who states that, "If the usual, typical developmental route is blocked, the child may find an unusual, atypical one that somehow gets him to at least approximately the same cognitive destination." Physically disabled children may be able to use the robot as one of the "unusual or atypical" routes that enables them to interact more independently with their educational environments.

A case can be made for using the robot as an environmental manipulator with the disabled student directly experiencing important processes and educational concepts within a laboratory environment. As a result of this interaction, the applications of robotic devices are expanded to include educational interventions and eventually will be seen as a functional manipulation tool among other tools within education. It may be that the use of a robotic device acts as a linkage between the disabled student and instructional materials in an laboratory setting, with the student gaining knowledge, skills and motivation from the interactions.

The Prototype Robotic Environment

The work at the ERL/OSU has focused specifically on the cognitive and academic impact of the use of robotic assistive tools within an educational environment (Howell, Damarin, Clarke, and Lawson, 1989; Howell, and Clarke,1986). The specific content area selected as the focus for instructional development was science education and the instructional context was the science laboratory. A sequenced set of 10 training activities and 22 science-education activities were implemented during the 1988-89 school year using the prototype system. The findings indicated that the use of a two-phased educational intervention was an important feature for effectively using robots as instructional aids. The two phases can be described as follows: 1) **Training:** students learn how to use the hardware and software in order to control the various movements of the robot. These skills are predicted to eventually become "automatized" with students requiring progressively less mental energy in order to use the robot as a tool; and 2) **Education:** students use the robot as a manipulation tool within a rich, science-education, laboratory-based environment for purposes of academic and cognitive enhancement (Howell, Baker, & Mayton, 1988).

The use of commercially available robots, computers, and adaptive input devices have led to the design of a robotic system with a relatively reasonable cost of approximately $12,000.00. The current prototype robotic system consists of a UMI-RTX robot, an IBM-PC AT computer system, and a Prentke-Romich 5-Slot Switch device. The control software that the student uses to send commands to the robot is a unique program that allows for the student to have adapted access to the entire 3-dimensional workspace (envelope) of the robot. The software provides easy access to: 1) programmable, specific positions anywhere in the workspace, 2) individual axis motors of the robot, and 3) motions along cartesian coordinate system axes, and 4) motions along cylindrical coordinates. It is written in Turbo "C" language and is modular in format, allowing for easy debugging, expansion, and portability.

[[INSERT PHOTOGRAPH #1 HERE]]

Primary Software Design Considerations

The primary design goal was to utilize the available capabilities of the severely physically disabled students in order to understand and use the software to control a robotic tool. These considerations include specific problems that had to be resolved and partial (or en-route) solutions that had to be designed in order that the emergent software was accessible and useful to the students. The specific software design considerations facing the design team were threefold:

1) The students' disabilities required the software to be **easily accessed** while maintaining a **reasonable interactional speed** as the student worked with the robot and the instructional materials.
2) The **user control features** incorporated into the software must be understandable and transparent.
3) The conceptual, engineering, and mathematical problem of **defining the optimal robotic motions** had to be solved in order to provide the most powerful interactional learning environment within the limitations of the particular robotic manipulator.

Software Consideration #1: Easy Access and Interactional Speed

Developing access to the robot through a software control interface is a difficult software engineering process. Schneiderman (1987) asserts that, "The goal is to increase the productivity of users by providing simplified data entry procedures, comprehensible displays, and rapid informative feedback that increase feelings of competence, mastery, and control over the system." The conflicting demands of easy access and maintaining a fairly high rate of meaningful robot/user interactions presented a dilemma to the design teams. Compromises were made in both areas such that a single-screen control menu was designed allowing the student to utilize the robot in any part of the robot's envelope (the robot's operational 3-dimensional workspace) by a minimal number of switch closures.

The control screen display that was determined best able to meet the needs of the students currently utilizes a matrix format that graphically resembles the columnar format of the Prentke-Romich switch device (See Figure 1).

[[INSERT FIGURE #1 HERE]]

Students use the software via a two-step process: 1) they must first set up the desired motion by selecting an appropriate position in one or more of the columns, and 2) then press the "GO" button to execute the motion. The columns are accessed by a scanning method that requires the student to depress the switches either discretely or continuously. The five (5) columns have the following designated functions reading from left-to-right:

Column 1: activates the "GO" option
Column 2: a direction selection column with "+" and "-" symbols
Column 3: a column with "X", "Y", "Z" and "R" symbols (cartesian and cylindrical coordinates).
Column 4: a robotic arm-joint selection column with letters "A" - "F" indicating each joint ranging from the gripper ("A") to the "shoulder" motor ("F")
Column 5: a pre-programmed position selection column, that includes six (6) available positions each indicated by a colored rectangle

The type of **Interface Strategy** used when the students access the software is a primary consideration in both initial and later interactions with the robotic system. The ERL/OSU software design features **menu selection** as its interface strategy.

The **Menu Selection** method includes axis, vector, and directional control features that allow the student to make a structured response to a manipulation task. Menu selection systems require less training and memorization of complex sequences of commands. They allow for a more simplified interactional style that: 1) requires fewer keystrokes to enact robotic motions, and 2) allows a student to mentally structure the actions required in order to successfully complete the task. Schneiderman (1987) describes menu selection as, "especially effective when users have little training, are intermittent in using the system, are unfamiliar with the terminology, and need help in structuring their decision-making process." (p.86)

Another important decision was whether to use multiple menus or to incorporate all the command structures on a single menu. Basically, the relationship between levels of menu trees involves an interaction between the depth (the number of levels) of menu(s) in a program; and the breadth (the number of items per level) in any single menu. In order to increase interactional speed and decrease keystrokes, the ERL/OSU software program uses a menu that has a depth of 1 Level and a breadth of 19 items. Some support for this design position was given by Dray (1981) who compared a one-level menu having 23 one-word items arranged on 6 lines, with a two-level menu having 6 items in the main menu. Subjects had 138 trials in each of the two conditions in a counterbalanced, within-subjects design. The results indicated that neither menu was definitively superior, but a significant order effect was interpreted by the authors that the one-level menu was easier to learn. Informal reports from subjects supported the conclusion that seeing the full picture on a single menu continuously aided their decision-making. More support for the use of fewer levels of menus (less depth) was given by research conducted by Landauer and Nachbar (1985), who provide additional support for the clear advantage of breadth over depth in menu design strategies.

Finally, although menu selection allows for many more complex, constructed responses, the scanning search strategy that was employed for selection of commands by the user slows down the overall interactional speed of the user, and consequently, the robot's effectiveness. The current tradeoffs between access and speed have resulted in a functional program that allows for ramping (increment or decrement) of scan rate, selection delays, and repeatability of input(s) to facilitate user access. Unfortunately, a complete cycle-of-use is still slower than desirable and much work remains to increase the interactional rate without increasing the complexity of the screen display.

Software Consideration #2: User Control Features

The features of the software environment which make it understandable and transparent describe the ways in which the user learns about, applies, and receives meaningful feedback from the control software. The more effectively and efficiently the learner acquires this information in large part determines the degree of control the user has over the robotic device.

Software is considered **Understandable** when the user is able to comprehend the meaning and arrangements of the screen features. A user learns how to use robot control software by first encoding the operational commands and then relating the use of these commands with the movements and actions of the robotic manipulator. An "understandable" program includes not only the conceptual framework but also certain aesthetic and pleasurable features that make it desirable to interact with. Ivan Illich (1973) in a discussion of technological tools coined the term "convivial tool" as "tools which reveal their underlying model and allow for interaction, tools that emphasize comfort, ease and pleasure of use." The goal of all device control software must be to make the interaction as practical and pleasurable as possible and might be considered to be "convivial" if they meet these basic requirements.

Riley (1986) discusses work initially performed by Greeno (1978) in describing the ways in which users come to understand a program and suggests that the adequate representation of a problem solving situation (such as that involved in using a software program) is partially dependent upon an evaluation issue called, "internal coherence". Riley views internal coherence as, "the extent to which the components of knowledge are related in an integrated structure." After determining the student input mode(s), and the movement potential of the robotic manipulator, the design of a syntactic structure (or model) can be undertaken. Several different studies have linked the degree of syntactic coherence within a software program to the user's ability to learn, remember and regenerate (Payne & Green, 1983, Reisner, 1981).

The ERL/OSU software was designed to incorporate a syntactic structure that embodies a parallel and rhythmic sequence of commands that initiate robotic motion with minimal cognitive and physical demands on the user. The following diagram analyzes the syntactic structure of this software program.The syntactical structure of the program involves three different ways in which **Motions** can be enacted, two different **Directions** that a Motion can take, and the **Execution** of the constructed response.

[[INSERT FIGURE #2 HERE]]

Some examples of how a student might use the menu employing a "syntactical lens" perspective are:

Example #1: If the goal is to move the robot to position #1, the student must:
Step #1: Select MOTION Position "1"
Step #2: Select Execution icon "GO"

Example #2: If the goal is to move the robot axis (joint motor) "E" in the positive direction, the student must:
Step #1: Select MOTION Axis "E"
Step #2: Select DIRECTION indicator "+"
Step #3: Select EXECUTION icon "GO"

From the learner's perspective, syntactic knowledge must be "automatized" in such a way that the mental load of using the software is decreased over time as the various command sequences become progressively more automatic responses (LaBerge and Samuels, 1974). An "automatized" response is a skill that does not require a great deal of deliberate or focused attention, and which can co-exist with other skills or functions in the learner. This process is thought to involve the use of practice over time as a key condition, and as a determinant of the level of integration that eventually occurs.

The next consideration involves the concept of **Transparency**. The degree of transparency is determined by the ease by which the user transitions from focusing effort on the technological tool (in this case, the software and robot), and increases their awareness and participation in the task at hand. The principle of transparency was first articulated by Rutkowski (1982) as when, "The user is able to apply intellect directly to the task; the tool itself seems to disappear." The goal of educational activities should primarily be on the content of instruction not on the tools used to deliver it; therefore, the easier it is to be trained in how to control and use robotic aids, the quicker that education can begin. The current ERL/OSU training program requires about 6 - 8 hours of training over 10 training activities and is not designed to create fully automatized skills in the learner. Students acquire experience with all the critical features and functions of the software, but spending the necessary time to completely internalize and automatize the menu commands was a considered to be a waste of precious academic time. The compromise was to initially train the students so that the commands were familiar and accessible, and allow them to develop the more fully automatized skills as a function of extended practice gained while engaged in educational tasks.

Software Consideration #3: Defining Robotic Motion and Control

The definition of robotic motion was developed by first determining the space requirements of the student's educational tasks and the available space within the robot's envelope. It was determined that the spaces behind the robot and on the periphery of it's operational envelope would eventually be used as tool storage places, while the primary working areas should be kept clear to allow for easy set up and use by teachers, therapists and students. Once the workspace's designated uses were determined it was possible to investigate the types of motions that students would need to appropriately access and use the robot. In the course of the work at ERL/OSU, five robotic movements were determined to be critically related to control over a workstation-based educational environment:

AXIS CONTROL: Movement of the robot is by commands that indicate the degree of rotational movement and direction of a specific robotic axis motor (In this case, the commands A-F). The individual motors at each of the axis points (degrees of freedom = 6) activate simple movement of the joints (axis) of the robot in an available direction. The commands are always relative to the robot's current status. <u>All points</u> in the robotic workspace are accessible via axis control movements.

Movement Examples:

Move axis motor (B) 50 degree counterclockwise.

Move axis motor (D) 40 degrees clockwise.

VECTOR CONTROL: Movement of the robot is by commands that indicate a coordinate position (x, y, or z) and a direction in the Cartesian coordinate system. The resulting motions can be grossly described as "up, down, left, right, in and out." The commands are always relative to the robot's current status. All points in the robotic workspace are also accessible via vector control movements.

Movement Examples:

Move 5 units in the +X direction.

Move 8 units in the -Y direction.

CYLINDRICAL CONTROL: Movement of the robot is by commands that indicate a coordinate position (F, Z, or R) and a direction in the Cylindrical coordinate system. This includes the three coordinates of height, angle, and distance from origin. The commands are always relative to the robot's current status. All points in the robotic workspace are accessible via cylindrical control movements.

Movement Examples:

Move in +F direction, 5 units.

Move in -Z direction, 8 units

Move in -R direction, 3 units from origin.

POSITION CONTROL: Movement of the robot is by commands that indicate a desired end position in a predefined, structured environment. The resulting robot position is a specific location irrespective of the robot's physical status at the time of the command. Only a limited number of predetermined positions are available in the robotic environment at any one time.

Movement Examples:

Move to Toolspace A.
Move to Workspace D.
Move to Fork.

PROGRAMMED TASK CONTROL: Movement of the robot is by commands that indicate a process and/or task that the robot is programmed to carry out. Movement Examples:

Pick up tooth brush, bring it back to position 1.
Shake up the bottle.
Turn on the light switch.

These types of robot control features effectively encompass the necessary and available motions of the UMI-RTX manipulator. They may also describe the range of control features available to all manipulators, regardless of the geometric shape of the robot's envelope.

Emerging Issues in Robot Control Software

"Emerging issues" are robotic software design problems that may be generalizable to other robotic environments and which are unresolved at this time. Meaningful solutions, even though not optimal, were made to each issue within the ERL/OSU project, but the issues remain under investigation. It may be that certain patterns may emerge from concerted research into the topography of the following issues and problems.

Direct Control versus Deferred Control

Most of the time, control of the human arm is carried out without conscious intervention. We seldom compose a plan of how we must move individual parts of our arms in order to accomplish a goal. In this way, the human arm functions under a kind of "direct control" that allows for selection, targeting, and activation without excessive planning of movements. **Direct control** is an analogous robot control feature that involves a single specific student input or response immediately activating a single specific robotic motion (i.e. "move the wrist to the left", "go to the spoon", or "move up"). **Deferred control** is a control feature that involves a two step process: the user first constructs a planned robotic motion by selecting one or more inputs from the menu; and secondly, makes a final input that executes the previously planned robotic motion. (i.e. [step1] select wrist and select left, [step 2] go; or [step 1] select spoon, [step 2] go; or [step 1] select z axis and select +(up), [step 2] go).

The benefits of direct control are: 1) feedback from actions and knowledge of results is immediate and observable; and 2) fewer inputs from the user are required to move the robot. However, the possibility for making errors using direct control input devices is high, especially with students who experience severe spasticity or athetosis of muscular responses.

Deferred control allows for more flexibility in student input options by adjusting to the student's access needs as a result of feedback from previously planned inputs. However, a greater number of student responses are usually required in deferred control software, with less stringent demands for accuracy in movements. This means that deferred control access strategies are almost always slower and require more student responses than direct control, but they also allow for students to reflect upon their choices and compose responses. Their use in educational endeavors must be cautiously employed so that students are both successful in their planning of actions and also have quick and effective interactions with the intended focus of the effort -- the instructional materials and related concepts.

The Balance of Control: Student and Computer

The popular vision of tomorrows robots are the "androids" we have seen in "Star Wars" or "Star Trek" which seem to be intelligent and autonomous, but which are nominally subservient to humans. In this and other ways, technology has traditionally been conceived of as the servant of humanity. However, when technology and people work together the delineation of roles blurs somewhat, raising important questions about the shifting balance of control within the interaction. Norman (1986) speaks of these tradeoffs between an "intelligent" and "powerful" computer-controlled system and a user-controlled system:

> A "powerful," "intelligent" system can lead to the well documented problems of "overautomation," causing the user to be a passive observer of operations, no longer in control of either what operations take place, or of how they are done. On the other hand, systems that are not sufficiently powerful or intelligent can leave too large a gap in the mappings from intention to action execution and from system state to psychological interpretation. The result is that operation and interpretation are complex and difficult, and the user again feels out of control, distanced from the system. (p. 49)

This is a critical design issue because inappropriate or prolonged control by the computer, or the user, might be deleterious in meeting the needs of the disabled student. The reasons for this are twofold: first, since the students have generally been passive observers most of their lives, maintaining a passive mode of interaction with the environment would be in direct conflict with the fundamental goal of personal independence in an educational setting. Secondly, the students have lived with the frustration of being distanced from the world because of its complex and difficult-to-control nature. The software design should address these human concerns by determining the levels and balance of computer-control and human-control required to successfully interact with the educational tasks.

The ERL/OSU software had to be flexible enough to operate within the science laboratory domain without being required to identify and map out the exact placement of each object within the workspace. A range of control options were available for the student to use that would maximize the advantages of both computer-controlled and student-controlled motions. The benefit of having this capability is that the student has control of the more precise workings of the robot within the lower-level areas (i.e joint control), as well as the speed and power of the preprogrammed positions that can move the robot quickly over a large area or through a complex, multi-part task.

[[INSERT PHOTOGRAPH #2 HERE]]

The Representation of Dimensional Motion

This area is the unique domain of software meant to provide control of robotic devices within mobile or workstation environments. The software design team posed several different design scenarios that were investigated as potential methods of adequately representing the critical features of the robotic environment, including the components of the robotic system and the actions that it could perform in three-dimensional workspace. The three scenarios developed as potential solutions were:

1. A **Characterization** of the robot with an anthropomorphized description of joint parts (i.e. wrist, elbow, shoulder, waist); or as an animated creature (i.e. a goose, turtle). Schneiderman (1987) discusses the temptation to use anthropomorphic characterizations of a program by saying, "Attributions of intelligence, independent activity, free will, or knowledge to computers can deceive, confuse, and mislead users. The suggestion that computers can think, know, or understand may give users an erroneous model..." The temptation to anthropomorphize a robotic manipulator is even stronger because of the impact of early engineering robotic designs that sought to imitate the movements of the human arm. In fact, the shorthand manner of referring to the manipulator as a "robotic arm" when they may not even resemble human arms (as in the SCARA industrial configuration) is clear evidence of early and persistent anthropomorphic images of robotic devices.

The Characterization representation also has useful associations to the outside world that may make it easier to learn than the other options, however some of these associations had a number of distracting inconsistencies. For example with the human arm as the exemplar, one quickly notices that the functioning of the robotic "wrist" differs dramatically compared to that of the human wrist. The robot "wrist" is more like the human knee that only moves in one plane as compared to the multi-planar and highly versatile human wrist. In other comparisons, one finds that the robotic device has many more capabilities than the human arm, reinforcing differences rather than similarities. Finally, there was the potential problem that since the physically disabled student may have problems visualizing what "normal" arm/hand movement is, the use of such characterizations for this population may be meaningless.

2. An **Iconic Representation** of the robot with either a **Static Iconic** representation utilizing a static graphic image of the robot which would highlight axis motions as they were inputted by the student user; or a **Dynamic Iconic** representation utilizing an animated graphic image which would move on the monitor in synchronization (real time) with the robot movements. Useful graphic representations are very difficult to accomplish because of the robot's ability to make movements resulting in the joints transforming into totally different orientations than the iconic image. In a situation like the static iconic representation, the movement directions will sometimes be reversed and the student will likely become confused about the actual position of the manipulator in relation to the corresponding highlighted joints. This problem is apparently endemic to all stationary, non-rotating images of any device that is meant to operate in three dimensional space.

The dynamic iconic representation was another possible solution to the problems encountered with the static iconic representation. If the screen could display the robot dynamically, then the graphic image could always be in the same orientation the robot is, with none of the confusion associated with static iconic images. One potential visual spatialization issue that arises with this solution is related to the the effectiveness of using wireframe or solid graphic images to portray robotic joints. According to research by Savotka (1988), wireframe icons, when displayed at most angles, did not provide sufficient visual information required by most students to determine joint angulation. Her findings indicated that some students don't see wireframe icons as 3-dimensional images when the figures are rotated and transformed in dimensional space. The possible limitations of wireframe images and the transformational problems of solid graphic images present serious issues to the designer of robot control software which can only be resolved by further research.

3. An **Abstract Symbolic Representation** utilizing unrelated letter, numbers, colors, or other symbols to represent the functional hardware components or spatial locations designated in the workspace. This form of representation was chosen for use in the ERL/OSU software primarily because the motion of the robotic arm was determined to be unique, and not able to be consistently and accurately compared to any other concrete or graphic representation. It was conjectured that raising the level of abstraction would eliminate the inconsistencies and inaccuracies in representation experienced by the two previously described methods.

Basically, abstract representations require that the student create a "robotic identity or marker" for each individual character without distractions originating from externally imposed representations. This makes the task of initially learning the system harder because of the difficulties with linking abstract symbols to functional movements of the robot. However, once the student achieves a reasonable degree of automatization of the software through the training and educational activities -- they are able to use the robot to do a variety of object manipulations, working semi-independently in a science education laboratory setting.

Evaluating the Effort

The evaluation of the effectiveness of the ERL/OSU software is incorporated within a larger research agenda that seeks to understand the interactional nature of the educational robotic environment. Research in the work performed with disabled students includes pretest and posttest data on the development of automaticity in motor control skills and in qualitative descriptions of the interactions occurring in the robotically-aided laboratory environment. Methods for data collection include field observations, interviews, the Space Visualization Test from the Southern California Sensory Integration Tests, the "Single-Input Control Assessment" from the Easter Seal Communication Institute, and a Motor Control/Cognitive Mapping Assessment.

The field based research has yielded several themes pertaining to those factors that influence the acceptability and usability of the robotic environment. These themes include training methodology, the transparency of the robotic system (the degree to which the technology itself is apparent to the user as he/she performs tasks), and curricular applications. Continuing data collection and analysis will solidify and/or modify the elements of each theme. The motor control/cognitive mapping test is beginning to yield some interesting data regarding time/accuracy trade-offs and spatial processing. Each test requires progressively more difficult spatial processing but maintains the same motor control effort. Two measures are taken on each of the three tests: 1) accuracy in pressing a switch on the input device that corresponds to a menu item on the computer monitor, and 2) time between the appearance of the stimulus and the press of the switch. The third test was designed to reflect the development of cognitive mapping skills of the menu the students use while manipulating the robot. The arrangement simulates the robot, monitor, and input device working space. It is hypothesized that as the menu becomes better mapped in the students' minds, the students won't need to look at the monitor for the corresponding column. Cognitive mapping may also serve as an indication of technology transparency, yielding new evidence of the importance of a good fit between the input device and the device-control software.

Future Directions and Conclusions

Limitations of the ERL/OSU Design

Some limitations have become evident in the initial field testing of the ERL/OSU program which should be noted:

Flexibility: the current software screen display is device-dependent in that it was designed and developed specifically for a 5-slot switch device. This severely limits the generalizability of the screen design to other input devices (e.g. single-switch devices, touchscreens, light/laser).

Interactional Speed: is considered to be inadequate for purposes of effective and speedy manipulation of educational materials. The causes for the inadequate pacing could be due to either the complexity of the current menu's abstract characters or the scanning methods used to access the commands.

Future Directions in Robot Control Software for Disabled Users

The "optimal" software interface will provide powerful technical features in the construction of their libraries, position and object data structures, and in their user input drivers (Gilbert, 1989; Gosine, Harwin and Jackson, 1988). In addition, they will feature effective control and display functions that provide the cognitive and affective bridges for the student to access the power of the robot and computer. One idea that may facilitate this bridge-building involves the use of "hybrid" designs which integrate both Menu Selection and Direct Interactional strategies for the input of information. There is a need for the user to be able to alternate between the types and levels of control available with robots, since at times the most effective movement may be via direct manipulation while at others via a sequence of pre-planned movements. Direct manipulation methods allow for more immediate and repeated robotic movements, both of which allow for a faster interactional speed between user input and robotic response. However, the inability of some disabled students to use direct manipulation methods and the need to use deferred control methods for certain educational activities make it important to also have available menu selection methods for the planning of robot movements.

A Last Look at "Access and Control"

The critical issues identified by work at ERL/OSU revolve around the companion concerns of access and control of the educational robotic environment. An attempt has been made to describe a set of considerations that involved specific adaptations toaccommodate disabled users; and also a more generic set of software design issues that appear to be relevant in the use of robots as educational tools by either non-disabled or disabled students.

Access has physical, cognitive and affective aspects which must be considered when designing both adaptive input hardware and a software interface that provides the disabled user a window for using the robot as a functional educational tool. **Physical access** involves the identification and selection of the appropriate adaptive input device(s) that allow for the disabled user to make a series or sequence of planned responses. **Cognitive access** implies that the program is understandable and transparent to users within specified reading, grade or age levels. Finally, software that affords **affective access** is pleasurable and aesthetic to the intended users.

The reality of the software design process often imposes a number of logistical and practical barriers that disallow extensive design and testing of a variety input devices and related control software. The selection of a multiple-switch device as the primary input strategy for the ERL/OSU software program provided a moderate degree of access for physically disabled students able to reach for, cross the midline of their bodies, and depress switches. This does not imply that such strategies are optimal or recommended for all populations of potential robotic users. The decision to emulate the switch's columnar layout on the control menu is considered to be a potential model for achieving compatible access strategies using a particular adaptive input device. It may be that layout or format should follow function; that is, the software displays may be most powerful when they exemplify the type of control strategies that are made possible by a specific type of input. For example, the joystick provides easy, continuous control over two-dimensional space; a screen display that effectively portrays this type of control will utilize characters and icons that provide easy linkage between the concepts that describe the continuous flow of control available via this device and the physical demands required to input information using the joystick. This modeling process implies that a variety of strategies might be employed with different input devices, and perhaps with different populations. The area is rich with possibilities for developing new and innovative access methods which work for different populations, ages and disabling conditions.

A great deal of design time is spent concerned with providing adequate levels of **Control** to the user. The functional and conceptual differences between interactive software designed for instructional purposes and control software for robotic devices requires that new approaches be identified and tested that deal with manipulation and mobility control as outcomes of software usage. The key design issues that must be dealt with include: 1) direct versus deferred control, 2) student versus computer control, and 3) the representation of dimensional motions. Each of these areas was found to be a determinant certain features of the internal and external components of the prototype robotic software developed by the ERL/OSU team. The notion of a powerful, vicarious control tool that can be easily accessed by even the most disabled of students offers new hope for independence in work, home and school life.

Our experiences have opened up a number of new windows on the effective control of complex technological devices by young disabled children. The design features discussed in this article attempt to create a basis for the discussion of robot control software and specifically, its efficacy and utility in educational environments. The larger issue of whether robots can be effective, cheap and friendly tools for the disabled remains an unanswered question. However, one of the determinants of the eventual outcome of the larger issue will be the quality of the software which the child will use to gain access and control to the capabilities of the robot.

REFERENCES

1. Anderson, L. Small Robot Arm in the Workplace to Aid in the Empoyment of Severely Physically Disabled Persons. *Proceedings of the Ninth Annual Conference on Rehabilitation Technology* , 1986, 6, 244-246.

2. Amori, R. (1988) TODUS: An English Interface with Rehabilitation Potential. *Proceedings of the 12th Annual Conference on Rehabilitation Technology(RESNA)*, 1989, 9, 189-191.

3. Bruner, J. The Course of Cognitive Growth. *American Psychologist*, 1964, 19, 1-15.

4. Dray, S.M. Ogden, W.G. and Vestewig, R.E. Measuring Performance with a Menu-Selection Human-Computer Interface. *Proceedings of the 25th Annual Meeting of the Human Factors Society*, 1981, 746-748.

5. Flavell, J.H. *Cognitive development*. Englewood Cliffs, NJ: Prentice-Hall Inc., 1977.

6. Gilbert, M., Caruso, J., Mahoney, R. and Fee, J.Development of a programming environment for rehabilitation robotics. *Proceedings of the 12th Annual Conference on Rehabilitation Technology*, 1989, 9, 377-379.

7. Gilbert, M., Minneman, S., and Pham, T. CALVIN: New Perspectives on a Robot Language. *Proceedings of the Tenth Annual Conference on Rehabilitation Technology*, 1987, 7, 802-804.

8. Gosine, R.G., Harwin, W.S., and Jackson. R.D. (1989) Applications of the CURL programming environment. *Proceedings of the 12th Annual Conference on Rehabilitation Technology(RESNA)*, 1989, 9, 192-194.

9. Hofman, H.H. & Ricker, K.S. *Science Education and the Physically Handicapped*. National Science Teachers Association, Washington, D.C. 1979.

10. Horowitz, D.M. and Hausdorff, J. *A User-Intuitive Speech Control Language for Text Processing and Robotic Task Planning.*

Unpublished manuscript. Rehabilitation Engineering Program. Tufts University School of Medicine. Boston, MA., 1989.

11. Hoseit, K., Liu, N., & Cook, A. (1986). Development and Use of a Robotic Arm System with Very Young, Developmentally Delayed Children. *Proceedings of the Ninth Annual Conference on Rehabilitation Technology* , 1986, 6, 244-247.

12. Household Economic Studies. *Disability, Functional Limitation, and Health Insurance Coverage: 1984-85*. U.S. Department of Commerce, 1986, Series P-70, No. 8.

13. Howell, R.D., Damarin, S.K., Clarke, J.A., & Lawson, J. Design Issues in the Use of Robotic Devices as Cognitive Prosthetic Aids with Physically Handicapped Children. *Transitions in Mental Retardation*. In Mulick, J. and Andorak, R. (Eds.) Ablex Publishing Co.: Norwood, NJ., Forthcoming, 1989.

14. Howell, R.D., & Clarke, J. A.. The Use of Robotic Devices as Prosthetic Learning Aids. *Proceedings of the 2nd Invitational Research Symposium on Special Education Technology*. Center for Special Education Technology, Reston, VA., 1986.

15. Howell, R.D., Baker, P., and Mayton, G. Design Issues in the Use of Robots as Cognitive Enhancement Aids." *Proceedings of the Fifth International Conference on Technology in Education*, Edinburgh, Scotland,1988, 1, 50-54.

16. Illich, I.*Tools for Conviviality*. Harper & Row: New York, 1973.

17. Kephart, N.*The slow learner in the classroom (2nd ed.)*. Columbus, OH: Merrill, 1971.

18. Kwee, H.H., Duimel, J.J., Smiths, A.A., Tuinhof de Moed, Van Woerden, J.A., and v.d. Kolk, L.W. The MANUS Wheelchair-Mounted Manipulator: Developments Towards a Product Model. *Proceedings of the 11th Annual Conference on Rehabilitation Technology*, 3, 460-462, 1986.

19. LaBerge, D., and Samuels, S.J. Toward a Theory of Automatic Information Processing in Reading. *Cognitive Psychology*,1974, 6, 293-323.

20. Landauer, T.K., and Nachbar, D.W. Selection from Alphabetic and Numeric Menu Trees Using a Touch Screen: Breadth, Depth, and Width. *Proceedings of Human Factors in Computing Systems*, New York: ACM SIGCHI,1985.

21. Leifer, L. *Robotics for the disabled.* Rehabilitation Research and Development Center. Palo Alto, CA.,1983.

22. Levine, S., Korem, Y., Kirsch, N., Borenstein, J., Yaros, L., BeMent, S. Intelligent and Mobile Robot Guidance System for Cognitively Impaired People. *Proceedings of the National Science Foundation Conference, "Intelligent Control to Aid Persons with Cognitive and Physical Disabilities"* (in Press), 1989.

23. Michalowski, S. The Need for Intelligent Assistive Robots, *Proceedings of the National Science Foundation Conference, "Intelligent Control to Aid Persons with Cognitive and Physical Disabilities"* (in Press), 1989.

24. National Health Interview Survey. *Disability Statistics*, 1985.

25. Norman, D.A. and Draper, S.W.*User Centered System Design.* Lawrence Erlbaum Associates, Hillsdale: NJ.,1986.

26. Payne, S.J., and Green, T.R.G. The User's Perception of the Interaction Language: A Two-Level Model. In A. Janda (Ed.) *Proceedings of the CHI '83 Conference on Human Factors in Computing Systems*. ACM: New York,1983.

27. Piaget, J.*The Psychology of Intelligence.* Totowa: NJ: Littlefield, Adams and Co.,1976.

28. Reisner, P. Formal Grammar and Human Factors Design of an Interactive Graphics System. *IEEE Transactions on Software Engineering*, 5, 229-240, 1981.

29. Riley, M.S. User Understanding. In Norman, D.A. and Draper, S.W. (Eds.) *User Centered System Design.* Lawrence Erlbaum Associates, Hillsdale: NJ, 1986.

30. Rutkowski, C. An Introduction to the Human Applications Standard Interface, Part 1: Theory and Principles,1982,*BYTE*, 7, (11), 292-310.

31. Savotka, S.L. Three Dimensional Computer Animated Graphics: A Tool for Spatial Skill Instruction, 1984, *ECTJ*, 35, (3), 133-144.

32. Schneiderman, B. *Designing the User Interface*. Reading: MA: Addison-Wesley Publishing Co.,1987.

33. Seamone, W. & Schmeisser, G. (1986). Evaluation of the APL/JHU Robot Arm Work Station, *Proceedings of the Ninth Annual Conference on Rehabilitation Technology* , 1986, 6, 252-254.

34. Tachi, S. Electrocutaneous Communications in Seeing-Eye Robot (MELDOG). *Proceedings of the 4th Annual Conference, IEEE Engineering in Medicine and Biology*, 1982.

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ERL/OSU SOFTWARE
SCREEN MENU DISPLAY

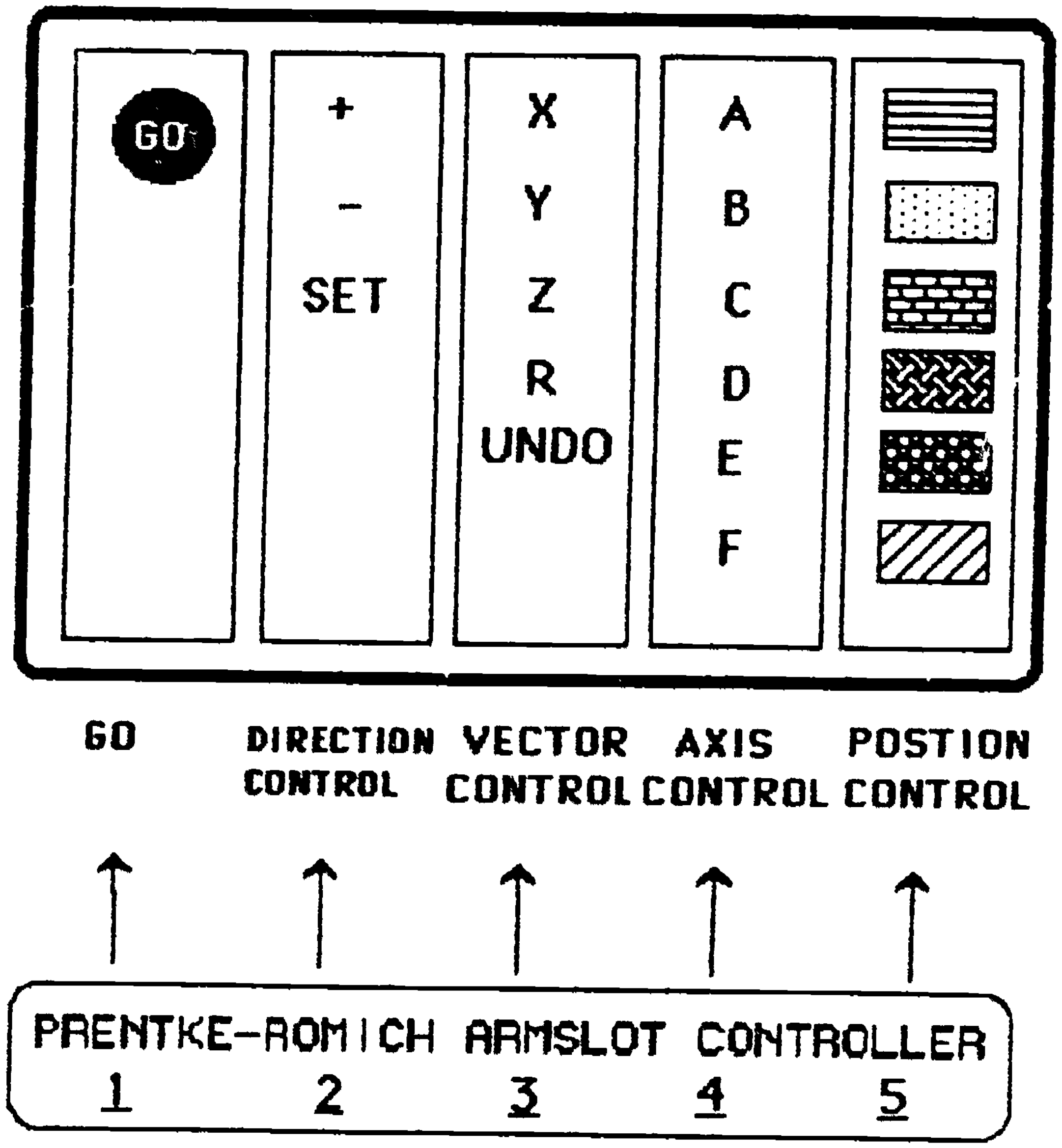
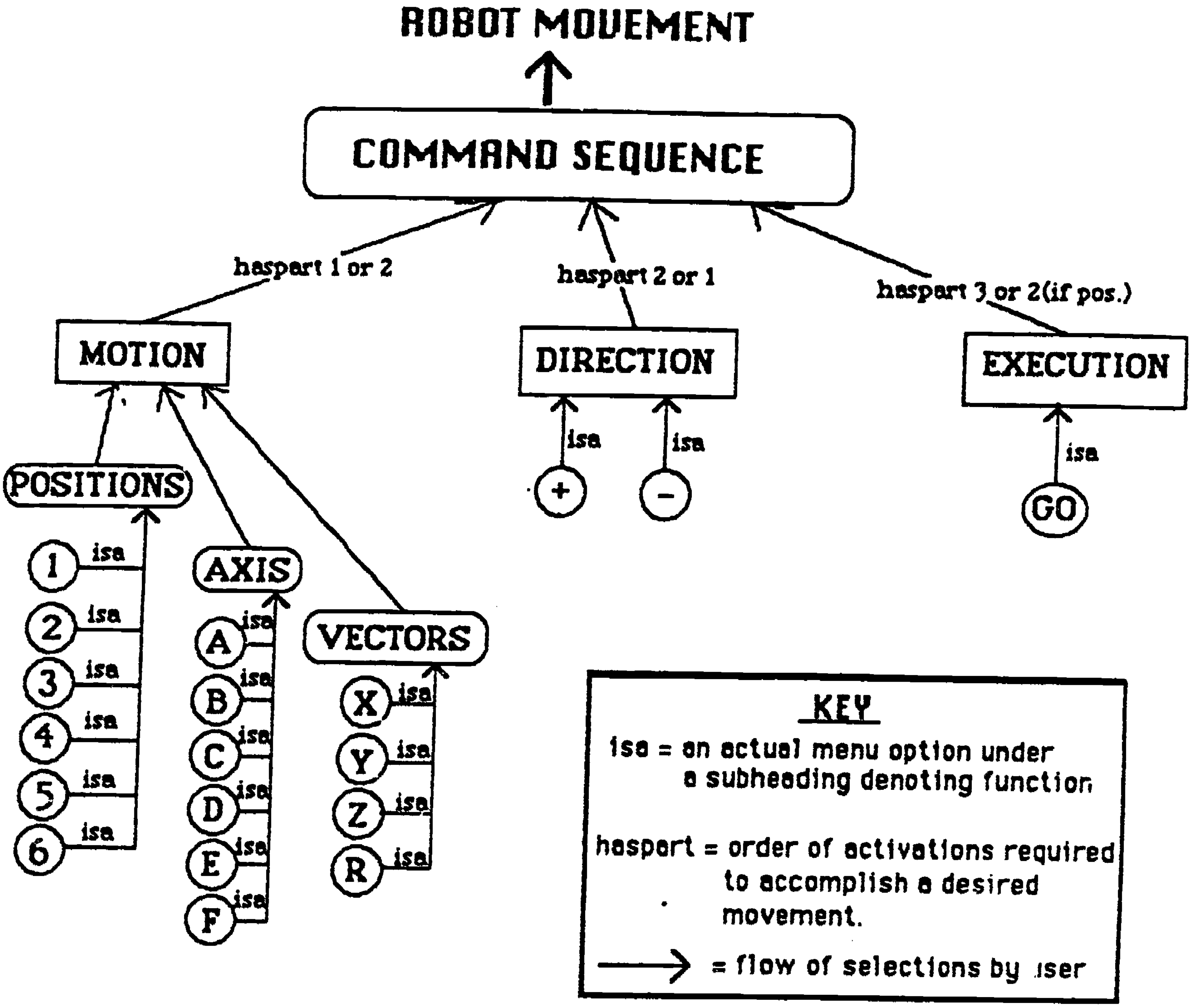


FIGURE 1

ERL/OSU SOFTWARE SYNTACTICAL STRUCTURE



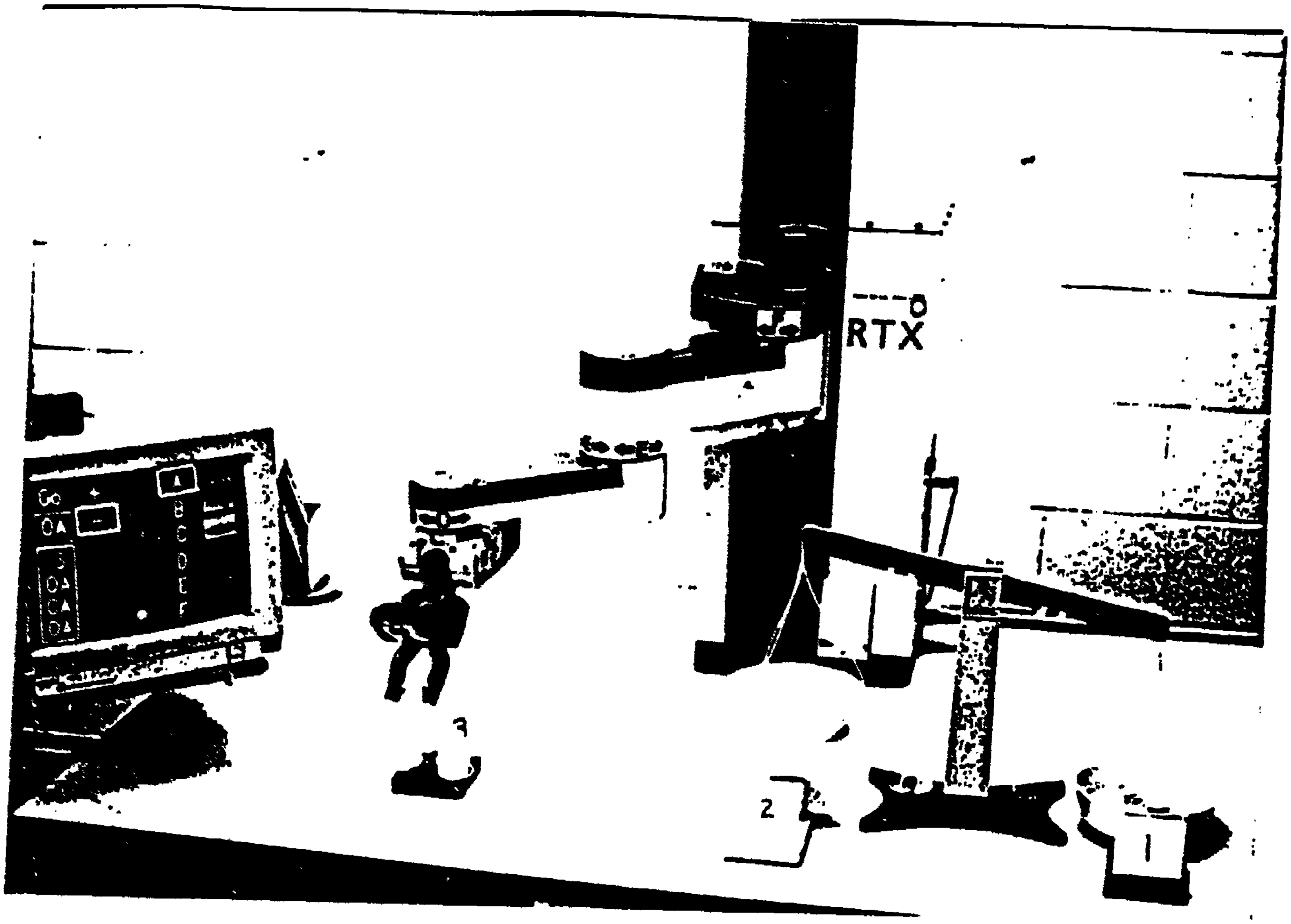
KEY

isa = an actual menu option under a subheading denoting function

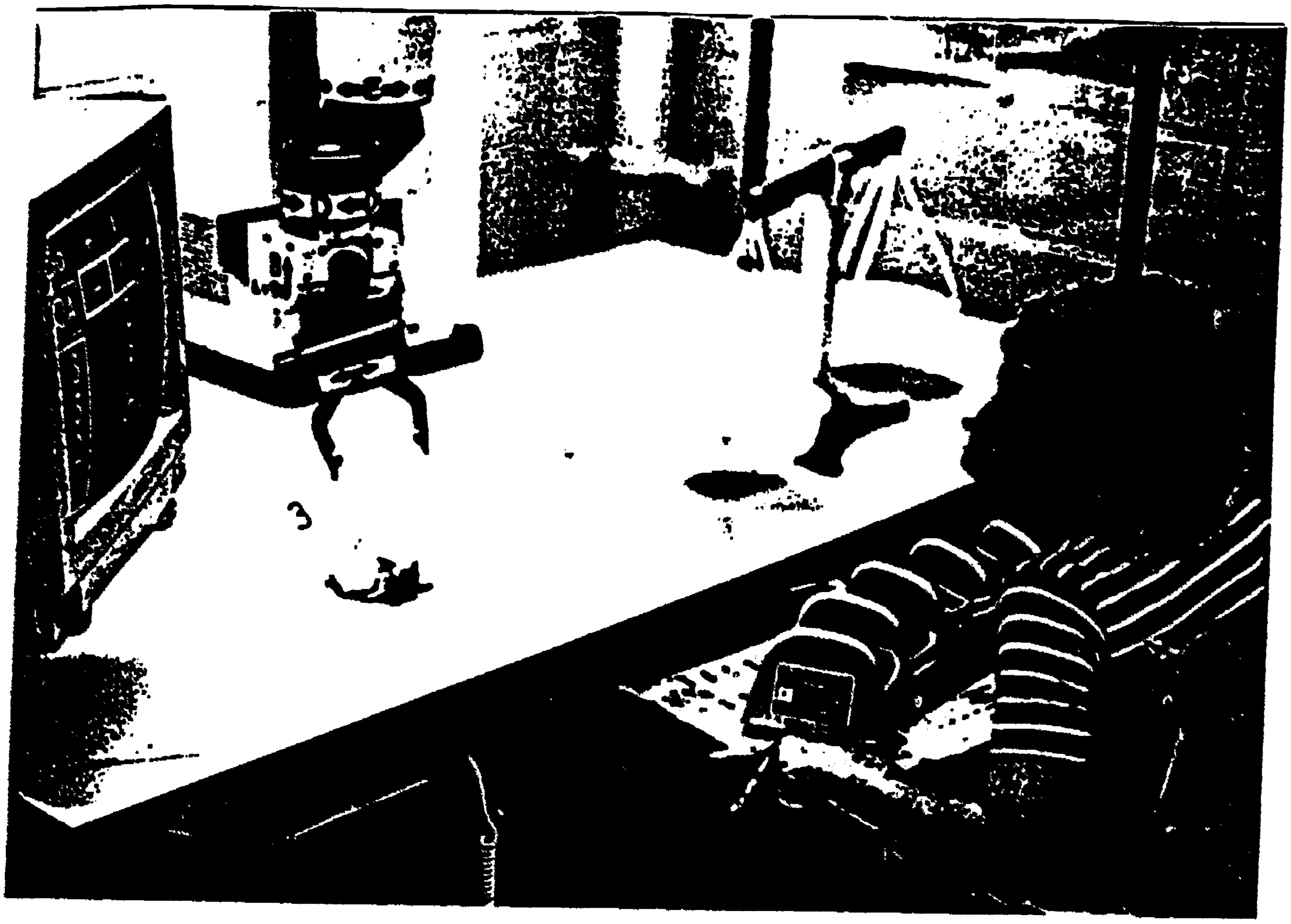
haspart = order of activations required to accomplish a desired movement.

→ = flow of selections by user

FIGURE 2



Photograph #1: Prototype Robotic Manipulator Hardware and Software



Photograph #2: Student using software to control a robotic manipulator

Robot Technology: Implications for Education

Paul E. Post, Richard D. Howell, and Lew Rakocy

Introduction to Robots

Robots are becoming increasingly more commonplace. The media have presented two disparate views of robots; (1) industrial robots touted to be a vital link to the future prosperity of our industries and (2) science fiction robots in films and literature that help us play out a variety of possible social futures. However, a third category of robots, meant to be used in education, is starting to make inroads in educational practice. The news media and several retailers have introduced robots for home use which are still very expensive, but give a glimpse of the future integration of robots into society.

Acting on the knowledge that today's students will probably live in a world in which robots will be commonplace, technology and science educators are starting to include robotics as integral parts of their curriculum. Educators, in general, are starting to realize some of the potential that robots have to offer. One of the largest areas of educational robot usage today is in the application of robotics to aid handicapped individuals. However, as robots become increasingly available, it is important that educators learn the basics of robotic technology and the variety of educational applications of robots.

What Is a Robot?

Joseph Engelberger, the founder of Unimation, a pioneer in the robotics industry has said, "I don't quite know how to define one but I know one when I see it (Bonnett & Oldfield, 1984, p. 8)." A more precise definition is offered by the Robotics Institute of America, "A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks (p. 8)." In essence, a robot is a combination of computer technology and mechanical technology with the dual goals of manipulation and movement. Two key elements differentiate robots from other types of devices: first, they are reprogrammable, allowing functional changes to be made easily; secondly, a robot has controlled movement either by changing its location or by moving objects.

People have been attempting to create mechanical helpers since antiquity. It is only in the last 40 years that these mechanical devices have been given programmable computers that function as 'brains.' The addition of computers to various mechanical devices has allowed robots to become adaptable for a variety of tasks. This flexibility has revolutionized industry and will eventually revolutionize our homes and offices as well. Research is continuing to improve the ways in which robots sense their environment, process information, and manipulate objects. Robot technology still has a long way to go before robots as sophisticated as those seen in science-fiction films are commonplace.

Several different robots now exist that can be used in education. Perhaps the most exciting applications of robots use the robot as a prosthetic aid to allow handicapped persons to interact with their environment in ways that have not been previously possible. Robots can also serve as a teaching tool to help handicapped students learn. A robot is an exemplar of many aspects of the technological world that we live in today. How a robot works, how to program it, maintain it, and develop applications for it are all possible means of using the robot as an object-of-study. Finally, the logical thought processes developed in programming a robot can be applied to many other curricular areas.

What Makes Up a Robot System?

A complete robot is not a single object but actually a system of parts working together as one unit. Each part is indispensable to the function of the robot. The major parts of a robot are the controller, the power supply, the manipulator, and the end effector. (See Figure 1).

The controller tells the rest of the robot systems what to do. Controllers vary from mechanical devices that turn on and off switches through the use of a rotating drum, to computer systems that deal with a variety of information from sensors, video signals, and other computers. The controller is the part of the robot that is programmed with the steps needed for the robot to accomplish its task. The necessary steps may be entered into the controller by a computer keyboard or a teach pendant. After the program has been entered the controller implements the program.

The power supply provides the energy that allows the robot to perform its designated func-

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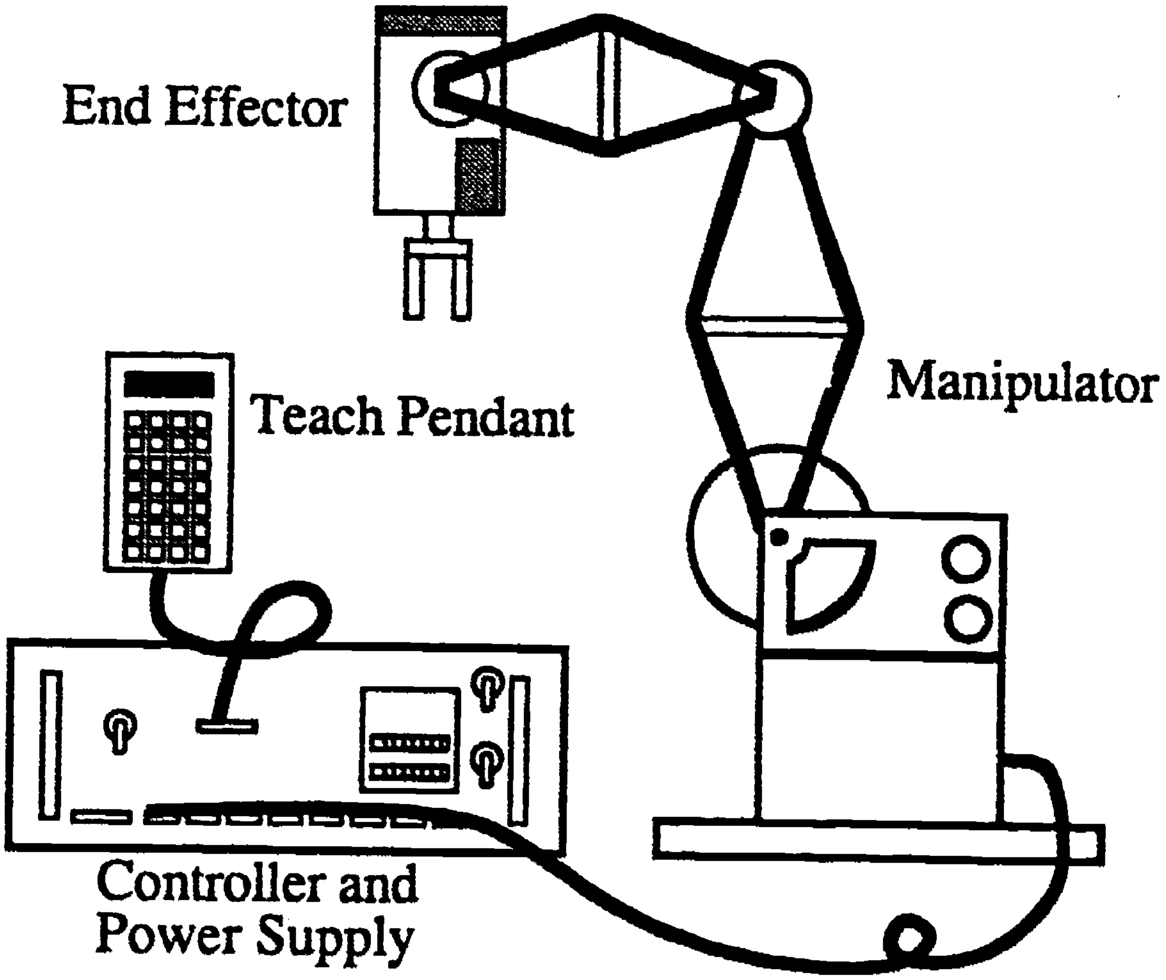
Figure 1

Major Robot Parts



tions. There are three major types of power sources used with robots: electric, hydraulic, and pneumatic. Some robots are powered by electric motors which allow accurate positioning, a clean, quiet work environment, and are fairly inexpensive. The major disadvantages of electric motors is that they have limited power and are usually somewhat slow. Hydraulic robots use hydraulic fluid to power the movements of the robot. Through the use of cylinders and motors, both linear and rotary motion can be achieved. Hydraulic robots are both strong and fast but are also complex and expensive. Pneumatic robots are very similar to hydraulic robots but use compressed air as the power transmission medium. Pneumatic robots are very fast but not as precise as the other two types.

The manipulator is the mechanical part of the robot. It contains the actuators which convert power into useful [illegible]ements. The manipulator most commonly re[illegible] to the 'arm' of a robot arm. The purpose of the manipulator is to position the end effector. Manipulators are commonly made of metal and may have an outer covering of metal or plastic while some have an exposed skeleton and cabling.

An end effector is in essence a 'hand.' In industry, there is a wide variety of end effectors, however, the most familiar is the two-fingered gripper. Other end effectors include vacuum and magnetic pickups, welding torches, paint guns, laser measuring tools, and three-fingered hands. Currently, end effectors are being developed that have a sense of 'feel' and flexibility greater than or equal to human fingers.

What Types of Robots Are There?

There is a wide variety of robots available today with differences between robot models ranging from trivial to total incompatibility. Knowing how to match your needs with the terminology used to describe robots is an important step in deciding which robot to purchase. Perhaps the most important aspect of controlling a robot is whether or not the controller receives feedback from the manipulator. For accuracy over repetitive tasks, feedback is essential. Feedback is information originating from the robot that indicates it has done what it was requested to do. A robot with feedback capability is more expensive and is described as being a 'servo robot.' A robot without feedback is a 'nonservo robot.'

Some robots are described in terms of the environment for which they are designed to be used. Industrial robots are designed in a wide range of styles and sizes depending on their intended purpose. Examples of industrial robots range from small but extremely precise robots that can assemble watches to robots that can lift tons of red-hot steel from a mold. Educational robots are small and designed to simulate industrial robots. Generally educational robots trade lifting capabilities and feedback for lower cost.

Axes of motion are used to describe how many independent movements a robot can make. Sometimes called degrees of freedom, increasing the number of axes gives greater flexibility but also requires greater complexity in controlling the robot.

The type of end effector being used by a robot can also be used to identify it. Keep in mind that end effectors can usually be changed. A robot holding a welding torch would be considered a welding robot. A robot with suction cups as an end effector is a pick-and-place robot. Robots with grippers are more flexible and usually not defined by their end effector.

How Do the Parts Connect Together?

Robots are rarely self-contained and require their separate parts to be connected. The power supply is connected to the manipulator and the end effector with wires, or hoses depending on the power source. The end effector is connected to the manipulator mechanically. The controller is connected to the manipulator and the end effector using electrical cables. If used, a computer can be connected to the controller through standard serial or parallel interfaces; occasionally a special interface is required.

How Do You Program Robots?

Robots can be programmed using two basic methods. Teach pendants can be used to move the robot through the motions needed with each step being recorded; the robot then plays back each step as it was previously entered. The information for each step may be entered from a hand-held teach pendent or from a computer keyboard. After a program has been entered and debugged, there is usually some means of storing it either on disk or cassette tape. A second method is to directly program the robot using either a special robot programming language or one of the common programming languages such as Pascal or BASIC.

The teach pendant style of programming lends itself to working with handicapped people. If a person is unable to work either the teach pendent or the keyboard, a variety of input devices can be used in conjunction with menus to allow the robot to be programmed. Joysticks and switches, like the Prentke-Romich Arm Slot Controller can be used to enable the physically handicapped to assess and interact with the robot.

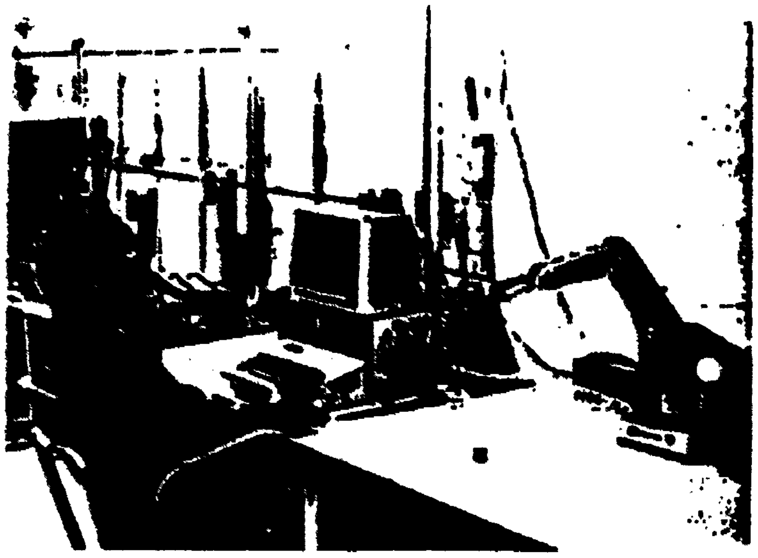
Table 1

Definition of Robot Utility Specifications

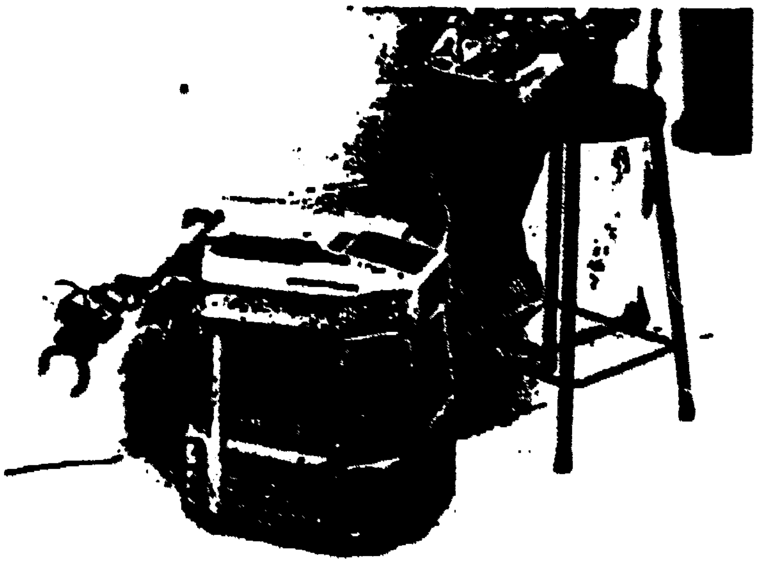
Payload	The type of load the robot can manipulate-considerations here include weight, size, and type of material.
Reach	The volume of space the robot can manipulate objects within. In addition to considering whether a robot will reach the points required it is important to consider if the robot can be physically limited from reaching points that may be hazardous to the user.
Speed	How fast the robot can move from one point to another-often each axis of movement has its own speed.
Controllability	The means of communicating commands to the robot. This may be a teach pendant, directly programming a computer, or even by voice.
Accuracy	The precision with which the robot can position itself. There are two components: a single movement accuracy, and repeatability, which describes its accuracy over a number of moves. Like speed, accuracy is often specified by axis of movement.
Mobility	The ability of a robot to move itself from one location to another. This may be through limited motion on tracks or independent motion on wheels.

Criteria for Selecting a Robot for Education

There are seven important criteria to be con-



The Marcraft Pro-Arm



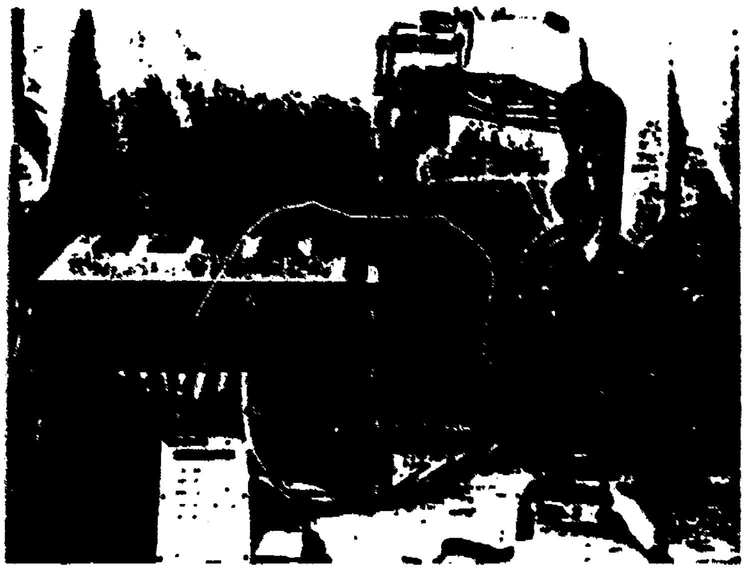
The Heathkit Hero I

sidered when selecting a robot for use in educational settings. First, and most importantly are questions related to utility. Is the robot under consideration appropriate for the task? In order to determine a robot's utility, the tasks to be performed must be identified, after which physical requirements can be determined, and then the requirements are compared with manufacturers specifications for the various robots being considered. The primary requirements important in considering a robot's utility include payload, reach, speed, controllability, accuracy and mobility. (See Table 1.)

Additional considerations are only important if the robot meets personal requirements with regard to the previously mentioned specifications. First, the cost of the robot is often determined by how stringent your specifications are. Currently there is growing competition in the educational robotics field; as sales increase so does competition. The availability of robots has also grown; most educational robot companies sell their products either directly or through representatives. Again, as sales increase so do marketing channels. The reliability of a robot is currently very closely related to price (basically, you get what you pay for!) and is generally pretty good since the market is small enough that producing a shoddy product might mean instant bankruptcy to a manufacturer. Second, a robot's maintainability is an important concern since any repairs not done by the customer will probably require that the robot be sent back to the factory for repairs. Third, versatility is important in allowing the robot to grow to meet future requirements and may also allow the cost to be shared with other programs in a school. Fourth, safety is a very important constraint. While Issac Asimov (1950, p. 6) has described three very important rules that all robots should follow, no robots today are manufactured with obedience to those rules. Most robots do allow both physical and programmed limits to keep the robot operating in a clearly defined work space. By keeping these considerations in mind while looking for the right robot, a decision can be reached that will be beneficial to your students.

Educational Applications of Robots

The educational applications of robotics in the mainstream of American education have been limited for several reasons. Among these are the cost of the hardware, a lack of knowledge about robots, and a lack of clearly defined curricular objectives. This set of shortcomings in the planning and implementation of robotic devices is quite common in contemporary education as educators attempt to make sense of and assimilate the new technologies that are becoming available at this time. However, a number of attempts have been made in using robots in a variety of different classes at different grade levels, from kindergarten to high school. It appears that most of the contemporary educational applications of robots can be grouped into one of several categories. (1) where robots are used as Exemplar of other concepts of processes; (2) where the robot is the **Object-of-Study**; and (3) where the robot is used as a **Functional Prosthetic Aid** with the handicapped. Each of these roles will be discussed in light of recent documentation of research and implementation efforts across the U.S.



The Rhino XR-2

Robots as Exemplars

The robot can be used as a physical exemplar of computer control over a mechanical device. The users can act on their environment from a long distance using a sophisticated mobile computer with manipulation capabilities. This ability to exert a more complex level of control over the external environment presents a philosophical dilemma to educators, since the use of "intelligent" machines poses ethical and social issues of growing importance in light of the inexorable advance of technology. The robot is perhaps the machine most often identified as a potential threat to the social milieu, but 'intelligent dishwashers,' VCRs, and telephones also impact our lives daily. It is important for students to learn about the uses and limitations of robots in order to put them to their best use.

The robot also functions as an exemplar of the programming process by accepting and responding to instructions sent to it in any one of a number of programming languages, including LOGO or BASIC (Watt, 1984; Marsh and Spain, 1984; Delgado, 1986). In this capacity, the robot accepts computer-transmitted data via a receiver and then responds to the commands with movement and/or manipulation. This use of the robot as a visual, "real-time" correlate of a program is a more concrete example of what programs are actually doing than many other ways of demonstrating coded structures or processes. As such, the use of the Terrapin Turtle, Topo, and the RB-5X robot as exemplars of Logo procedures has found its way into elementary and some kindergarten classes.

Many parts and subsystems on a robot may be used to exemplify scientific and mathematical principles. In science, the concepts of force, speed, acceleration, angular, momentum, and levers can all be demonstrated using robots. Math classes can see the relationships between three-dimensional cartesian points and see how trigonometric functions can be used to develop robot moves. In these ways, the robot becomes a part of other curricula and can become integrated into the educational process.

Robot as an Object of Instruction

The expanding uses of robots in industrial manufacturing and production has led to the development of a new curricular initiative in physics and industrial technology courses involving the robot as a field of study. These courses usually emphasize the integration of a number of interrelated areas: mechanical and electrical engineering, computer programming, and industrial design. These courses vary greatly in sophistication and are primarily designed to develop general literacy and pre-vocational skills at the middle and high school level; and engineering, programming, or technical support skills in higher education for later work in industry. These courses put a tremendous demand upon the knowledge of the instructors because of the complex and multidisciplinary nature of robots, especially in developing an understanding of how they work and how they can be used effectively in various settings. One approach to the introduction of robotics involves starting with a history of robotics and automation. The types of robots and terms used to describe them are introduced next. An in-depth look at each of the four robot systems might be followed by application of robots to solve common industrial problems. Throughout the process of learning about robots, students learn about safety and careers that are related to robotics (Michigan State Board of Education, 1985; Heath, 1985).

Vocational education is also deeply involved in teaching about robotics. Overseas competition has provided an impetus for American manufacturers to increase factory automation. Many states are working hard at attracting new industries, and an important part of the package they offer potential manufacturers is a work force trained to meet the needs of today's production. Many states therefore have invested in developing vocational education programs to provide skilled technicians that can install, use, and service robots. Vocational schools also have had to readjust their curriculums to account for the fact that as the use of robots becomes more widespread they will replace certain types of workers and that the demand for those workers decreases over time.

Robots as Functional Prosthetic Aids

Research and development work done throughout the U.S. has demonstrated the utility of the robot as a physical prosthetic devices for use by the orthopedically handicapped. These projects are primarily research-oriented, since the state of knowledge is in a seminal stage, with new information being developed at a rapid rate concerning hardware, software, training methodologies, and evaluative procedures.

The use of robotic devices as prosthetic physical aids has been shown to be technologically feasible and functionally effective (Hoseit, Liu, and Cook, 1986; Seamone and Schmeisser, 1986; Leifer, 1983). Progress in this area promises to generate a variety of electromechanical devices for the enhancement of human abilities which have been damaged or are non-functional. Although the use of robots in the field of rehabilitation engineering has demonstrated the prosthetic value of the devices (Dungan and McGill, 1985; Leifer, 1983), their potential in the comprehensive rehabilitation plan of physically handicapped individuals has yet to be fully realized. It appears that the prosthetic advantage afforded by robotic devices applies to certain physically handicapping conditions including spinal cord injury (Petrofsky and Phillips, 1983; Marsolais and Kobetic, 1986); with cerebral palsied children (Howell, Damarin, and Post, 1987), and with disabled geriatrics patients (Englehardt and Awad-Edwards, 1985).

Yet, there are many barriers hampering the adequate investigation of robotic applications in special education, including cost, hardware adaptation, and a software design and development (Moore, Yin, and Lahm, 1985). In addition there has been no specification of effective training methodologies in the work that has been done up to this time. Much of the work has focused primarily on the development of the physical parameters of robots, without acknowledgment of the significant cognitive impacts that probably accompany the manipulative prosthetic advantages. The cognitive impact of robotic use by the handicapped, especially by the young physically handicapped student, is an area which shows great promise but has received little research and development attention. With these considerations in mind, it is possible that the use of robotic devices may not only act as physical prosthetics but also as cognitive aids (Howell, Damarin, Clarke, and Lawson, 1987). The future of these devices is promising in this area and may provide answers to vocational and recreational needs of the orthopedically handicapped.

Summary

Robots are becoming increasingly visible in our society. They have become a focal point of our industrial rejuvenation and are starting to come into our schools and even our homes. A robot is a reprogrammable device that can manipulate its environment. In industry robots typically transport parts, weld, paint, and do a number of production tasks. A robot is a system comprised of four major subsystems; a controller, a power supply, a manipulator, and an end-effector. During the selection process it is important to keep an eye on the goals for using the robotics device and to be sure the robot under consideration can achieve those goals.

Three areas of robot usage are developing in education. In general, robots can be used to exemplify a number of scientific and technological principles. In the more specialized fields of technology and vocational education, the robot serves as a direct object of study by allowing students to learn how the robotic systems fit together and how robots influence society. Finally, robots are also serving as functional prosthetic aids allowing handicapped individuals greater access to their environment. The future will be an interesting and complex environment composed of 'intelligent' machinery coexisting side-by-side with human beings. The practical and philosophical issues posed by these devices promise us new levels of productivity and leisure-time, and new problems as the distinction between human and machine becomes more blurred. It will be up to educators at all levels to grapple with the issues raised by this new technology and integrate it where it is needed in order to prepare students for the future. ☐

References

Asimov, I. *I. Robot.* New York: Doubleday & Company, 1950.

Bonnett, K.R., and Oldfield, G. *The Everyone Can Build a Robot Book.* New York: Simon & Schuster, 1984.

Delgado, N. Push My Button. *Electronic Education*, 1986, *6*(2), 19-20.

Englehardt, K.G., and Awad-Edwards, R. Robotics in Long Term Health Care. *Proceedings of the Eighth Annual Conference on Rehabilitation Technology.* Memphis, TN: Rehabilitation Engineering Society of America, 1985.

Heath, L. *Fundamentals of Robotics: Theory and Applications.* Reston, VA: Reston Publishing, 1985.

Heckard, M. Career-Minded High School Students Are Commanding Robots. *TechTrends*, January 1986, 15-17.

Hoseit, K., Liu, N., and Cook, A. Development and Use of a Robotic Arm System with Very Young Developmentally Delayed Children. *Proceedings of the Ninth Annual Conference on Rehabilitation Technology*. Minneapolis, MN: Rehabilitation Engineering Society of America, 1986.

Howell, R.D., Damarin, S.K., Clarke, J.A., and Lawson, J. *Design Issues in the Use of Robotic Devices as Cognitive Prosthetic Aids with Physically Handicapped Children*. Manuscript submitted for publication, 1987.

Howell, R.D., Damarin, S.K., and Post, P.E. The Use of Robotic Manipulators as Cognitive Prosthetic Aids. *Proceedings of the Tenth Annual Conference of the Rehabilitation Engineering Society of North America*. Palo Alto: Rehabilitation Engineering Society of North America, 1987.

Leifer, L. *Robotics for the Disabled*. Palo Alto: Rehabilitation Research and Development Center, 1983.

Marsh, G., and Spain, T. Robots in the Classroom. *Electronic Learning*, March 1984, *3*, 48-53+.

Marsolais, E.B., and Kobetic, R. *Walking of Paraplegic Subjects with Computer-Controlled Electrical Stimulation*. (Report No. MSL 3). Cleveland: Motion Study Laboratory, 1986.

Michigan State Board of Education. *Michigan Industrial Arts Curriculum: Robotics*. Lansing, MI: Author, 1985.

Moore, G., Yin, R., and Lahm, E. *Robotics, Artificial Intelligence, Computer Simulation: Future Applications in Special Education*. Washington, D.C.: COSMOS Corporation, 1985.

Petrofsky, J.S., and Phillips, C.A. Electrical Stimulation of Paralyzed Under Feedback Computer Control. *IEEE Transactions of Biomedical Engineering*, 1983, *BME-30*(8), 510.

Seamone, W., and Schmeisser, G. Evaluation of the APL/JHU Robot Arm Work Station. *Proceedings of the Ninth Annual Conference on Rehabilitation Technology*. Minneapolis, MN: Rehabilitation Engineering Society of America, 1986.

Watt, M. The Robots Are Coming. *Popular Computing*, Mid-October, 1984, *3*(13), 71-77.

Designing an Educational Computer Game: Guidelines That Work

Audree Reynolds and Jeanette V. Martin

For thousands of years games have been played for amusement, but only recently has education applied the elements of game strategy to instructional purposes (Sleet, 1985). Many educational games are highly abstract, such as word games and crossword puzzles. Others are more concrete, representing life situations (de Tornyay and Thompson, 1982).

An educational computer game is an innovative learning activity in which the characteristics of effective computer-assisted instruction and game strategy are incorporated to meet a specific educational objective. The intent of this learning activity is to supplement and augment classroom learning, not to replace it. An appropriate game design capitalizes on the interest and motivational potential inherent to game strategy. Thus, the student's attention span is extended and a feeling that learning is fun can be created.

When the characteristics of effective CAI are combined with the motivation and interest potential of game strategy, an effective educational computer game can be designed.

The following design guidelines are offered to those who plan to develop an educational computer game and to those who will be evaluating the educational worth of such games. A well-developed, effective educational computer game includes these characteristics: (1) clearly stated educational objective and content; (2) gaming interactions that facilitate the mastery of the objective; (3) player control of interaction and game progression; (4) incorporation of challenge, fantasy, and curiosity; (5) prompt feedback on performance and progression; (6) mechanism for correcting errors and improving performance; and (7) positive reinforcement that is appropriately timed.

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Design Issues in the Use of Robots as Cognitive Enhancement Aids for Disabled Individuals

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The use of robots in the delivery of services to disabled individuals is a relatively new and unexplored branch of educational technology. Until recently, the complexity and cost of robotic systems made them impractical as educational interventions However, there are a variety of new robotics research and development efforts in the areas of rehabilitation, engineering, and education. The focus of this paper is upon several design issues involved in the development of robots as tools in the education of severely disabled individuals. The information presented has been developed from work on the cognitive and educational implications of robotic use by school-aged, orthopedically disabled children. The purpose of the research is to increase the learning potential, and consequently the personal independence, of disabled individuals through the use of robotic devices in educational environments.

INTRODUCTION

The presence of robots among us is a growing phenomenon that is often seen as the ultimate personification of the recent computer-related technological impetus. The notion of a mobile thinking device that can act on the world has both intrigued and horrified people since our first view of a robot in Fritz Lang's 1927 movie, "Metropolis". Historically, the predominant response to portrayals of such mechanical devices was negative, the robot was seen as an unnatural and unfeeling entity. Contemporary images of the robot as portrayed in children's cartoons, toys, books, and movies have done little to contradict this notion. Thus it is with apparent trepidation and fear, that society begins to confront the question of robots in their midst. The reality of the robot and its potential in our present and future society evokes a myriad of questions regarding technological development and the place of machines among humans.

Practical uses of robots began in the industrial sector, where robots have become a vital part of the automobile and ship manufacturing processes. Industrial robots are considered to have made a critical difference in the growth and dominance of the Japanese automobile industry (Feigenbaum & McCorduck, 1983). The performance of industrial robots has demonstrated the economical advantage over human workers on specified assembly and welding tasks. This advantage has spurred a new level of economic and industrial competition among the international trading community, creating an acknowledged need to maintain a strong robotics research and development emphasis in the U.S. (The Robotics Institute, 1986).

The use of robots in education has been confined primarily to vocationally-oriented classes, with most of the applications involving the teaching of programming languages and physics (Heckard, 1986), and industrial arts education (Marsh & Spain, 1984). Although robots have been used to teaching programming languages such as LOGO and BASIC to elementary-aged school children (Delgado, 1986; Marsh & Spain, 1984; Watt, 1984), these applications tend to use and view the robot as a physical exemplar of certain processes rather than as a tool within everyday life. The lack of clearly defined educational applications has hampered both the experimentation with and use of robots in educational settings. As a result, while robotic uses have had a significant impact in the industrial sector and the educational pathways associated with it, broad applications have not yet been made in education and training.

The use of robotic devices as physical prosthetics has already been shown to be technologically feasible and functionally effective in rehabilitation settings. Pioneering work by Leifer (1983) demonstrated that high-level spinal cord injury patients could use voice-activated robotic manipulators to do a variety of self-care tasks, such as brushing teeth, or fixing and presenting meals. Extensions of this work by Van der Loos, Michalowski, & Leifer (1987) have resulted in the development of a mobile robotic device that is presently being field tested with the same population. Specific issues in the ongoing research effort involve: 1) the human/machine interaction, 2) mobility, 3) machine autonomy, and 4) evaluation. Perhaps the most important contribution of the research of Leifer and his co-workers are the specification of a set of demands that can be applied to the robotic aid in order to achieve maximum utility to the handicapped user. These demands on the robotic system are:

1. It must be able to *acquire data* about the environment.
2. It must interpret the data in terms of an *internal representation* (or model) of the environment.
3. It should be able to *plan and execute* simple manipulative motions.
4. It must have a means of *communicating with the user* to present the results of data-taking, analysis, and planned motions.

> 5. It must be *safe*, in that the user must be able to stop any planned or ongoing motion at any time. (p.172)

The only study found which used handicapped children as subjects (Hoseit, Liu and Cook,1986), investigated the ability of seven young (CA < 36 months), developmentally delayed (MA = 5-6 months) children to use switch-driven robotic manipulators. The goal of the project was to provide a computer-controlled, manipulative system that would increase the control disabled children have over objects and social events in their environment. Field-based performance data was collected using the raw number of switch closures, switch closure durations, and patterns of switch activations. Observational data was also collected during the course of the robotic interaction with the subject. No quantitative data was reported in the article, but conclusions indicated that, "the use of continuous switch activation to complete movements of the robotic arm proved to be valuable in determining if the child understood that the arm would eventually bring the desired object within his/her reach." (p. 243)

Other workers in the field have discussed the prosthetic advantage, and cost-benefits afforded by robotic devices with very ill, home-bound patients and disabled geriatrics patients (Englehardt, 1984; Englehardt & Awad-Edwards, 1985). Projective cost comparisons of human attendant versus robotic aids indicate that, "robots, at an estimated $6.00 per hour, could reduce the cost of attendant care which now has a net cost of as much as $15.00 hour" (p.105). Progress in this area promises to generate a variety of electro-mechanical devices for the enhancement of abilities which have been damaged or are non-functional due to the effects of diseases and aging. Although the use of robots in rehabilitation work settings has demonstrated the prosthetic value of the devices (Anderson, 1986; Seamone & Schmeisser, 1986), their potential in the comprehensive rehabilitation and educational plan of disabled individuals has yet to be fully realized.

The future of robots in rehabilitation and special education is ambiguous and unpredictable due to a variety of factors. Specific barriers to the adequate investigation of robotic applications in special education were discussed in an interview-based study of the ways in which robotics, artificial intelligence and computer simulations might be applied to special education (Moore, Yin, & Lahm, 1985). The research methodology involved the construction of several future scenarios which were then rated by a panel of experts in each of the three technology areas. The experts in the robotics area concluded that the robotic applications would require the most technical development time before implementation could occur in special education classes. The panelists estimated that the earliest time period for the development of a functional "educational" robot might be nine years with a purchase cost of approximately $9000. The conclusions of the research state that,

> All robotic applications will face significant technical and cost barriers before they can be used with special education students (for other than vocational purposes). The technical barriers primarily involve the development of adequate auxiliary control systems (e.g. vision and voice control) and the required degree of flexibility for use in everyday settings. (p.76)

In addition, while a robotics training manual containing training procedures for persons with ,high-level. spinal cord injuries has been developed (Holloway, Van der Loos, Leifer, & Perkash, 1986); there has been no specification of effective training methodologies for children, home-bound, or geriatrics patients. Much of the contemporary research has focused on the development of the physical parameters of robotic use, without acknowledgement of the significant cognitive impact that probably accompanies the manipulative prosthetic advantages. The potential cognitive impact of using robotic devices includes a number of educational and learning issues such as accessibility to educational materials, effects on visual and spatial abilities, and on the ways in which information developed in the robotic environment is assimilated and processed.

Research on the potential and actual cognitive impact of use of robotic devices by handicapped individuals requires attention to a number of these educational and learning issues. One goal of such research is to enhance physical accessibility to existing educational materials; therefore, researchers need to attend to the nature of these materials and to the cognitive pre-requisites for their use as well as their meaning to the user. As increasingly complex tasks are made physically accessible to disabled learners, developmental learning theories, especially those concerned with the process by which we come to understand space and movement (Piaget & Inhelder, 1963), will be pressed to explain the ability of a person to learn by directing physical movement, rather than by experiencing it directly.

Robots as Cognitive Aids

Learning theorists have stressed the importance of early motor learning in normal cognitive development for many years (Bruner, 1964; Kephart,1971; Piaget,1976). Since movement is one of the first overt and observable responses of the child, it is natural to view motor learning as an essential part of cognitive development. The role of direct experience and manipulation of the world as a major determinant of later functioning is discussed by Flavell (1977):

> According to this [Piaget's] model, the individual plays a very active role in his cognitive interchanges with the environment. He creates a mental construction of reality in the course of numerous experiences with his milieu, rather than simply making a mental copy of what is experienced. (p.12)

It has been asserted by Kephart (1971) that it is necessary for children to manipulate objects physically in order to develop their sensory organs and motor systems. Such activities perfect the sensory-motor processes and help children to learn to match sensory and motor experiences. The development of perceptual motor abilities such as eye-hand coordination, temporal-spatial translations, and form perception progresses from initial motor performance, through perceptual-motor matching, to the development of form perception and space structuring abilities. In some cases, deficiencies in a child's developmental sequence can be attributed to injuries or physical disabilities that disallow these interactions.

These studies suggest that the implicit outcome of a physical deficit could be significant mental retardation or severe developmental delays. But our everyday interaction with orthopedically handicapped individuals contradicts the notion of a causal linkage between physical disabilities and mental handicaps. Even though there are obvious and problematic effects of a physical disability that can lead to cognitive developmental delays, these delays can be partially offset by educational and therapeutic intervention. The integration of more severely physically and mentally handicapped students into public education has shown that, given the appropriate interventions, many of these children can be successful learners.

The ability for many orthopedically handicapped individuals to succeed in certain situations where they would be assumed to fail leads us to suspect that our theoretical understanding underestimates the adaptability of developing humans, handicapped or non-handicapped. This may require that we postulate new theoretical explanations for the development of abilities and behaviors in the absence of direct physical experience. Bandura and Walters (1965) proposed that a type of social learning behavior called "modeling" allows for an observer to learn a behavior in the absence of physically performing the behavior. It may be that this type of "vicarious learning" is a very powerful source of learning to individuals suffering from a variety of severely handicapping physical disabilities.

Cognitive and physical abilities are so closely interrelated in their development that physical exploration of the environment and manipulation of its elements contribute to the formation of mental skills, such as those associated with spatial awareness. These skills help children to develop a sense of control over their environment as they gradually move from an egocentric perspective, in which they view the world solely from a personal orientation, to an allocentric perspective and viewing the world from an orientation other than their own (Piaget & Inhelder, 1963).

While the lack of direct sensory input may have potentially deleterious effects on cognitive growth, it is possible that the developing human uses whatever skills and abilities <u>are</u> present in order to maintain cognitive growth. Some support is given for this position by Flavell (1977) who posits that, "if the usual, typical developmental route is blocked, the child may find an unusual, atypical one that somehow gets him to at least approximately the same cognitive destination" (p.238). For example, by using the robot as a mechanical sensor and manipulator, the child may be able to experience important aspects of the world and grow cognitively from those experiences. In the robotic environment, the handicapped child can move the device to designated locations, use it to speak and gather information, grasp and interact in a real, physical sense with a world that was formerly completely out of reach.

The cognitive demands of learning to use robots effectively have yet to be completely defined, but a number of abilities are involved in the use of a robotic system, consisting of a computer, software, and a robotic device. Of particular interest are the developmental issues

related to the individual's control of the environment, spatial concepts and mental imagery, and their attititudes toward the robot.
Through creative play, directed experimentation, and exploration activities, the handicapped individual can use the robot to develop strategies for interacting with the environment. These interactions may even change the basic knowledge-gathering and environment-structuring capabilities of the individual. In addition, the individual is required to use directional concepts in order to operate the robot, thus enabling the user to learn more about the outside world as they structure it in increasingly complex ways.

Research using Robots

Research into the usefulness of robotics as cognitive tools for disabled learners demands carefully conceived designs. While conceptualization of prior studies and attention to data analysis are important aspects of all research, attention to these issues is of particular importance in this area. A parsimonious approach to the research endeavor is demanded not only by the scarcity and limitations of resources, but also by the unique needs of the individual students who serve as subjects. In particular. the research design selected must yield meaningful data with regard to performance, attitudinal, and technical aspects of the experiment. At the same time, the design must be responsive to the limitations imposed by the capabilities of subjects and by the actual (as opposed to theoretical) capabilities of the particular robotic device being used. These limitations must be overcome if research performed with a small sample of subjects using a particular hardware and software configuration is to be generalizable to the larger and more diverse population of people who are physically disabled.

The research team must view the conceptualization and design of instructional treatments and measures as a major part of its work. Using an instructional design model developed by Damarin (1987), our team begins each investigation with analyses of the content of instruction. These analyses go beyond traditional task analysis by including a delineation of both the cognitive and affective contexts of the task. The content analysis process includes: (a) consideration of the general nature of the subject population, (b) an analysis of the particular physical control and positioning needs of the subjects, and (c) the generation of viable research hypotheses. This information leads to the development of the training sequence and finally, to the development of the specific software and hardware required for the subjects. This approach provides the foundation for the training which is evaluated throughout the course of the study in order to modify any inappropriate hardware, software, or training methods.

Finally, research designs must include specific information about the use of robotic devices. In particular, designs should include:

1. A description of the hardware used and any modifications to those systems.
2. A description of the training procedures and the sequence of instruction used with the population, including the theoretical orientation that underlies the curriculum and training methodology.
3. A description of the software developed and used, including menu structures, input and output features, and safety specifications.
4. A description of the evaluation methodology, the types of measurement instruments used, and their origin.

Training Design Specifications

Our research has focused on the development of an effective training methodology for the transfer of knowledge and skills required to operate the robotic device in an educational environment. The process involved first comparing the utility of mobile versus fixed-base robots and investigating perspective-taking in the robotic environment. The results of this pilot research indicated that contemporary, commercially-available, mobile robots are not practical for use in educational settings at this time. In addition, some evidence indicated that a shift in perspective-taking, from an egocentric to an allocentric perspective, had occurred in at least two of the four original subjects.

Subsequent research using robotic arms found that orthopedically disabled children could successfully learn to use the robotic arm in a progressively complex set of tasks involving reaching, grasping and retrieving objects. Performance-based measures of the number of errors per individual task component and the time to completion of each component showed a uniformly high level of task performance ranging from 60% to 85% correct responses on solo operation of the robotic arm by 75% of the subjects. The knowledge and skills gained using the robot also showed a surprising resistance to extinction after an unplanned, three-week hiatus in the study.

An analysis of the content involved in gaining mastery of a robotic arm reveals that the subject needs to acquire skill at a series of levels and that these levels are likely to require the application of increasingly complex strategies and diverse cognitive abilities. The skills gained at each level must be mastered but not overlearned; overlearning may lead to fixation at a level of control which is relatively primitive with respect to the desired flexibility of user knowledge and control. This is especially important since the primary objective of training must be the ability to use the robot effectively in unstructured tasks and environments. The description of our experimental training sequence is attentive to these issues.

An Example of a Robotic Training Sequence

Level I: DEMONSTRATION

Purpose: To demonstrate the functionality of the robotic arm in a context that is reinforcing to the student and to establish a relationship between the input device, the robotic manipulator and the menu and graphic displays on the monitor.

Objectives: 1) Students will express interest in the capabilities of the arm;

2) Students will understand the basic relationships involved in using input devices, the robotic arm, and the screen display.

Level II: BEGINNING CONTROL

Purpose: Students will operate the robotic arm to perform several well-defined tasks in which help and feedback are provided by the computer and instructor.

Objectives: 1) Students will learn to distinguish the different movements of the robotic arm; 2) Students will learn the common vocabulary associated with the parts of the robotic arm; 3) Students will learn to relate two-dimensional screen text and graphics with the movement of the robotic arm in three dimensions.

LEVEL III: INTERACTIVE CONTROL

Purpose: Students will interact with the robotic arm in an unstructured environment and be given progressively greater control over the different types of movements.

Objectives: 1) Students will control the robotic arm by using a point-to-point referencing system to initiate movements; 2) Students will develop planning and sequencing skills that involve successive approximations of robotic arm movements to the desired goal; 3) Students will gain skill in the use of quantities (e.g. distance, angles measurement) in relation to the movement tasks.

LEVEL IV: PROGRAMMING THE MANIPULATOR

Purpose: Students will create and save procedures for using the robotic arm in functional and recreational tasks within unstructured environments.

Objectives: 1) Students may be required to use abilities related to visualization (e.g. mental rotations, perspective-taking) in order to perform complex, multi-level tasks with the robotic arm; 2) Students will perform, the programming tasks necessary to complete multiple levels of interactions between the robotic arm and an unstructured environment.

The training sequence described can be implemented effectively only with well-defined and internally consistent specifications for hardware and software. The importance of these specifications is derived from several needs. First, the hypotheses and related objectives of the study must be clearly mirrored in the system; otherwise, the relationship between the observed results and the hypotheses will be obscure. Second, the subjects must be able to rely upon the software to deliver instructions and actions reliably and consistently. Third, the subjects should be able to access and learn the instructional content easily; that is, if learning basic control of the hardware and software is too complex, variable, and burdensome, the value of the robot control system as a cognitive aid will be minimal or even negative.

Hardware Specifications

Some of the most important considerations involved in the selection, adaptation, and use of hardware for robotic systems include the following:

Adaptability/Flexibility. a) adaptable for use with a variety of disabilities; b) its operation is easily learned; c) allows simple and comfortable access to input devices.

Mechanical/Electronic integrity. a) incorporates a high-quality architectural design, b) well-constructed and integrated hardware system, c) accurate, extensive and well-organized documentation, d) parts are readily available.

Cost Effectiveness. a) low cost adaptations can be made, b) reasonable total cost.

The hardware required for the research project includes the adaptive input devices, the computer system, and the robotic arm. The adaptive input devices vary according to the type and degree of the user's physical disability. These devices range from a standard computer keyguard placed over the keyboard and used by students having slightly impaired physical control (e.g. capable of pointing and pressing single keys), to the multiple-switch input device, brow switch, or voice-activated control devices used by students having highly impaired physical control (e.g. capable of only a gross pressing movement using their hand, a brow movement, or with no controllable physical movements). The adaptive input device is usually interfaced with the computer via the standard input-output gameport. The computer used in our research project is an Apple IIe with a monochrome monitor.

The robotic arm used in our research is the Rhino XR-2 and XR-3. This robotic arm is capable of 5 degrees of freedom utilizing servo-control motors. The arm is attached to a workstation designed to provide a flexible working environment which ensures that the user is safe from being injured by the arm. Another safety consideration that involves the workstation is the use of physical and software restraints over arm motion that assure limits on arm movement and act as a fail-safe system. The configuration of the workstation is presented in Figure 1.

Insert Figure 1 About Here

Software Specifications

Although the important source of safety specifications lies in the design of the hardware system, safety of the subjects must also be a specific concern in the development of software to control the actions of the robotic arm. Basically, the software must be designed to protect the user from any adverse effects of movement which he or she initiates unintentionally. Software must, for example be designed so as to prevent jerky, unpredictable motions or procedural loops which would result in dangerous movements of the robotic arm.

A major issue of robotic software design can be viewed as subject verses computer control. Within this issue are several sub-issues that must be answered in a manner which is consistent across all levels of training and be responsive to the needs of users as they increase their control over robot actions. Subject control is accomplished primarily via a number of different types of adaptive input devices, depending upon the physical control capabilities of the user. Software specifications are required to give consistent meaning to each input mechanism and to assure that an appropriate level of control is available to the subject at each stage of the training. If, at the beginning stages, the subject is given control of too many options, he or she will likely become frustrated by the number of choices to be made in order to get some meaningful action from the robot. On the other hand, the subject must be given the capability to fine-tune the robotic arm movements in later phases of the training. Students can be given control over a very complex, unstructured environment though the careful delineation of a hierarchy of tasks enacted through a simple menu structure which allows for eventual programming of arm movements.

Another aspect of software specifications has to do with the nature of feedback given to the subjects. While some visual feedback is manifest in the motion of the arm, this motion will not always be correctly interpretable or helpful to the subject. At each stage, decisions must be made about the nature and amount of assistance to be given. In the task environment, the design of the screen is critical in providing effective visual feedback to the user.

In general, feedback must be designed with allowances for differences in the cognitive development of the users. At the early stages of the training, feedback concerning low level tasks must be readily accessible through transparent procedures. However, low level feedback should not present an unavoidable barrier to students who have progressed past the need for it.

Testing and Evaluation

Student progress with the robot should be evaluated to (a) allow for continuous checks on the progress and quality of the training procedure, (b) provide accurate measurement of cognitive goals, and (c) evaluate the accessibility and utility of the equipment. Energy must also be directed toward the adaptation of the data gathering instruments and consideration must be given to the implications of changes in the reliability and validity of the evaluative instruments. The communication problems of many physically handicapped individuals provides an important challenge to future researchers in this area. Accessing and correctly interpreting relevant feedback from the student is critical to the understanding of the cognitive demands associated with using robotic devices.

Implications for the Future

The purpose of the research and development activities described previously is to understand and create a Functional Learning Environment (Newman, 1987), in which young learners with normal intelligence and severe orthopedic handicaps could work on meaningful tasks having potentially rich cognitive benefits. The particular environment studied is a complex one composed of: (a) students, each of whom possesses a unique set of learning needs, (b) a robotic device, (c) computer hardware and control software, and (d) adaptive devices which facilitate communication from the student through the computer to the robot. The complexity of this environment can itself be a barrier to widespread research and development efforts. Moreover, other barriers to research are consequent upon this complexity; these include:

Cost: At the present time, the cost of a complete hardware and software system ranges from $3,000 to $50,000. The cost of a practical educational robotic system which is usable for educational research purposes begins at $7000.

Expertise: The design of a functional learning environment which maximizes the capabilities of the learners, the utility (and ease of use) of the robot, and the cognitive messages of instruction requires that a wide variety of capable professionals work together. These professionals include instructional designers, software design specialists, instructors, occupational therapists, programmers, engineers, and hardware technicians.

Hardware Limitations: Although adaptive input devices designed for individuals with a variety of handicaps are becoming increasing available, existing robotic devices have not been designed with these populations in mind. Low cost robots designed for school use tend to be toy-like and are lacking in extensibility, effective weight-bearing capacity, and control over fine movements. Industrial robots, on the other hand, are extremely costly and often inappropriate for classroom use, either because of physical factors or because of limitations in software support.

Community and School Support: In order to establish and maintain research programs, support is needed from a variety of people in addition to the research team. The school environment must be one which values both researcher access to students and student access to robots. Professional expertise available in the schools, especially in the area of occupational therapy, must be available to researchers.

The resolution of issues which form these barriers must be a major goal of research in the immediate future. The accumulating body of research findings provides sufficient evidence that robotic environments can enhance learner's spatial cognition as well as their motivation. Given these findings, a primary question for immediate research lies in the area of costs and benefits: How sophisticated must a robotic device be in order for a variety of disabled learners to benefit maximally from its use? Answering this single question could form the basis of a lengthy research agenda. It is not obvious that the most sophisticated robot, supported by the most sophisticated control software, would be the answer even if cost were not a consideration. Since spatial learning is a primary goal of our research agenda, the analysis of spatial relationships should reside, in general, with the learner and not with robots controlled by software responding to sensors. On the other hand, the ideal robot for school use should not cause learners undue frustration due to its limitations, especially in accumulating errors of measurement and movement; an unreliable robot cannot support the acquisition of concepts in a consistent and reliable fashion. Thus, questions of the nature of ideal hardware and software systems must be studied independently of cost. At the same time, these same issues must be addressed in relation to cost of the hardware and software systems. It is the belief of this research team that answers to these questions will result in the willingness of more manufacturers to produce robots for functional learning environments.

Robotic devices have been shown to be useful to people with handicapping conditions in two ways: as physical aids, and as cognitive aids. As progress is made in each of these areas, researchers need to attend to the relationships that emerge between them. From the point of view of physical assistance, the ideal robotic system will likely perform tasks for the user in much the way that a personal aide would; that is, the user makes a request and the robot engages in both the planning and physical activities necessary to carry out the request. Thus, the ideal robotic aid could obviate the need for users to engage in cognitive activity relative to the execution of a given task. On the other hand, another purpose of the robot is to provide an environment in which the user can construct knowledge through cognitive activity (e.g. assimilation and accommodation). A robotic device which automatically "does it all" may not foster the acquisition of this goal.

The resolution of these goals within school settings is an area in need of considerable study. The tension between these two goals, and indeed, the value of the cognitive goals is a difficult concern both conceptually and pragmatically. Research on cognitive development consequent to the use of physical and cognitive aids is needed. The findings of such research must be made available both within the research community and among the various affected populations, including parents, teachers, and therapists from whom support is sought.

The overall goal of both kinds of research is the empowering of the disabled learner. It is therefore critical that researchers focus on enabling learners to build upon their existing cognitive structures. As research in the use of robotic devices as cognitive aids continues into the future, it is imperative that we learn more about the "natural" spatial cognition of the learners in question. Initial research has been conducted based upon the analysis of space and movement as it is constructed by the nonhandicapped learner. Further research will need to investigate how handicapped learners can elaborate, deepen, and make more useful their own constructed knowledge of space and movement. The understanding of a disabled individual's construction of their world view will eventually enable us to make a better determination of the benefits attributable to robotic devices and extend our knowledge of spatial learning in disabled learners.

REFERENCES

Anderson, L. (1986). Small robot arm in the workplace to aid in the empoyment of severely physically disabled persons. Proceedings of the Ninth Annual Conference on Rehabilitation Technology (pp. 244-246). Minneapolis, MN.

Bandura, A., & Walters, R. (1965). Social learning and personality development. New York: Holt, Rinehart & Winston.

Bruner, J. (1964). The course of cognitive growth. American Psychologist, 19, 1-15.

Damarin, S.K. (1987, April). Dimensions and characteristics of educational software: A framework for research and development. Paper presented at American Educational Research Association, Washington, DC.

Delgado, N. (1986). Push my button. Electronic Education, 6(2), pp. 19-20.

Englehardt, K.G. (1984). Robotic concepts and applications in health and human services. Proceedings of the Second International Robot Conference. Chicago, IL.

Englehardt, K.G., & Awad-Edwards, R. (1985). Robots in long term health care. Proceedings of the Eight Annual Conference on Rehabilitation Technology. Memphis, TN.

Feigenbaum, E., & McCorduck, P. (1983). The fifth generation: artificial intelligence and Japan's computer challenge to the world. Reading, MA: Addison-Wesley.

Flavell, J.H. (1977). Cognitive development. Englewood Cliffs, NJ: Prentice-Hall.

Hoseit, K., Liu, N., & Cook, A. (1986). Development and use of a robotic arm system with very young, developmentally delayed children. Proceedings of the Ninth Annual Conference on Rehabilitation Technology. Minneapolis, MN.

Heckard, M. (1986, January). Career-minded high school students are commanding robots. Techtrends, pp. 15-17.

Holloway, K., Van der Loos, M., Leifer, L., & Perkash, I. (1986). A training and reference manual for an interactive robotic aid. Proceedings of the Ninth Annual Conference on Rehabilitation Technology, Minneapolis, MN.

Kephart, N. (1971). The slow learner in the classroom (2nd ed.). Columbus, OH: Merrill.

Leifer, L. (1983) Robotics for the disabled. Rehabilitation Research and Development Center. Palo Alto, CA.

Marsh, G., & Spain, T. (1984). Robots in the classroom. Electronic Learning, 4(9), pp. 48-112.

Moore, G., Yin, R., & Lahm, E. (1985). Robotics, artificial intelligence, computer simulation: future applications in special education. Washington, D.C.: COSMOS Corp.

Newman, D. (1987). Functional environments for microcomputers in education. In R.D. Pea & K. Sheingold (Eds.), Mirrors of minds: Patterns of experience in educational computing (pp. 57-66). Norwood, NJ: Ablex Publishing.

Piaget, J. (1976). The psychology of intelligence. Totowa: NJ: Littlefield, Adams and Co.

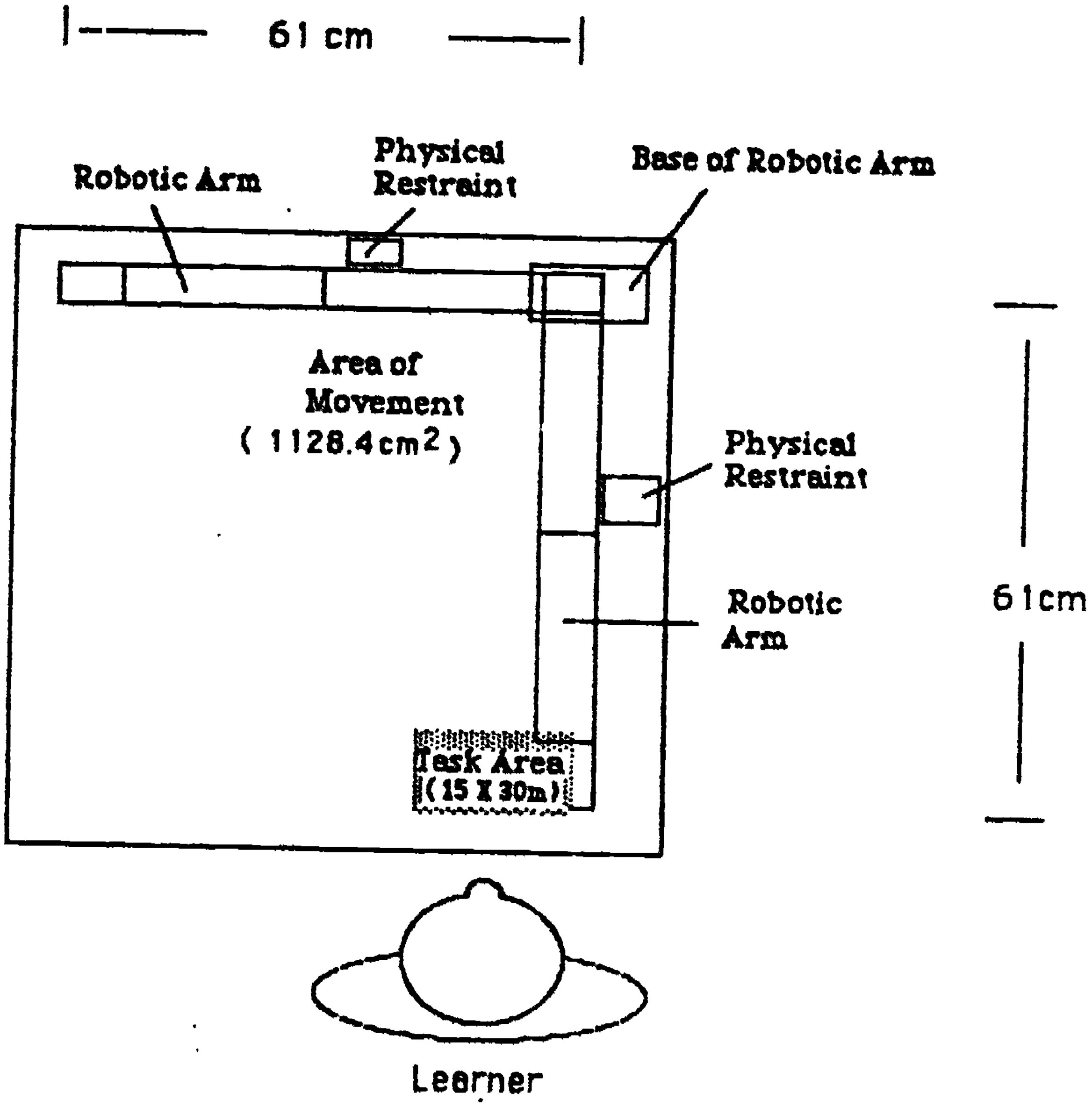
Piaget, J. & Inhelder, B. (1963). The child's conception of space. New York: Norton & Co.

Seamone, W. & Schmeisser, G. (1986). Evaluation of the APL/JHU robot arm work station. Proceedings of the Ninth Annual Conference on Rehabilitation Technology. Minneapolis, MN.

The Robotics Institute. (1986). 1986 Annual Research Review. Pittsburg, PA: Carnegie-Mellon University.

Van der Loos, H.F.M., Michalkowski, S., Leifer, L. (1987). Design of an omnidirectional mobile robot as a manipulation aid for the severely. disabled. Proceedings of the Ninth Annual Conference on Rehabilitation Technology, Minneapolis, MN.

Watt, M. (1984). The robots are coming. Popular Computing, 3(8).


61 cm
Robotic Arm
Physical Restraint
Base of Robotic Arm
Area of Movement
(1128.4cm2)
Physical Restraint
Robotic Arm
61cm
Task Area
(15 X 30m)
Learner

(ii) Costs are reasonable in relation to the objectives of the project.

(d) *Evaluation plan.* (10 points)

(1) The Secretary reviews each application to determine the quality of the evaluation plan for the project.

Cross-reference: 34 CFR 75.590, *Evaluation by the grantee.*

(2) The Secretary considers the extent to which the methods of evaluation that are appropriate for the project and, to the extent possible, are objective and produce data that are quantifiable.

(e) *Adequacy of resources.* (5 points)

(1) The Secretary reviews each application to determine if the applicant plans to devote adequate resources to the project.

(2) The Secretary considers the extent to which—

(i) The facilities that the applicant plans to use are adequate; and

(ii) The equipment and supplies that the applicant plans to use are adequate.

(f) *Importance.* (10 points) The Secretary reviews each application to determine if—

(1) The service delivery problem addressed by the proposed project is of concern to others in the Nation, and;

(2) The importance of the project in addressing the problem or issue.

(g) *Innovativeness.* (15 points)

(1) The Secretary reviews each application to determine the innovativeness of the proposed project.

(2) The Secretary looks for a conceptual framework that—

(i) Is founded on previous theory and research; and

(ii) Provides a basis for the unique strategies and approaches to be incorporated into the model.

(h) *Organizational capability.* (10 points) The Secretary considers—

(1) The applicant's special education experience; and

(2) The applicant's ability to disseminate findings of the project to appropriate groups to ensure that they can be used effectively.

(i) *Technical soundness.* (25 points)

(1) The Secretary reviews each application to determine the technical soundness of the plan for the development, implementation, and evaluation of the model with respect to such matters as—

(i) The population to be served;

(ii) The model planning process;

(iii) Record keeping systems;

(iv) Coordination with other service providers;

(v) The identification and assessment of students;

(vi) Interventions to be used, including proposed curricula;

(vii) Individualized educational program planning; and

(viii) Parent and family participation.

(20 U.S.C. 1441–1442)

§ 324.33 What are the selection criteria for evaluating research-related activities other than research and model projects?

The Secretary uses the criteria in 34 CFR 75.210 (*Selection criteria for a discretionary grant program that does not have regulations*) to evaluate applications for new awards for research-related activities other than research and model projects.

(20 U.S.C. 1441–1442)

§§ 324.34–324.39 [Reserved]

Subpart E—What Conditions Must Be Met by a Recipient?

§ 324.40 What conditions must be met by a recipient?

Not more than 90 days after the completion of a project assisted under this part, each recipient must submit a report to the Secretary that includes—

(a) An abstract of the project.

(b) For a research project, a description of the research problem and the methodological approach used in the research study; or

(c) *For a model project*—

(1) A description of the model which permits replication, in part or in whole, by appropriate parties to which it is disseminated; and

(2) A description of the evaluation procedures and findings related to the effectiveness of the model;

(d) A summary of the project findings; and

(e) A statement of the conclusions.

(20 U.S.C. 1442(d))

(Approved by the Office of Management and Budget under control number 1820-0502)

§§ 324.41–324.49 [Reserved]

Appendix

Note.—This appendix will not be codified in the Code of Federal Regulations.

Guidelines—Research in Education of the Handicapped Program

Part 1—Introduction

Sec.
1.1 Scope of guidelines.

Part 2—Application Information

2.1 Preparation of applications for research projects.
2.2 Preparation of applications for model projects.

Part 1—Introduction

§ 1.1 Scope of guidelines.

The guidelines contained in this document are recommendations and suggestions for meeting legal requirements which apply to Federal assistance under the Education of the Handicapped Act, Part E, sections 641–644. The legal requirements include the Act itself (20 U.S.C. 1441–1444) and applicable regulations (34 CFR Parts 75 and 324). The guidelines are not requirements. However, where the guidelines set forth a permissible means of meeting a legal requirement, the guidelines may be relied upon.

(20 U.S.C. 1441–1444)

Part 2—Application Information

§ 2.1 Preparation of applications for research projects.

It is suggested that project applications include the following features in the order listed:

(a) *Abstract.* A narrative abstract should describe—(1) The problem or issue the project is addressing; (2) the project's goals and products; and (3) the methodology. The overview of the methodology should provide specific detail on the sample, if one is to be used (i.e., number of local educational agencies, number of students, category of exceptionality), and a brief description of the project's design, measurement, and analysis procedures.

(b) *Importance.* This section should present the problem or issue to be addressed. Using previous research findings, the experiences of service providers, and a conceptual framework, the applicant should make a convincing argument for the significance of the need which exists, and the importance of the proposed project in understanding, remediating, or compensating for the problem/issue. This section should also include a description of the expected outcomes. Finally, it should provide a list of procedural objectives which describe the major activities to be implemented during the project and for which detailed explanations and justifications are provided in the subsequent sections of the application.

(c) *Technical Method (Soundness).* This section should provide both a description and justification for the project design, sample, measurement techniques, instrumentation, and data analysis procedures. This section should provide sufficient detail for reviewers to be able to make informed judgments about the soundness of the proposed research procedures. This is the one aspect of the application narrative which is frequently too short. Applicants need to explain and justify their selection of procedures. The relationship between the proposed activities and the proposed duration of the project should also be made apparent in this section.

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