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AUTHOR	Moore, Gwendolyn B.; And Others
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ABSTRACT

The report describes three advanced technologies--robotics, artificial intelligence, and computer simulation--and identifies the ways in which they might contribute to special education. A hybrid methodology was employed to identify existing technology and forecast future needs. Following this framework, each of the technologies is defined, considered in terms of the state of the art, discussed according to ratings of scenarios by a panel of technology and special education experts; and predictions are made for the likelihood of those scenarios. Near-term applications are identified: an object and mechanical device manipulating robot to help students perform independently daily living or vocational activities (robotics); a clinical diagnostic expert system to help in screening, diagnosis, and placement (artificial intelligence); and a personal management simulator to teach students about practical living skills (computer simulation). A series of eight conclusions are offered, including that certain applications of artificial intelligence and computer simulation appear more promising, in the foreseeable future, than those in robotics; that some significant technical and cost barriers exist; and that most of these barriers are generic to all applications of the technologies, not solely to special education settings. Appendixes contain summaries of industrial applications for which in-depth reviews were conducted, a questionnaire for expert panelists, instructions to panelists for developing scenarios, and scenarios of technologies in special education. (CL)

Robotics, Artificial Intelligence, Computer Simulation:

Future Applications in Special Education

Gwendolyn B. Moore
Robert K. Yin
Elizabeth A. Lahm

July 1985

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PREFACE

This report describes three advanced technologies--robotics, artificial intelligence, and computer simulation--and identifies the ways in which the technologies might be used to help special education students in the future. The report does the following: 1) describes the context for the study and the methods used to examine the technologies; 2) defines the three technologies and describes the "state-of-the-art" of each one; 3) discusses the findings regarding the possible future uses of the technologies in special education, based on iterative reviews by expert panelists; and 4) sets forth the study's conclusions, which have been draw from the panelists' reviews as well as analyses of other information examined throughout the study.

The study upon which this report is based has benefitted from assistance from numerous sources. First, the study was made possible with support from the Office of Special Education Programs of the Department of Education, and we wish to thank Jane Hauser, our project officer, for her assistance throughout the course of the project.

Second, the authors extend their thanks to the countless individuals in the robotics, artificial intelligence, computer simulation, and special education communities who so generously provided information about current applications of the technologies and who helped to identify individuals to serve on the study's expert panel. This study has been strengthened by the contributions of these individuals.

Third, the authors are indebted to the expert panelists who participated in the study. Although the panelists remain anonymous, their contribution to the study cannot be overstated. They responded to the tasks put before them with a thoughtfulness and timeliness that helped assure the successful completion of the study. Even though they remain nameless, each panelist is aware of our debt to them.

Fourth, the study benefitted from the assistance of two COSMOS staff members, in addition to the authors. The first was Judith A. Alamprese, who conceptualized and drafted the study's dissemination plan. The second important staff contribution was made by J. Lynne White throughout the study. In particular, White coordinated the three iterations of reviews by expert panelists and handled the many administrative matters associated with the study. The study also received help from two external sources. The first was from Edward J. Cain, Jr. (Director of Student Services, Commack Union Free School District), who served as a consultant and to whom we are greatful. The second external resource to whom we extend our thanks is Carol Daniels of LINC Resources, Inc., who has worked with the study staff to promote the dissemination of the study's findings.

Finally, we appreciate the detailed comments on the draft of this report provided by five individuals: Michael M. Behrmann, George Mason University; Mark B. Friedman, Carnegie-Mellon University; Alan M. Hofmeister, Systems Impact, Inc.; and Jane Hauser and Jim Johnson, Office of Special Education Programs.

Despite all of this assistance and the efforts of the reviewers, the authors alone assume full responsibility for any errors or misinterpretations.

ROBOTICS, ARTIFICIAL INTELLIGENCE, COMPUTER SIMULATION: FUTURE APPLICATIONS IN SPECIAL EDUCATION

(Executive Summary)

Gwendolyn B. Moore
Robert K. Yin
Elizabeth A. Lahm

We live in an exciting age in which technology is being used in ways not conceived of a decade ago. Technology is changing the way we train students, changing the way we conduct business, and changing the way we produce manufactured goods. One incentive underlying these uses of technology is to conduct activities more effectively and efficiently, at less cost. Exploring possible new ways to use technology is a continuing challenge, and one that warrants careful analysis and examination.

Background and Purpose

The benefits of technological advances, during the last few decades, have been gradually and impressively applied to special education. Technology has been central to numerous applications, including communications devices for speech and hearing, electronically controlled prosthetic devices for improving mobility, and microcomputers for enhancing educational activities. Most of these technologies were originally designed for settings outside of special education, yet their adaptation to the field has provided untold benefits to special education students.

Just as technology has benefitted special education in the past, new technologies also promise to be important aids:

- Robotics research has produced robots with sophisticated vision systems and touch-sensitive grippers that select machine parts during manufacturing. **Can robotics help handicapped people to be more self-sufficient in educational settings?**

- Artificial intelligence research is rapidly developing "expert systems," natural language systems, and machine vision systems that mimic human reasoning processes. **Can such advances help special education students to learn more effectively?**

- Computer simulation research now allows sailors, pilots, and combat personnel to practice activities and maneuvers in classrooms. **Will computer simulations allow handicapped students to "experience" activities they would otherwise be prevented from sharing?**

These three technologies were the topics of the present study. The purpose of the study was to enumerate and describe the ways in which robotics, artificial intelligence, and computer simulation are being applied in other fields, and to identify the potential uses of these technologies for special education students.

Methodology

A new methodology was created especially for the present study. The methodology was designed to overcome inherent limitations of the two other approaches traditionally used for identifying new technologies--i.e., the "technology-push" and "demand-pull" approaches. In technology-push, a new product idea is developed and commercial outlets for it are subsequently found. The assumption behind this approach is that innovations possess some type of inherent "good," and that they will thereby attract a sufficient market to justify the expenditure of development costs. This approach also does not recognize the "economic realities" of modern-day society, which require decisionmakers to operate on the basis of future profit expectations.

The second approach, demand-pull, is where a demand for a new technology is said to induce its development. With this process, the needs of potential users are identified, and technologies are identified or developed to meet those needs. However, two key assumptions are at work here, neither of which appear to be well founded. The first is that an R&D organization will muster its resources if a sufficient demand exists. The second is that the needs of users are best met with technological solutions. Thus, as with technology-push, demand-pull is not sufficient for identifying new uses of technologies.

Therefore, for the present study, a new methodology--the hybrid approach--was developed. This approach identifies existing technologies (analogous to technology-push) and forecasts future needs (analogous to demand-pull), in the hope of matching available technologies with anticipated or existing needs. The hybrid approach was used to examine how robotics, artificial intelligence, and computer simulation might be used to help special education students in the future. The five steps of the approach are:

1. Define the technology of interest;
2. Identify current uses of the technology conduct in-depth examinations of the uses, and describe the "state-of-the-art" of the technology;
3. Obtain ratings, from knowledgeable specialists, of the potential applicability of the current uses in new settings, and develop "scenarios" of those uses in new settings;
4. Obtain further ratings of the scenarios for the likelihood that they will succeed in the new setting; and
5. Disseminate information about possible new uses of the technology.

The hybrid approach helps to overcome some of the shortcomings of the traditional technology-push and demand-pull approaches. The approach has been applied successfully during the present study, and may be used in other settings in the future to help to promote the transfer of technologies from one setting to another.

Findings and Conclusions

Analyses of the current applications of the three technologies--together with the ratings of scenarios by a panel of technology and special education experts--form the basis for the study's findings and conclusions (see Table A, which identifies and briefly describes the applications and their counterpart scenarios). These analyses lead to: 1) findings about specific scenarios, 2) findings about the scenarios more generally, and 3) conclusions about the three technologies. Three caveats precede these findings and conclusions.

Caveats to the Conclusions. The conclusions must be interpreted in light of three caveats. The first relates to the breadth of the three technologies studied in contrast to the fact that the conclusions are based on an analysis of a limited set of technology applications. If a larger set of applications and scenarios had been covered, the conclusions might be viewed with even greater potential for generalizability to the three technologies as a whole.

The second caveat is that the present study specifically focused on ways in which technology might be brought to bear in meeting the needs of special education students. As such, the study did not attempt to compare technological as opposed to non-technological ways of meeting students' needs. Thus, the conclusions presented here should not be interpreted to mean that, in all suggested instances, technology is the best alternative to meeting students' needs.

The third caveat is that the study did not attempt to ascertain the specific educational value of using the technologies with special education students. Thus, before specific steps are taken to use one of the three technologies, further research may be appropriate to assure the educational value of technology-related activities.

Scenario-Specific Findings. Among the specific scenarios, some stand out as most promising in terms of their aid to special education students in the relatively near future and with a limited financial investment. For robotics, one scenario--Scenario 1A: object and mechanical device manipulating robot--might help students to perform, independently and for the first time, daily living or vocational activities. The robot might be affixed to a student's desk or worktable, and be activated by English commands, using voice or keyboard input. The panelists believed that such a robot might be available to some

Table A

THE APPLICATIONS AND THEIR COUNTERPART SCENARIOS

Applications (n=17)	Corresponding Scenarios (n=13)
Robotics	
1. Material Handling Robot (multi-purpose robot used in manufacturing "job-shop")	1A. Object and Mechanical Device Manipulating Robot (robot used to move objects and manipulate mechanical devices)
2. Welding Robot (robot with sensing system used to weld metal containers for nuclear waste)	2A. Welding Robot (robot used in work-study or manufacturing setting by handicapped people)
3. Machine Vision Robot (robot with vision system used to identify and select parts on a conveyor belt)	3A. Multiple Environment Assistive Robot (robot attached to wheelchair, controlled by speech, and used to manipulate objects in different settings)
4. SCARAB X-1 (a robotic bartender that takes verbal orders and prepares beverages)	[None]
5. Circuit Board Assembly (a robot with vision system used to assemble electronic circuit boards)	[None]
6. Spray-Painting System (a multi-robot system used to spray paint truck chassis)	[None]

Table A, Page 2

Artificial Intelligence

7. Clinical Diagnostic Expert System (an expert system used to diagnose pulmonary functioning of patients)	7A. Screening and Evaluation System (an expert system used to screen mildly and moderately handicapped students)
	7B. Interactive Diagnostic/Treatment Tool (an expert system used to communicate via symbols and English language)
8. Natural Language Processing System (a system used to query a personnel database in a large company using common English sentences)	8A. Resource Database Retrieval System (a system used to query a database of instructional and physical resources)
9. Planning System (a system used to design and arrange complex schedules of unmanned spacecraft)	9A. Curriculum Planning System (a system used for planning curriculums for special education students)
10. DELTA/CATS-1 (an expert system used to diagnose mechanical problems in locomotives)	[None]
11. Sensory-Information Processing System (a system that identifies digitized signals for recognizing vessels in the ocean)	11A. Mobility Aid (a system that detects objects and informs blind individuals of the nature of the object in their path)

Table A, Page 3

Computer Simulation

12. Simulated Cockpit (a mock-up of a jet cockpit used to test man/machine interface questions)	12A. Mobility Training Simulator (a system for identifying the best fit for wheelchairs and prosthetic devices)
13. Nuclear Control Room (an exact replica of a nuclear power plant control room used for training and testing new systems)	[None]
14. Video-Simulated Cockpit (an interactive video used to introduce trainees to the rudiments of a jet aircraft)	14A. Kitchen Training Simulator (a video simulation of the events and processes in a typical kitchen)
	14B. Object Recognition and Task-Sequencing Simulator (a system to allow students to recognize items in a vocational setting and learn common sequences required)
15. COMDAC Ship Bridge (a replica of the control room in a cutter used for training and electrical troubleshooting)	[None]
16. Video-Simulated Store (a system used to train market personnel how to manage the customer check-out and bagging processes)	16A. Personal Management Training Simulator (a "game" for teaching personal management problem-solving)
	16B. Facility Management Training Simulator (a simulator for training administrators of special education facilities)
17. On-Scene Commander (a system for training individuals to manage the clean-up of oil spills)	[None]

special education students in fewer than nine years, and at a cost of under $300,000.

For artificial intelligence, one scenario--Scenario 7A: screening and evaluation system--might provide administrators and other school personnel with a tool to screen, diagnose, and place students. For example, the system might be used with a non-vocal, motor-impaired student for diagnosing and identifying the appropriate curriculum and prosthetic materials to best fit the student's needs. Such a system might be available in a short time (i.e., fewer than four years), but at a cost of over $500,000.

Finally, one computer simulation scenario--Scenario 16A: personal management training simulator--also appeared to hold near-term promise for special education students. This simulator might be used to teach students about personal management, and the simulator might also be modified to teach students about money management, mobility within a community, shopping, work habits and behaviors, or buying a meal in a restaurant. This simulator might be developed in fewer than four years, at a cost of $200,000 to $500,000.

General Findings from the Scenarios. A number of findings come from the expert panelists' ratings of the scenarios of possible future uses of the three technologies with special education populations. At the most general level, these findings are:

- The robotics scenarios might require the most technical development and time before benefits were likely to be realized by special education students, because counterparts are almost exclusively used in manufacturing settings.
- The artificial intelligence scenarios have well-developed counterparts in similar settings (e.g., medicine), but customized versions of these in special education settings may be expensive and time-consuming to develop.
- The computer simulation scenarios appear to present the fewest number of technical barriers, and the scenarios have counterparts that closely resemble the possible uses of simulations for special education students (e.g., training simulators used in businesses).

The ratings of the individual scenarios were all quite different, and indicated a wide range of beneficiary populations, cost investments required for development, and time before implementation might occur. The cost often varied as a function of technological developments _outside_ the special education field, and as a function of the "distance" a scenario was, technologically, from the practice described in the scenario. The time for implementation varied as a function of the level of investment in R&D, and as a function of the specific characteristics of the technology described in the scenarios themselves (e.g., the precision of the robot, the comprehensiveness of the artificial intelligence system, and the realism of the simulation).

The panelists' ratings of the scenarios were similar to their ratings of the industrial counterparts of each scenario (the industrial counterparts are applications of the technologies currently operating in settings other than education, and upon which the scenarios were based). Where the ratings were not the same, the differences usually involved the identification of different beneficiary populations or time and cost estimates (the estimates of time and cost were generally lower for the industrial counterparts than for the scenarios). This similarity of ratings tends to increase the confidence in the ratings of both the scenarios and the applications, and to suggest that the scenarios are valid portrayals of technological possibilities.

Conclusions about the Three Technologies. Analyses of the state-of-the-art of the three technologies, as well as of the results from the panelists' ratings of the applications and of related scenarios, lead to several conclusions about the potential usefulness of robotics, artificial intelligence, and computer simulation in special education. These are:

1. The applications of all three technologies are very heterogeneous, and thus, generalizations about the individual technologies must be made with care. Nevertheless, certain applications of artificial intelligence and computer simulation appear to be more promising, in the foreseeable future, than those in robotics.

2. Certain applications of all three technologies which exist in other fields (e.g., health care and military training) may serve as models for possible adapted uses in special education.

3. Some artificial intelligence and computer simulation applications are technically feasible today, and could be developed with limited expenditures of funds (e.g., under $1 million). These include AI expert and natural language processing systems and "desktop" computer simulations.

4. A substantive barrier--i.e., the need to develop behavioral, diagnostic, and prescriptive norms--may exist with regard to the use of AI expert systems.

5. Other artificial intelligence and computer simulation applications will need to surmount some significant technical and cost barriers. These applications include AI sensory information processing and planning systems, as well as computer simulations requiring replicas of real-life environments.

6. All robotics 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.

7. Most of the technical barriers associated with the technologies are generic to <u>all</u> applications of the technologies, and are not peculiar to uses in special education settings. Thus, it is unlikely that the barriers will be overcome for special education alone, unless a similar application of the technology is also needed in some other setting (e.g., industry, health care, or military).

8. A necessary precursor to many applications of the technologies in special education is likely to be the commercial development and utilization of the technologies in other settings.

CONTENTS

Appendix

FIGURE

TABLES

I. INTRODUCTION

Technology and Special Education

During the last few decades, the benefits of new technologies have been gradually and impressively applied to special education populations. Some of these advances have reflected a broader national commitment to serve the general needs of handicapped persons both as individuals and as students in special education settings (e.g., Brown and Redden, 1979; and "Application of Technology to Handicapped Individuals," 1980). The technology applications cover such diverse uses as:

- Computer-assisted instruction (e.g., Cartwright and Hall, 1974; Hallworth and Brebner, 1980; and Lindsey, 1981);
- Communications devices, such as the Kurzweil Reading Machine (e.g., Cushman, 1980);
- Sensory devices, such as those used for speech and hearing (e.g., Jones, 1981; and Barden, 1982);
- Adaptations in environmental facilities, such as the use of special signs incorporating textured surfaces and braille writing;
- Rehabilitative technologies, including the whole range of prosthetic devices and travel and positioning aids; and
- Numerous individual technologies, such as microcomputers (e.g., Behrmann and Lahm, 1984; Yin and White, 1984), videodiscs (e.g., Thorkildson, Allard, and Reid, 1983), and the development of large-scale databases, such as NIMIS (e.g., Zucker, 1981-1982).

Many if not all of these uses were based on technologies originally developed for settings outside special education. Characteristically, the technologies were first demonstrated in fields other than special education, with use in special education encouraged through the efforts of the federal government (e.g., see Zucker, 1981-1982) and of private industry (e.g., Apple Computer's microcomputer awards emphasizing applications in special education).

The future development of technological knowledge and devices deserves continued attention, as more advanced technologies continue to emerge (e.g., Bell, 1984). The special education community already has improved its own capabilities for monitoring and encouraging new technological developments--e.g., through the creation of the Council for Exceptional Children's (CEC) Ad Hoc Committee/Task Force on Technology in Special Education, and also through CEC's ongoing Technology and Media (TAM) Division. However, the experiences of the past two decades suggest the need for repeated, future-oriented investigations on new technologies in other fields, to determine the potential implications for special education.

Currently, three technologies have advanced sufficiently in other fields to warrant this type of future-oriented investigation: robotics, artificial intelligence, and computer simulation. Robots, for example, are in regular use in industrial settings, and to a more limited extent in the home (e.g., Albus, 1982). Artificial intelligence systems have been developed that allow untrained users access to large databases through the use of the English language (e.g., Davis, 1984; Gevarter, 1983b). Computer simulation routines have successfully trained human operators in time and cost efficient ways, avoiding potential harm to individuals and equipment (e.g., Lizza, Howard, and Islam, 1983). All three technologies have produced such viable and beneficial applications in other fields that their potential for special education warrants investigation.

Thus, the purpose of the present study was twofold:

> To enumerate and describe the ways in which robotics, artificial intelligence, and computer simulation are being applied in other fields; and
>
> To identify potential uses of these technologies for special education students.

Identifying New Uses for Technology

Traditionally, two processes have been followed to address purposes such as these and to identify new applications of existing technologies: technology-push and demand-pull strategies. With technology-push strategies, new technologies are developed in the absence of pre-identified commercial outlets. With demand-pull strategies, the needs of a user population are established, and then technologies are developed to meet those needs.

A rich and diverse literature has analyzed these strategies and the processes by which technologies are put into practice in education and other public settings (e.g., see Berman and McLaughlin, 1974; House, 1974; Pincus, 1974; Feller and Menzel, 1976; Nelson and Sieber, 1976; Yin et al., 1976; von Hippel, 1978; and Roessner, 1979b). In this literature, the supply of technology (equated with technology-push) and the demand for technology (equated with demand-pull) are examined for their effectiveness in meeting the needs of "users" (e.g., school or municipal officials).

Technology-Push Approach

Technology-push is the process whereby research and development (R&D) organizations create new technologies without foreknowledge of a specific user audience or commercial market. An assumption behind the technology-push process is that innovations possess some type of inherent "good," and that they will thereby attract a sufficient market to justify the expenditure of development costs. For example, technology-push has been the motive behind a number of federally sponsored technology transfer efforts promoted nearly a decade ago, including a major one by the National Aeronautics and Space Administration (for examples of these programs, see U.S. Department of Transportation, 1976; and Executive Office of the President, 1977).

More recently, however, technology-push has been directly challenged for its failure to recognize the economic realities of modern-day society (Mowery and Rosenberg, 1979). These analysts argue (pp. 229-230) that "in a capitalist economy, where decision-makers operate on the basis of expectations of future profit, no substantial innovation activity will be undertaken unless there is some reasonable expectation that there exists a market demand sufficiently large to justify [the development expenditures]." Thus, although technological opportunity may be a necessary condition, it does not appear to be sufficient for projecting the applicability of technologies to future situations.

Demand-Pull Approach

Demand-pull is where a demand for a new technology is said to induce its development (Yin, 1978). With this process, the needs of potential users are identified,[1] and existing technologies are applied to meet those needs. However, a number of studies have shown that identifying users' needs is not an easy process (e.g., Feller et al., 1975; and Eckfield et al., 1978). This is complicated further by the ambiguity of the concept of "user," and that, even if defined, users are much more diverse and fragmented than is often anticipated (Yin, 1978).

The primary assumption underlying "demand-pull" is that R&D organizations will muster their resources to develop technologies if a sufficient demand (i.e., market) exists for them. Another assumption is that the needs of potential users are best met with technological solutions (e.g., see Szanton, 1981, pp. 34-38). The criticisms of Mowery and Rosenberg (1979) appear to challenge both of these assumptions. They are critical of demand-pull for its failure to recognize the distinction between the "systematic relationship between prices and quantities" (demand) and the "rather shapeless and elusive notion of 'needs'" (p. 229). Further, demand-pull also fails to recognize the influence of the variety of technological opportunities available to R&D organizations. Therefore, like "technology-push," demand-pull is seen as a necessary--but, again, not sufficient--process for identifying new uses of technologies.

A Hybrid Approach

In spite of the acknowledged limitations of both of these strategies (e.g., see Yin, 1978; Roessner, 1979a; and Rosenberg, 1983), the development of alternative strategies has remained an unfulfilled goal. However, one new strategy has been developed during the course of the present study and may be considered a hybrid of the technology-push and demand-pull processes. The hybrid approach identifies existing applications of technologies in one field (analogous to technology-push) and forecasts their future applicability to situations in another field (analogous to demand-pull). In the present study, the approach was used to identify how advanced technologies might be used in educational settings.

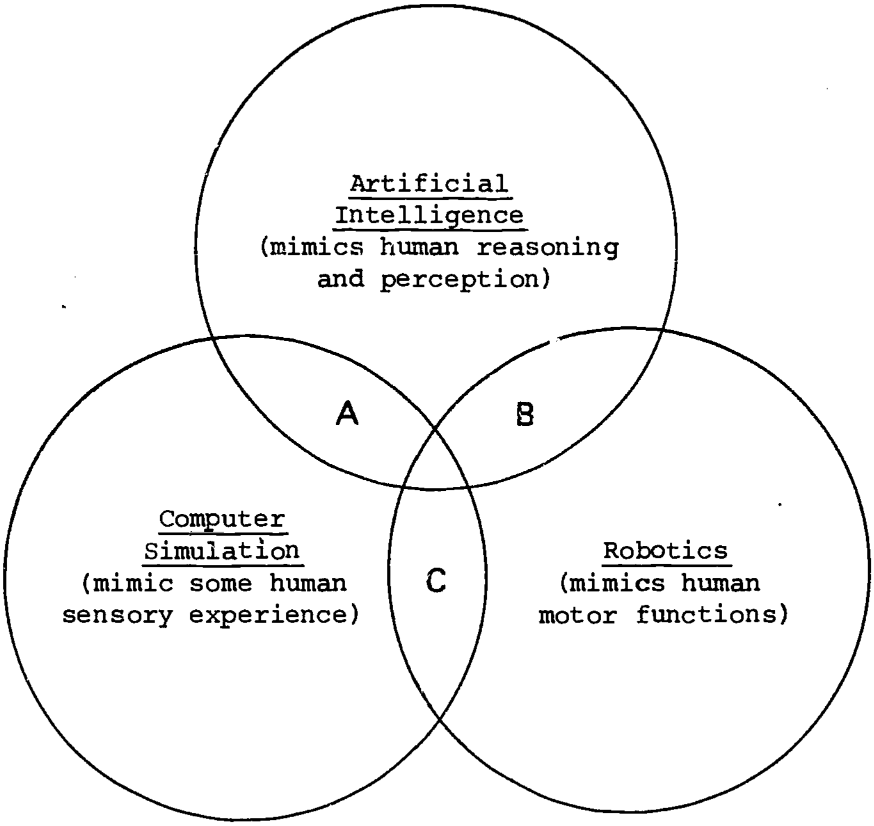
The approach involves five steps. These are: 1) define the technologies of interest; 2) identify current uses of the technologies; 3) establish a panel of knowledgeable specialists to rate the potential applicability of the current uses to new settings, and to develop "scenarios" about how those new uses might occur; 4) rate the scenarios for the likelihood that they will succeed in the new settings; and 5) disseminate information about the potential uses of the technology. Each of these steps, as followed for the present study, is described below.

1. Define the Technologies. The three advanced technologies all represent broad fields. Each one can be distinguished by identifying industrial, research, and professional organizations devoted solely to the technology. At the same time, the fields tend to overlap, especially at their most advanced edges. For example, overlaps occur where artificial intelligence is coupled with robotics or computer simulation (e.g, see Kinnucan, 1981; and Hollan, Hutchins, and Weitzman, 1984). However, an organizing framework, developed especially for the present project, helps to focus a set of working definitions that both reflect relevant elements of each of the technologies and provide a useful framework for special education.

Specifically, all three technologies can be related, directly, to some aspect of human life or behavior, but covering different domains.

Figure 1

ORGANIZING FRAMEWORK
FOR DEFINING THREE ADVANCED TECHNOLOGIES



Examples of Overlapping Technologies

A = "Intelligent," interactive simulation
B = Robot driven by visually guided (AI) system
C = Computer simulation of a robot's activities

As the first example, a fundamental defining principal of artificial intelligence is that it mimics human reasoning and perception. Similarly, the basic principal of robotics is that the technology mimics human motor functions. Finally, much (but not all) of computer simulation may be said to reproduce the conditions for engaging human sensory functions--e.g., visual, kinesthetic, or auditory elements of the human environment. These principles for the three technologies serve as the basis for the graphic representation shown in Figure 1. The figure shows the fundamental definition of each technology, for purposes of this project, and also suggests how overlaps may exist. Specific definitions of each technology are included in Sections III, V, and VII of this report.)

Overall, this framework is directly suited to the essence of special education needs: to use technology to allow individuals to maximize or extend their abilities and to operate more independently in the environment.

2. Identify Uses of the Technologies. Once a technology has been defined, the next step is identifying ways in which it is currently being used. The search for current uses, or "applications," reflects the view that the societal benefits from new technologies are embodied in their practical uses. These applications must occur in routine settings, and have normal support systems devoted to them--e.g., supply, maintenance, and repair resources. Further, the applications must be available through some commercial source, or be a working prototype supplied to the user as a prelude to full commercial development. These characteristics of an application help to avoid identifying ideas still in the R&D stage, and emphasizes the importance of user experiences in real-life settings. Applications can be found in industry, the home, the office, or other organizations such as hospitals. Specifically, the following characteristics of each application were examined:

1. The actual users of the technology,

2. The support systems that may be needed to sustain the use of the technology in a real-life setting,

3. The potential benefits of the technology in a real-life setting, and

4. The potential costs of the technology in a real-life setting.

These practical considerations were assumed to be critical to any projection to special education.

To identify applications of the three technologies, two activities were initiated: an inventory of applications, and in-depth reviews of selected applications. Both activities are described next.

In creating the inventory of current applications, nearly 50 individuals in the three fields were contacted. Each person was asked to identify applications that represented significant and advanced uses of one of the three technologies. In addition, the persons were asked to suggest other people who could make further nominations. The information obtained from this "snowballing" technique was combined with a review of available literature, which yielded the identities of yet other applications.

For each nominated application, further confirmatory information was sought by contacting a person directly involved with the application. This person was generally located in an industrial plant, commercial firm, or other institution that was the site of the application. However, in some cases, no such person could be found at that stage of the study. Therefore, the information about each application in the inventory should be viewed in light of this limitation. Errors may still exist in the information, although the research team has made every effort to assure that this is not the case.

Based on the information collected, a short vignette was prepared for each of the 59 applications identified (26 in robotics, 20 in artificial intelligence, and 13 in computer simulation). The vignettes are contained in a separate document, "Inventory of Applications," by Robert K. Yin, Gwendolyn B. Moore, Elizabeth A. Lahm, and J. Lynne White, November 1984. The vignettes contain the following information:

- The technology the application represents;
- The name of the application, if applicable;
- The location where the application is in operation; and
- A description of what the application is or does, and how it works.

The inventory of applications was not intended to generate comprehensive information about any single application, but was rather intended to illustrate the range of applications of the three technologies. As a result, the information collected during the inventory: 1) had not been verified to confirm its accuracy, and 2) did not provide detailed information about the application and its associated technological components. Thus, a set of in-depth reviews was initiated, to collect additional information about selected applications, through site visits or extended telephone interviews.

To conduct the in-depth reviews, it was necessary to: 1) establish criteria for selecting those applications to be reviewed, 2) pre-screen those applications selected to assure that they met the criteria, 3) determine the topics to be covered by the reviews, 4) conduct data collection, and 5) compile the information collected in summary form.

To be considered for in-depth review, all applications had to meet three criteria :

- Applications with promising characteristics for special education;
- Applications where a confirmed prototype, at a minimum, was in operation in a practice setting; and
- Applications that represented the most advanced state-of-the-technology.

The applications meeting these three criteria were further distributed according to two other criteria:

- Applications that represented a range of subcategories within the three technologies (see Sections III, V, and VII for lists of these subcategories); and
- Applications that clustered geographically, to allow for cost-effective site visit arrangements.

Of the 59 applications in the inventory, 17 met the criteria and were made the subjects of in-depth data collection efforts. Thus, the resulting 17 applications were those which were believed to be most promising for special education, were known to have a working prototype in operation in a practice setting, and were known to represent the most advanced state-of-the-art for the technology. Further, the applications to be reviewed in-depth represented the range of subcategories of the technologies (e.g., AI expert systems, welding robots, and training simulations), and were clustered geographically so as to be cost-effective to study.

The in-depth reviews were to yield a comprehensive picture of each of the 17 applications. As such, the reviews were to cover the day-to-day use of the application (e.g., what a robot does on the assembly line, how often an operation is performed, what types of problems are encountered, etc.); and certain of the technological aspects of the application (e.g., the type of software used, unique aspects of the technology, etc.). Specifically, the in-depth reviews covered five topics: 1) the application, 2) its support systems, 3) its underlying technology, 4) the benefits or drawbacks of the application, and 5) the origin and cost of the technology. Additional documentary information also was to be collected.

The in-depth information was collected in one of two ways--either through a site visit to the location where the application was in use, or through an extended telephone interview. In both cases, articles and other documentary information also were reviewed to confirm the information collected. The distinction between the applications visited and those to be the subject of telephone interviews was based primarily on: 1) the complexity of the application and its associated technology, and 2) whether or not there was anything to "see" during a visit--e.g., for certain artificial intelligence and computer simulation applications, the only thing to see is a computer and its paper output. In these circumstances, a visit was not deemed necessary to fully understand the application.

For the site visits, one or two investigators (depending on the complexity of the application) scheduled a visit with individuals who were knowledgeable about each application. The visits, which generally lasted about half a day, included both discussions with key individuals and observations of the application in operation.

For the telephone interviews, an appointment was made with key individuals, during which time the five topics were covered. For these applications, printed materials were solicited from the individuals and reviewed by a study team member before the interview was conducted.

The "product" of each in-depth review is a database, consisting of the study team's synthesis of information relating to each of the five topics. The database also includes the additional documentary information collected about each application. From this database, a summary of each application's operations and technical components was prepared. These summaries are intended to provide a sufficient amount of information to facilitate judgments about the potential relevance of the application to special education in the future (summaries of the 17 applications are included in Appendix A).

3. Establish Panel, Rate Applications, and Develop Scenarios. The third step, in projecting the applicability of technologies to new settings, was to establish a panel which would rate the current applications and develop "scenarios" of new applications. The ratings were made by a panel of experts, consisting of individuals who were knowledgeable both about the technology and about the target setting (in this case, special education). The panel made judgments about the settings, costs, benefits, and barriers likely to be related to the alternative uses of the current applications (i.e., the 17 applications which had been the subjects of in-depth reviews).

Panelists, or experts, as defined for this step, were individuals knowledgeable in the dual fields of special education and technology. Where possible, preference was given to individuals with knowledge of the three technologies under study. However, individuals with a balance of expertise in all these fields are rare, because the three technologies are just becoming of interest to special educators.

To establish the panel, nominations for experts were solicited from key individuals from both the special education and technology fields. Initially, the project team generated a list of nominators from the literature and from knowledge of both fields. These individuals were contacted by telephone and asked to nominate people whom they felt fit the definition of "expert." After names had been generated from this process, the nominees were contacted to determine their interest in participating in the study. They were asked to send a resume and two reprints of articles reflecting their involvement in technology applications in special education.

Of the 42 nominations received, 37 nominees sent the requested materials. Of these 37, the project team conducted an initial screening. Each nominee's materials were reviewed and rated according to three criteria:

1. Knowledge of special education,
2. Knowledge of technology, and
3. Demonstrated knowledge of the combined fields through professional publications and presentations.

Each criterion was judged on a scale from one to three. Thus, the total possible points to be assigned to each nominee was nine. Individuals with six or more points were considered to be sufficiently "expert" to be included in further evaluations, and 32 of the 37 nominees met this criterion. The list of 32 nominees was then reviewed with the staff of the Office of Special Education Programs, resulting in the selection of the final ten panelists. Although the panelists are anonymous, Table 1 summarizes their background and experience.

The panel was to be employed in a "peer judgment with feedback" rating process, which is similar in some ways to the Delphi method (e.g, Dalkey, 1969; and Helmer, 1983). A review and discussion of such methods is found in a separate document, "Review Methodology," by Gwendolyn B. Moore, Robert K. Yin, Elizabeth A. Lahm, and J. Lynne White, November 1984. For the ratings, the panelists were provided with three sets of information: 1) a set of assumptions about the social, political, and environmental contexts for the future uses of the technologies; 2) the definitions and descriptions of the state-of-the art of the technologies; and 3) the summary descriptions of the 17 applications.

On the basis of this information, each panelist "rated" the application along several dimensions, including the most relevant target population, the time period when the new application might be realized, the costs required to transfer the application, and activities that needed to occur to facilitate the transfer (the questionnaire used for this rating process is included in Appendix B). In addition, the panelists prepared scenarios that described hypothetical, new uses of the current applications.

Specific instructions for preparing the scenarios were provided to the panelists (the instructions are contained in Appendix C). The instructions included a specification of the contents and format of the scenarios, to assure that uniform information was provided by each panelist. Without such uniform information, the subsequent rating step would have been impossible to complete. In all, 13 scenarios were developed. The fact that there were not 17 is an artifact of the process used to assign the 10 panelists scenarios to prepare.

4. Rate the Scenarios. In this fourth step, the scenarios were rated by using the same process as had been used to rate the applications in the preceding step This step, however, used a subset of five of the panelists (these are the last five--nos.6-10--listed in Table 1). During this fourth step, two iterations of ratings and feedback occurred.

Table 1

SUMMARY OF BACKGROUND AND QUALIFICATIONS OF EXPERT PANELISTS

1. Project director for instructional development in communication program at an eastern technical institute for the deaf; M.B.A., 1983, management and general business; M.S. in Ed., 1974, instructional technology; B.S., 1970, professional photography; analyzes, designs, develops, and implements instructional development projects, including microcomputers and their related technologies.

2. Associate professor in special education at a southern university; Ed.D., 1979, special education and educational research; M.A.T., 1972, biology; B.S., 1971, secondary education and biology; conducts research on the use of microcomputers for computer-based teaching and computer-based assessment with young and mentally handicapped children.

3. Associate professor of industrial and management systems engineering, and director of division of automation, robotics, and productivity at an eastern university; Ph.D., 1980, industrial engineering and operations research; M.S., 1978, industrial engineering and operations research; B.S., 1976, industrial engineering; conducts research on industrial robotics and their application in regular and special education settings.

4. Director of rehabilitation in an R&D organization and associate professor at a western university; Ph.D., 1969, biomedical engineering; M.S., 1963, mechanical engineering product design; B.S., 1962, engineering; conducts research in rehabilitative engineering including robotic assistive devices, wheelchair controllers, and mobility aids.

5. Senior researcher in education systems R&D at a major north central computer corporation; Ph.D., 1979, curriculum and instruction; M.Ed., 1975, curriculum and instruction and mathematics education; B.A., 1973, mathematics, education and sociology; conducts research on the design and development issues of computer-based instruction, with special emphasis on testing, artificial intelligence, and instructional design.

Table 1, page 2

6. Department chair of special education programs at an eastern university; Ed.D., 1978, special education and special education administration; M.Ed., 1972, special education; B.S., 1971, biology; conducts research on the use of the microcomputers in teaching severely, multiply handicapped infants.

7. Research engineer at a robotics institute and research associate at a communication design center in a Great Lakes region university; Ph.D., 1972, psychobiology; B.S., 1966, life science; completed coursework for M.S., 1983, electrical engineering; conducts research in robotics and communication design; develops adaptive hardware which incorporates advanced technologies for physically disabled individuals.

8. Associate vice president of research at a western university; vice president and director of product development, private small business with microcomputer-related products; Ph.D., 1969, special education; M.S., 1967, corrective physical education and special education; B.E., 1965, psychology and educational research; conducts research and develops products for special education populations using microcomputer, videodisc, and expert system technologies.

9. Director and researcher, at an eastern technology research center; Ph.D., 1970, low temperature physics; M.S., 1964, physics and mathematics; B.A., 1963, physics; conducts research on microcomputers in education.

10. Director of a research center for communicatively handicapped and lecturer at a mid-western university; clinical staff, communication aids and systems clinic, mid-westernern hospital; M.S., 1974, biomedical engineering; B.S., 1972, electrical engineering; conducts research, evaluation, and training in the areas of augmentative communication and computer access for severely physically handicapped inidividuals.

The outcome of this iterative process was the generation of findings, specific to each of the scenarios (see Sections IV, VI, and VIII). These findings deal with the specific beneficiary populations, the costs associated with developing the technology described in the scenario, the year it is likely to be available, and judgments about the technological and organizational changes that need to occur to facilitate the transfer process.

5. Disseminate Information about New Uses. The final step was to inform technology developers and funders (e.g., industrial and university research organizations, federal government agencies, and foundations) about the directions for developing and marketing a new technology, and to inform potential users (e.g., teachers and other educators) about the possible benefits to be derived from the technology. The purpose of the present report is to serve, in part, this dissemination purpose.[2]

Organization of This Report

This introductory section has: 1) briefly described the benefits of technology in special education in the past, and how that relates to the purposes of the present study; 2) discussed methods that have been used previously for identifying new uses for technologies; and 3) described the activities of the "hybrid approach" used in the present study for identifying ways in which robotics, artificial intelligence, and computer simulation might be used in special education settings in the future.

Section II contains the findings and conclusions of the study, which are based on detailed analyses of the individual technologies and the ratings of the expert panelists. The data and information upon which the conclusions have been based are included in the next six sections of this report. Section III defines robotics and describes the "state-of-the-art" of this technology. Section IV continues the robotics focus and: 1) describes the scenarios of how robotics might play a role in special education in the future, 2) discusses the panelists' ratings of these scenarios, and 3) compares the ratings of the scenarios with those of their counterpart applications. In the same manner, Sections V and VI focus on artificial intelligence, and Sections VII and VIII focus on computer simulation.

NOTES TO SECTION I

[1] A number of different methods have been used to identify the needs of future users. These have included needs assessments, technology assessments, and Delphi studies. As with "demand-pull" itself, these methods each present their own unique advantages and disadvantages.

[2] The study's other dissemination activities include:

- Conference Presentations

  -"Computer Technology for the Handicapped" Conference, cosponsored by Closing the Gap, The Johns Hopkins University, and the Technology and Media Division (TAM) of CEC, September 15, 1984, Minneapolis, Minn.
  -"Computers for the Handicapped" Conference, cosponsored by The Johns Hopkins University and TAM, March 20-23, 1985, Baltimore, Md.
  -American Educational Research Association Annual Meeting, March 31 to April 4, 1985, Chicago, Ill.
  -The Council for Exceptional Children Annual Conference, April 15-19, 1985, Anaheim, Calif.
  -"Invitational Research Symposium on Special Education Technology," sponsored by CEC's Center for Special Education Technology Information Exchange, June 2-4, 1985, Washington, D.C.

- Publications

  -A brochure describing the project's goals and activities was prepared and disseminated.
  -Two articles have been prepared for publication in professional journals.
  -An executive summary of the final report has been prepared and disseminated to key organizations and individuals in the technology and special education fields.

II. FINDINGS AND CONCLUSIONS

This section contains the major findings and conclusions from the study, based on analyses of current applications of the three technologies--robotics, artificial intelligence, and computer simulation--and on the results of a series of ratings of scenarios of technology uses by a panel of technology and special education experts. The applications and scenarios studied are listed in Table 2 (the numbering system used in the table--e.g., with Application 1 being the counterpart of Scenario 1A--will be used throughout the text of this report).

Specifically, this section presents: 1) three caveats to be considered in interpreting the conclusions; 2) findings related to specific scenarios; 3) findings about the scenarios more generally; and 4) conclusions about the three technollogies. Sections III - VIII present the information and data upon which these findings and conclusions are based.[1]

Caveats to the Conclusions

The conclusions presented here must be interpreted in light of three caveats. The first relates to the breadth of the three technologies and the fact that the conclusions are based on an analysis of a limited number of applications of the three technologies, and an assessment, by the expert panelists, of even fewer scenarios. The implication of this is not that the conclusions are any less meaningful, but, rather, readers should recognize that the three technologies represent extensive fields and incorporate numerous ways in which the technologies are being (and may be) used. To this extent, had a larger set of applications and scenarios been analyzed, the conclusions might have been even more generalizable with regard to the three technologies as a whole.

The second caveat is that the present study specifically focused on ways in which technology might be brought to bear in meeting the needs of special education students. As such, the study did not attempt to compare technological as opposed to non-technological ways

Table 2

THE APPLICATIONS AND THEIR COUNTERPART SCENARIOS

Applications (n=17)*	Corresponding Scenarios (n=13)**
Robotics	
1. Material Handling Robot	1A. Object and Mechanical Device Manipulating Robot
2. Welding Robot	2A. Welding Robot
3. Machine Vision Robot	3A. Multiple Environment Assistive Robot
4. SCARAB X-1	[None]
5. Circuit Board Assembly	[None]
6. Spray-Painting System	[None]
Artificial Intelligence	
7. Clinical Diagnostic Expert System	7A. Screening and Evaluation System 7B. Interactive Diagnostic/Treatment Tool
8. Natural Language Processing System	8A. Resource Database Retrieval System
9. Planning System	9A. Curriculum Planning System
10. DELTA/CATS-1	[None]
11. Sensory-Information Processing System	11A. Mobility Aid
Computer Simulation	
12. Simulated Cockpit	12A. Mobility Training Simulator
13. Nuclear Control Room	[None]
14. Video-Simulated Cockpit	14A. Kitchen Training Simulator 14B. Object Recognition and Task-Sequencing Simulator
15. COMDAC Ship Bridge	[None]
16. Video-Simulated Store	16A. Personal Management Training Simulator 16B. Facility Management Training Simulator
17. On-Scene Commander	[None]

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*Summaries of the applications are included in Appendix A.
**The scenarios are included in Appendix D.

of meeting the needs of special education students. Thus, the conclusions presented here should not be interpreted to mean that, in all suggested instances, technology is the best alternative to meeting students's needs. As with the use of any technology, care should be taken to assure that the needs of special education students are not overshadowed by the capabilities of, or the desire to use, specific technologies.

The third caveat is that the study did not attempt to ascertain the specific educational value of using the technologies with special education students. The study, rather, attempted to identify ways in which technology might be used. Thus, before specific steps are taken to use one of the three technologies, further research may be needed to assure the educational value of certain types of technology-related activities.

Scenario-Specific Findings

Among the specific scenarios, some stand out as most promising in terms of their aid to special education students in the relatively near future with a limited financial investment. For robotics, one scenario--Scenario 1A: object and mechanical device manipulating robot--might help students to perform, independently and for the first time, daily living or vocational activities. The robot might be affixed to a student's desk or worktable, and be activated by English commands, using voice or keyboard input. The panelists believed that such a robot might be available to some special education students in fewer than nine years, and at a cost of under $300,000 (refer to the column for this scenario in Tables 3-7).

For artificial intelligence, one scenario--Scenario 7A: screening and evaluation system--might provide administrators and other school personnel with a tool to screen, diagnose, and place students. For example, the system might be used with a non-vocal, motor-impaired student for diagnosing and identifying the appropriate curriculum and prosthetic materials to best fit the student's needs. Such a system might be available in a short time (i.e., fewer than four years), but at a cost of over $500,000 (see the column for this scenario in Tables 3-7).

Finally, one computer simulation scenario--Scenario 16A: personal management training simulator--also appeared to hold near-term promise for special education students. This simulator might be used to teach students about personal management, and the simulator might also be modified to teach students about money management, mobility within a community, shopping, work habits and behaviors, or buying a meal in a restaurant. This simulator might be developed in fewer than four years, at a cost of $200,000 to $500,000 (see the column for this scenario in Tables 3-7).

General Findings from the Scenarios

A number of findings come from the expert panelists' ratings of the thirteen scenarios of possible future special education uses of the three technologies (see Section I for a description of how the rating process was conducted). At the most general level, these findings are:

- The robotics scenarios might require the most technical development and time before benefits are likely to be realized by special education students, because counterparts are almost exclusively used in manufacturing settings.
- The artificial intelligence scenarios have well-developed counterparts in similar settings (e.g., medicine), but customized versions of these in special education settings may be expensive and time-consuming to develop.
- The computer simulation scenarios appear to present the fewest number of technical barriers, and the scenarios have counterparts that closely resemble the possible uses of simulations for special education students (e.g., training simulators used in businesses).

The ratings of the individual scenarios were all quite different, and indicated a wide range of beneficiary populations, cost investments required for development, and time before implementation might occur.

The cost often varied as a function of technological developments <u>outside</u> the special education field, and as a function of the "distance" a scenario was, technologically, from the practice described in the scenario. The time for implementation varied as a function of the level of investment in R&D, and as a function of the specific characteristics of the technology described in the scenarios themselves (e.g., the precision of the robot, the comprehensiveness of the artificial intelligence system, and the realism of the simulation).

The panelists' ratings of the scenarios were similar to their ratings of the industrial counterparts for each scenario (the industrial counterparts are applications of the technologies currently operating in settings other than education, and upon which the scenarios were based). When the ratings were not the same, the differences usually involved the identification of different beneficiary populations or time and cost estimates (the estimates of time and cost were generally <u>lower</u> for the industrial counterparts than for the scenarios). This similarity of ratings tends to increase the confidence in the ratings of both the scenarios and the applications, and to suggest that the scenarios are valid portrayals of technological possibilities.

More specifically, the findings about the scenarios derived from responses to the the following five questions:

1. What special education populations will <u>benefit</u> by each type of technology?
2. In what <u>activities</u> will each type of technology assist special education populations?
3. How many <u>years</u> will it take before each type of technology will benefit 10, 50, and 90 percent of the special education population?
4. What factors <u>inhibit</u> the implementation of each type of technology?
5. What dollar <u>investment</u> will be necessary to implement each type of technology for special education populations?

The results with regard to each of these questions follows. (The reader is referred to Appendix B, which contains the questionnaire the experts used in making their ratings. Appendix D contains the full scenarios, and detailed analyses of the ratings of the scenarios are presented Sections IV, VI, and VIII.)

Beneficiary Populations. For each of thirteen scenarios, the panelists identified the special education populations most likely to benefit from them. Across the three technologies, the panelists identified three populations as those most likely to benefit: mild and moderate mentally handicapped/learning disabled, physically handicapped/other health impaired, and multiply handicapped, as Table 3 shows.

This pattern of beneficiary populations was consistent for two of the three technologies, but for robotics, mild and moderate mentally handicapped/learning disabled students were not identified as the primary beneficiary population. Also, an additional beneficiary population--special education administrators--was identified for artificial intelligence and computer simulation. The use of these technologies by administrators could be said to benefit all populations of special education students indirectly, through better diagnostic and prescriptive activities, enhanced decisionmaking capability, and more effective educational programming.

Activities Assisted. Special education students may benefit by using the technologies to perform or augment a number of routine and special activities, as shown in Table 4. The types of activities vary systematically with the technologies, as might be expected. The panelists' judgments indicated that robotics might help students to manipulate objects in their environment, and computer simulation might be used to provide "experience" within their environment. The panel believed that artificial intelligence might assist in the widest range of activities, with "understanding" the most prevalent. However, three of the five scenarios of artificial intelligence described the activities of administrators, not of the students themselves, and thus the activities would only indirectly benefit special education students.

Table 3

Q: WHICH SPECIAL EDUCATION POPULATIONS WILL BENEFIT BY EACH TYPE OF TECHNOLOGY?

	Technology Scenarios												
	Robotics			Artificial Intelligence					Computer Simulation				
Special Education Populations	1A. Object and Mechan. Device Manip. Robot	2A. Welding Robot	3A. Multiple Environ. Assistive Robot	7A. Screening and Evaluation System	7B. Interactive Diag/ Treatment Tool	8A. Resource Database Retrieval System	9A. Curriculum Plng. System	11A. Mobility Aid	12A. Mobility Training Simulator	14A. Kitchen Training Simulator	14B. Object Recog. and Task Sequen. Simulator	16A. Personal Mgmt. Training Simulator	16B. Facility Mgmt. Training Simulator
Mild and Moderate Mentally Handicapped/ Learning Disabled		1		1		1				1	1	1	2
Communication Disordered/ Speech and Language Impaired				2	1	2							
Behavior Disordered/ Emotionally Disturbed										2		2	
Physically Handicapped/ Other Health Impaired	1	1	1	1	2	1	2		1	2	2		
Severe and Profound Mentally Handicapped										2			
Visually Handicapped								1					
Hearing Handicapped													
Multiply Handicapped	2	2	2		2	1	1	2	2				
Other						*							1 **

KEY: 1 = Population receiving highest total points from five panelists.
2 = Population receiving second highest total points from five panelists.

* "Other" included: professional staff; administrators; placement teams.
"Other" included: administrators of special education schools; administrative personnel.

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Table 4

Q: IN WHAT ACTIVITIES WILL EACH TYPE OF TECHNOLOGY ASSIST SPECIAL EDUCATION POPULATIONS?

	Technology Scenarios												
	Robotics			Artificial Intelligence					Computer Simulation				
Activities	1A. Object and Mechan. Device Manip. Robot	2A. Welding Robot	3A. Multiple Environ. Assistive Robot	7A. Screening and Evaluation System	7B. Interactive Diag/ Treatment Tool	8A. Resource Database Retrieval System	9A. Curriculum Plng. System	11A. Mobility Aid	12A. Mobility Training Simulator	14A. Kitchen Training Simulator	14B. Object Recog. and Task Sequen. Simula.	16A. Personal Mgmt. Training Simulator	16B. Facility Mgmt. Training Simulator
Writing													
Moving about								◆					
Understanding				◆		◆	◆						◆
Eating													
Talking					◆								
Reading													
Seeing													
Experiencing	◆								◆	◆	◆	◆	
Manipulating	◆	◆	◆					◆					
Playing													
Other				*	#	**							##

KEY: ◆ = Activity that received the highest total points from panelists.

* "Other" included: educational programming; diagnosis; screening/placement.

** "Other" included: diagnosis and prescription; decisionmaking; better services.

\# "Other" included: diagnosis and planning; administrative decisionmaking; getting services.

\#\# "Other" included: crisis management; large scale integration; management skills.

Years to Implementation. There was a considerable amount of variability in terms of the number of years before the special education populations might benefit from the technologies (see Table 5), according to the panelists. At least one application of each technology might be available to ten percent of the students in the relevant populations in fewer than four years; all of the potential uses except two (both artificial intelligence) might be available to at least ten percent of the special education populations in fewer than nine years. Further, all but three of the potential uses (one robotics and the same two artificial intelligence) might be available to at least half of the individuals in each relevant special education population in fewer than fourteen years.

These relatively optimistic time frames may be slightly misleading, however, because there was a great deal of variability in the panelists' estimates of the time it would take before certain scenarios might be realized, with some estimates exceeding twenty-five years. Thus, it is important to look at each scenario individually (which is done in Sections IV, VI, and VIII) in making judgments about when special education populations might benefit from specific technological alternatives.

Factors Inhibiting Implementation. Three factors were consistently identified as those which may be barriers to the future uses of the technologies: cost, technical difficulties, and the need for training of users (see Table 6). Although other potential barriers--e.g., commercial availability and attitudes of parents--were also named, there was a clear consensus of the three barriers named. A number of different ways to ameliorate these barriers were identified in relation to individual technological options, and are discussed later in this report.

Required Development Investment. There was a pattern of differences among the three technologies in the level of investment that would be required before the relevant special education populations might benefit (see Table 7). Robotics and computer simulation showed the greatest range of costs, and artificial intelligence was generally

Table 5

Q: HOW MANY YEARS WILL IT TAKE BEFORE EACH TYPE OF TECHNOLOGY WILL BENEFIT 10%, 50%, and 90% OF THE SPECIAL EDUCATION POPULATION?*

Technology Scenarios

	Robotics			Artificial Intelligence					Computer Simulation				
Number of Years	1A. Object and Mechan. Device Manip. Robot	2A. Welding Robot	3A. Multiple Environ. Assistive Robot	7A. Screening and Evaluation System	7B. Interactive Diag/ Treatment Tool	8A. Resource Database Retrieval System	9A. Curriculum Plng. System	11A. Mobility Aid	12A. Mobility Training Simulator	14A. Kitchen Training Simulator	14B. Object Recog. and Task Sequen. Simulator	16A. Personal Mgmt. Training Simulator	16B. Facility Mgmt. Training Simulator
0 - 4		10%		10%		10%				10%		10%	
5 - 9	10%	50%	10%	50%		50%	10%		10%	50%	10%	50%	10%
10 - 14	50%			90%			50%		50%	90%	50%	90%	50% 90%
15 - 19	90%	90%	50% 90%		10% 50%	90%		10%	90%		90%		
20 - 24							90%	50% 90%					
25+					90%								

* Median of five panelists' responses.

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Table 6

Q: WHAT FACTORS INHIBIT THE IMPLEMENTATION OF EACH TYPE OF TECHNOLOGY?

Technology Scenarios

	Robotics			Artificial Intelligence					Computer Simulation				
Inhibiting Factors	1A. Object and Mechan. Device Manip. Robot	2A. Welding Robot	3A. Multiple Environ. Assistive Robot	7A. Screening and Evaluation System	7B. Interactive Diag/ Treatment Tool	8A. Resource Database Retrieval System	9A. Curriculum Plng. System	11A. Mobility Aid	12A. Mobility Training Simulator	14A. Kitchen Training Simulator	14B. Object recog. and Task Sequen. Simulator	16A. Personal Mgmt. Training Simulator	16B. Facility Mgmt. Training Simulator
Cost	1	1	1			2			1	1	1	1	1
Federal Government Policy													
State and Local Policy													
School Setting													
Need for Technical Assistance	2												
Technical Difficulties			2	2	1		2	1	2		2		2
Training		2		1	2	1	1			1		2	
Behavior of Private Industry													
Commercial Availability								2		2	1		
Other							*		**				

KEY: 1 = Factor receiving highest total points from five panelists.
2 = Factor receiving second highest total points from five panelists.

* "Other" included: attitudes of parents; professional behavior; implementation.
** "Other" included: inadequacy and limited utility of scenario.

Table 7

Q: WHAT DOLLAR INVESTMENT WILL BE NECESSARY TO IMPLEMENT EACH TYPE OF TECHNOLOGY FOR SPECIAL EDUCATION POPULATIONS?

Technology Scenarios

	Robotics			Artificial Intelligence					Computer Simulation				
Investment Categories	1A. Object and Mechan. Device Manip. Robot	2A. Welding Robot	3A. Multiple Environ. Assistive Robot	7A. Screening and Evaluation System	7B. Interactive Diag/ Treatment Tool	8A. Resource Database Retrieval System	9A. Curriculum Plng. System	11A. Mobility Aid	12A. Mobility Training Simulator	14A. Kitchen Training Simulator	14B. Object Recog. and Task Sequen. Simulator	16A. Personal Mgmt. Training Simulator	16B. Facility Mgmt. Training Simulator
Under $100,000													
$100,001 - 200,000		◆											
$200,001 - 300,000	◆									◆			
$300,001 - 400,000												◆	◆
$400,001 - 500,000						◆							
Over $500,000			◆	◆	◆		◆	◆	◆		◆		

KEY: ◆ = Investment category median of five panelists' responses.

rated by the panelists as more expensive than the other two. However, the variability in costs depends in large measure on the specific characteristics of each possible future use as described in the scenarios.

Summary. Based on the judgments of the expert panelists, a wide range of special education populations may benefit from robotics, artificial intelligence, and computer simulation in the future. The students may benefit through several activities, including manipulating, experiencing, and understanding their environments. At least one use of each technology might be expected to be available in fewer than four years, and most might be available to a limited number of students in fewer than nine years. However, the time before benefits may be realized depends directly on the specific characteristics of each application of a technology, and may require many years (e.g., over twenty) before benefits begin to accrue to special education students.

The cost of development, technical difficulties, and the need for training of users were identified as the three primary barriers which would need to be overcome for the technologies to be implemented. Finally, a wide range of costs may be associated with developing the technologies. Based on the information reviewed by the panelists, it appears that artificial intelligence may be more costly than robotics or computer simulation.

Given these results, future investments in developing the three advanced technologies appear to be warranted, and each technology presents unique opportunities and challenges. Based on the information reviewed, it appears that computer simulation may yield benefits sooner than the other two. Artificial intelligence technology is well enough developed in other fields to provide excellent models for efforts to customize artificial intelligence systems for special education uses. The benefits of robotics may not be realized for many years, but it, like the other two technologies, promises to be an important aid to the daily activities of special education students.

Conclusions about the Three Technologies

The analyses of the state-of-the-art of the three technologies, as well as the results from the panelists' ratings of the technologies and of related scenarios, lead to several conclusions about the potential usefulness of robotics, artificial intelligence, and computer simulation in special education. These are:

1. The applications of all three technologies are very heterogeneous, and thus, generalizations about the individual technologies must be made with care. Nevertheless, certain applications of artificial intelligence and computer simulation appear to be more promising, in the foreseeable future, than those in robotics.

2. Certain applications of all three technologies which exist in other fields (e.g., health care and military training) may serve as models for possible adapted uses in special education.

3. Some artificial intelligence and computer simulation applications are technically feasible today, and could be developed with limited expenditures of funds (e.g., under $1 million). These include AI expert and natural language processing systems and "desktop" computer simulations.

4. A substantive barrier--i.e., the need to develop behavioral, diagnostic, and prescriptive norms--may exist with regard to the use of AI expert systems.

5. Other artificial intelligence and computer simulation applications will need to surmount some significant technical and cost barriers. These applications include AI sensory information processing and planning systems, as well as computer simulations requiring replicas of real-life environments.

6. All robotics 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.

7. Most of the technical barriers associated with the technologies are generic to all applications of the technologies, and are not peculiar to uses in special education settings. Thus, it is unlikely that the barriers will be overcome for special education alone, unless a similar application of the technology is also needed in some other setting (e.g., industry, health care, or military).

8. A necessary precursor to many applications of the technologies in special education is likely to be the commercial development and utilization the technologies in other settings.

The following sections, divided according to technology, further describe the information and data upon which these findings and conclusions are based.

NOTE TO SECTION II

[1] The conclusions and subsequent sections of this report are based exclusively on materials developed and analyzed directly by the study's staff and its expert panelists. Neither the conclusions nor the subsequent sections of this report incorporate the findings generated as part of a subcontracted effort, managed by Edward J. Cain, Jr. (Director of Student Services, Commack Union Free School District, Commack, N.Y.). The purpose of that effort was to summarize the views of special education technology specialists on ways to promote the use of the three advanced technologies by soliciting input from the Task Force on Technology in Special Education of the Council for Exceptional Children (at the time, Cain was co-chair of the Task Force). Although the findings from the subcontracted effort were generally consistent with the findings produced by the study team, they have not been separately analyzed for purposes of this final report and they are not incorporated here.

III. THE DEFINITION AND STATE-OF-THE-ART OF ROBOTICS

Capsule Definition of Robotics

Robotics is the industrial and research field that develops and produces robots. In turn, a robot is:

> 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.

The capsule definition, based on that of the Robot Industries Association, formerly the Robot Institute of America (see OECD, 1983), has several implications worthy of further consideration.

Discussion of Robotics Definition

First, this definition of robotics is not universally accepted. In particular, the Japanese use a broader definition which includes robots that are neither multifunctional nor reprogrammable--i.e., what might be considered automated machines. Their definition would include as a robot certain types of manipulators operated by humans, either directly or remotely, but not self-standing. This broader definition was rejected for the present study due to the problems it would create in identifying a potential array of <u>advanced</u> applications. For example, non-multifunctional, non-reprogrammable manipulators operated by humans could readily include prosthetic devices which are beyond the scope of interest for the present study.

Second, industrial and personal robots are often further defined in terms of their specific components. Those most commonly used to define robots, and those described here, are: architecture, end effector, controller, operating method, and power supply. Further, review of some capabilities currently under development--such as locomotion, sensors, and intelligence--provides additional clarification of the robotics technology of interest.

Architecture. There are four basic configurations of robots: rectangular; cylindrical; spherical; and anthropomorphic articulated, or jointed arm. The four configurations can be combined in various ways to produce a large set of manipulator (i.e., arm) combinations and working envelopes (Gevarter, 1982). (A working envelope is simply the entire area over which a robot's arm can reach--see Susnjara, 1982.) The addition of mobility, as can be found in the personal robot, greatly increases the working envelope.

End Effector. The end effector (e.g., hand or gripper) can be a mechanical, vacuum, or magnetic device. The variety of tools and grippers that can be adapted for robot use is virtually infinite (see, for example, Engelberger, 1980, pp. 41-58). Nevertheless, the end effector remains one of the major limitations in robot manipulation, due to the lack of dexterity and programmability of end effectors (Gevarter, 1982).

Controller. The controller directs the robot unit and its end effector(s). Robots are often classified as "non-servo" or "servo," according to the type of controller used. Non-servo robots are generally limited to movement in two or three directions--e.g., in and out, up and down, or left and right. Movement terminates or changes direction only when a mechanical or switch stop is encountered. Due to their mechanical nature, a limited set of preprogrammed sequences are possible but these robots are very well suitable for repetitious and rapid tasks. Servo robots, in contrast, are quite flexible, because their task sequences are computerized. Servo robots can be programmed to control intermediate stops and velocity, and several movement directions can be incorporated into a task sequence, thus generating a large number of manipulator path options.

Operating Method. Additionally, robot controllers can use different operating methods: pick-and-place, point-to-point, or continuous-path. The pick-and-place robot is usually a non-servo type machine with fixed stops at the end of each axis. It is able to perform a limited sequence of events, often at high speeds and with good accuracy (Susnjara, 1982).

In contrast, the point-to-point and continuous-path robots are servo-controlled, and they are controlled by computer programs. The point-to-point robot is capable of moving to any point in its working envelope. The controller directs the robot to a sequence of pre-programmed points, to which it proceeds in an approximate straight line.

The continuous-path robot operates internally much like the point-to-point robot. However, a continuous-path control system records the position of each axis many times per second, with each of the recordings being an individual point. When the program is executed, the points are played back at the same rate they were recorded, and the robot moves to each point as it is played back. This process allows the robot to closely approximate the original path that was entered (Susnjara, 1982).

Power Supply. There are three types of power supply systems used for robots. Pneumatic power (using compressed air) is lightweight, fast, relatively inexpensive, but sometimes difficult to control. Hydraulic power (using compressed fluids) is more expensive than pneumatic, provides more lift, but suffers from leakage problems and requires pumps, storage tanks, and other paraphernalia. Electric power has the greatest lifting capacity, and consumes the least energy, but is the most expensive to buy and maintain (OECD, 1983). Power supply systems are one of the most problem-prone areas of robotics due to their high costs or heavy weight (Gevarter, 1982).

Developing Capabilities. Computer scientists add to this list of robot components a few capabilities that are not generally available today, but which may be part of a general-purpose robot of the future (Weintraub, 1981). These include:

- Locomotion--i.e., some means of moving around in a specific environment;
- Perception--i.e., the ability to sense by sight, touch, or some other means, the environment, and to "understand" it in terms of the task; and

- Intelligence--i.e., the ability to plan and implement actions to overcome obstacles in achieving higher order goals.

Rudimentary forms of these components are currently being included in research laboratory activities, in personal robots (Rogers, 1984), and to a very limited degree in actual practice settings.

Robotics Distinguished from Other Technologies

It is the robot's potential for motion that most readily differentiates the field of robotics from that of artificial intelligence. Similarly, the ability of robots to operate independently distinguishes them from prosthetics. Also, to repeat an earlier point, the Japanese "manipulator" and "fixed consequence" robots are not classified as robots by the U.S. definition, but rather as automatic machines--because they are neither multifunctional nor reprogrammable. These two properties--flexibility and reprogrammability--also distinguish robots from hard automation or dedicated machinery. Finally, many "personal" robots are not truly robots at all, because they are radio- rather than computer-controlled, and, hence, are not re-programmable.

Subcategories of Applications in Robotics

Current applications in robotics can be divided into seven major subcategories. These subcategories are used by the Robotics International of the Society of Manufacturing Engineers (a primary professional association in the robotics field), and are:

- Machine vision,
- Mechanical and electronic assembly,
- Material handling,
- Remote systems,
- Robot finishing systems,
- Welding, and
- Non-industrial applications.

State-of-the-Art of Robotics Based on Applications Reviewed

In all, 26 industrial applications of robotics were reviewed--six as part of the in-depth reviews and 20 more in an inventory. (The reader is referred to the "Identify Uses of the Technologies" subsection of Section I for a description of the in-depth reviews and the inventory. Summaries of the information collected during the in-depth reviews are included in Appendix A and are referred to in this report as "applications.") The analysis of these applications yielded a number of conclusions about the state-of-the-art of robotics:

1. The robots with documentable, practical applications do not resemble the popular image of humanoid, self-locomoting robots;
2. The functions robots perform are extremely specialized and repetitive;
3. The settings within which robots typically operate are highly structured and systematized;
4. The robots routinely in use today can replace humans in hostile environments, and can be quite productive and reliable;
5. The capabilities of robots are beginning to be augmented by supplementary systems such as vision and voice control; and
6. The costs of obtaining a robot and putting it to work involve elements in addition to the robot itself.

Each of these conclusions is discussed in turn below.

Lack of Humanoid, Self-Locomoting Robots. "R2D2," the lovable robot from Star Wars, is the image most people see when they think about robots. The popular notion of a robot is a walking, talking, intelligent "being," capable of a multitude of tasks--including activities such as using a vacuum cleaner, walking a dog, and putting dinner in the oven. Such a robot, however, does not yet exist in practical settings.

It is true that several "personal" robots are currently on the

Table 8

VIGNETTES OF ROBOTICS USES*

"<u>Robotics Program</u>." This use is a robotics curriculum that has been implemented in grades 2-12 for the purpose of developing awareness and understanding of robots, including programming, design, applications, and social issues. The curriculum covers definitions and types of robots, functioning capabilities, programming, and applications in industrial, medical, space, scientific, and domestic settings. The program uses a HERO1 robot.

"<u>RB5X</u>." The use of a personal robot, the RB5X, is being explored for assisting bed-bound elderly individuals in a senior center. The robot has an arm and a gripper, and it is mobile. It is programmed through a separate microcomputer.

"<u>RoPet</u>." The RoPet robot is being developed to serve as a security guard system for residents in nursing homes. It is a personal robot that will be multifunctional, with speech, speech recognition, sonar and tactile sensing, and sound capabilities. It will also be reprogrammable and have a microprocessor contained in it.

"<u>Material-Handling Robot</u>." This robot, with material handling as its primary function, is used for loading and unloading machine tools and parts. In addition, the robot acts as a work station or cell controller/coordinator. It monitors a feedback center and operates clamps and locks, and it trips probe sequences based on data from the control center. It is multifunctional in that it is capable of handling a variety of parts in one programmed sequence.

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* These vignettes were not the subjects of indepth review. They have been taken from a separate study document, "Inventory of Applications," by Robert K. Yin, Gwendolyn B. Moore, Elizabeth A. Lahm, and J. Lynne White (COSMOS Corporation, Washington, D.C., November 1984).

market, some priced as low as a few hundred dollars. Many of these robots, as noted previously, are not truly robots, in that they are radio- rather than computer-controlled. Others are simply sold as novelties, and are not intended to serve any specific functions.

Some of these "personal" robots, such as Heath Kit's HERO1, are being used in educational settings to teach students the principles of robotics (see "Robotics Program" in Table 8). Further, some efforts are currently underway to use personal robots to serve functional purposes (see "RB5X" and "RoPet" in Table 8), although the robots' inherent capabilities are proving to have severe shortcomings in performing any practical tasks.

Thus, in contrast to the popular image of the humanoid robot, the vast majority of robots in actual, practical use today represent only a minor portion of the humanoid image--i.e., arms and hands.

Specialized Functions. The current robots are typically used to perform one or two specialized and repetitive functions, which are often only a portion of a more meaningful activity. For example, the BinVision robot (see Application No. 3 in Appendix A) picks up metal parts from a conveyor belt and places them on a table at a rate of one part every 15 seconds. Although the robot is programmed to recognize several different parts (it is equipped with a vision system), it only recognizes and picks up parts--and performs no other function. Of course, the robot could be reprogrammed to do alternative functions, but then one repetitive task would simply be replaced by another. In this sense, most of the actual applications of robots have only emulated "micro" behaviors--e.g., spraying an object with paint, picking or placing parts, or punching a hole in a sheet of metal.

Systematized Environment. The settings within which robots operate have had to be carefully designed to facilitate robotic activities. Robotic arms are limited, by their architecture, in their ability to reach distances or in multiple directions. Thus, the components upon which the robot is to perform a function were brought to the robot, as is the case of the SCARA robot (see Application No. 1 in Appendix A). Even robots that are used to move materials (see

"Material-Handling Robot" in Table 8) do so from one fixed place to another, repetitively; the robot's path does not vary. Also, even mobile robots, such as the HERO1, were operated on completely level and unencumbered surfaces, or they were carefully programmed to avoid obstacles.

In many instances, the operating environment also has had to be safeguarded against the potential dangers robots can pose to humans. The primary danger is that robot movements tend to be rapid, and robots are very strong. The working envelope of a robot (i.e., the space within which its movements occur) has been carefully cordoned off or otherwise controlled, to prevent humans--or even other machines--from being injured by the movements of the robot.

Productivity. Robots have replaced humans in hazardous settings, such as in spray-painting booths, and thus promise to eliminate many dangers to which humans would otherwise have to be exposed. Robots have also been used to replace humans in jobs which are tedious or boring, such as drilling holes.

The robots in these and other settings were found to be extremely productive. One robot (see Application No. 5 in Appendix A), which assembles circuit boards, produces one board every 40 minutes, where humans performing the same function previously produced one board every 40 hours. Such dramatic increases in productivity were common in the robotics applications. In addition to being very productive, the robots were also reliable and performed their functions with a high degree of precision.

Supplementary Systems. Many of the most advanced robots incorporated more than the manipulation capability associated with robotic arms. Robots incorporating vision systems, which help to direct or correct a robot's movements, were seen in the applications. Robots were also found that had been supplemented with speech synthesis or speech recognition systems, to allow them to "speak" back to operators or to take oral commands. Further, some robots were equipped with other types of sensory systems (e.g., see Application No. 2 in Appendix A), which can increase the accuracy and flexibility of robots.

Cost. There are three elements to the cost of using a robot. The first element was the analysis of the function(s) to be performed and the computer programming required to have a robot perform those functions. This can take several months to complete. The second was the purchase of the robot and associated hardware itself. In addition to a robotic arm, computer controllers, end effectors, safety enclosures, and supplementary systems were purchased. The final cost element was the preparation of the setting within which the robot operated. Custom-designed tables and work enclosures were often needed, as was the careful coordination of other work activities with which the robot interacted.

Given all three elements, it was not surprising that the uses of robots have involved a high level of costs. As an example, the applications reviewed indicated that the cost of using a robot ranged from $80,000 to $200,000. However, this estimate did not always cover the costs of planning and assembling the working environment in which the robot was to operate. When such costs were also included, the costs of the applications were much higher, and suggest an expense far beyond the resources of a casual user.

IV. FUTURE USES OF ROBOTICS IN SPECIAL EDUCATION

The expert panelists developed and then rated three scenarios describing the possible ways robotics might be used to help special education students in the future (refer to Section I for a description of how the scenarios were prepared and rated). The ratings identified the most likely beneficiary population, the activities that would be facilitated for the population, the length of time and costs which might be required for the benefits to be realized, and the barriers which might impede development and use of the technology in a special education context (see Appendix B for the questionnaire used for these ratings).

This section contains the information and data upon which the findings, conclusions, and tables in Section II of this report are based. Specifically, this section: 1) presents the analysis of the panelists' ratings of the scenarios; 2) compares their ratings of the scenarios with their ratings of the industrial applications upon which each scenario was based; and 3) presents the analysis of the panelists' ratings of the industrial applications themselves.

Ratings of Scenarios

Three robotics scenarios were rated by the panelists: 1A, object and mechanical device manipulating robot; 2A, welding robot; and 3A, multiple environment assistive robot. The ratings for each one follow.

The first robotics scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 1A: Object and Mechanical Device Manipulating Robot

> This robot is used to manipulate objects (e.g, toys, tools) and to operate mechanical devices. A teacher sets up the robot on a table and places the objects within its reach. The student operates the robot using English commands, with voice or keyboard input.

This scenario would equally benefit physically and multiply handicapped students, according to the panelists' ratings. However, the panelists noted the importance of precise alignment and feedback for the effective use of this type of robot, and questioned whether such precision was possible in a special education (i.e., non-industrial, non-repetitive) setting. Nevertheless, the panelists identified a number of different activities that students might perform under the scenario. These include:

- Providing physically handicapped students with the ability to do, with control, a number of tasks for the first time;
- Allowing very young children, who are largely not interactive at all, to discover their ability to communicate and control in a new and very direct way;
- Facilitating or conducting activities of daily living or vocational tasks;
- Providing time-order training (e.g., building with blocks) for children with cognitive disorders, or establishing three-dimensional relationships for other impaired students; and
- Learning, by physically handicapped students, about "static" balance and the "dynamics" of inertial movement by manipulating toys.

All but one of the panelists believed that such activities might be performed by the robot in the scenario in four to nine years (the fifth panelist thought it might take ten to fourteen years). There was less agreement as to how long it might be before the majority (i.e., ninety percent) of the special education population might benefit: the lowest estimate was fifteen to nineteen years, with other estimates exceeding twenty-five years. The panelists believed the time estimates were highly dependent on efforts to use robots in industrial settings.

The panelists indicated that a pilot version of the robot, to perform a limited set of exercises, might be developed for as little as \$200,000 to \$300,000. However, the cost would increase substantially--

up to $4 million over a multi-year period--to develop a flexible, accurate robot to perform the activities named. Much of the cost would depend on the continued development of sophisticated and flexible robotics applications in industrial and other settings.

The panelists generally agreed that cost would be the primary inhibiting factor to implementing the scenario. They also noted that, regardless of the cost of the robot, there should be a demonstrated, compelling need and superiority of the technology over other alternative ways of accomplishing the same activities. The biggest reduction of this cost factor would be the availability of lower-cost robots from other settings, including robot toys.

The need for technical assistance was the second-most important inhibiting factor. The panelists noted that a robot such as described in the scenario would be difficult to operate, and would require school systems to have programmers and other technical specialists available. No solutions to these technical assistance problems were posited by the panelists, perhaps because they generally questioned the cost-effectiveness of the robot described in the scenario in the first place.

The second robotics scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 2A: Welding Robot

> This robot is used in a special education work study setting, or in a factory which integrates handicapped individuals into the workplace. In this setting, it would train handicapped students to perform welding tasks. The scenario also calls for the robot to be used in an "assistant role," in which the robot would be set up to perform a stable, simple task for a handicapped person.

This scenario describes two different situations. The first does not involve the modification of the industrial application upon which it is based, as the other robotics scenarios do. Instead, the scenario suggests that handicapped people might be taught to operate robots in industrial settings. Second, the scenario suggests that a similar type of robot might be used as an "assistant" to a handicapped person, performing a specialized, repetitive function. Although the panelists believed that mild and moderate mentally handicapped and physically handicapped students were the target population for such a robot, they challenged the premise of both portions of the scenario, and questioned its eventual usefulness to any population.

With regard to the use of the robot in a training or work setting, the particular welding robot described requires a great deal of physical strength to position the parts to be welded. The panelists questioned whether a handicapped person would be able to perform such a task. One panelist commented that if the scenario were intended to imply the involvement of handicapped individuals in work settings requiring knowledge of robotic operations, then it had implications for vocational training. Otherwise, the scenario as written had little or no value, according to the panelists.

The second situation described in the scenario involved the use of the robot in an "assistant" role for handicapped individuals. The robot described is a "gantry-mounted" one (i.e., a metal track, fixed above the robot, across which the robot moves). Three of the panelists did not believe that such gantry-mounted robots--which are large, heavy, and take up a lot of room--were transferrable to settings other than heavy industrial ones.

The third and final robotics scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 3A: Multiple Environment Assistive Robot

> This robot will be utilized as a multiple environment (e.g., different rooms), single setting (i.e., single school) manipulating assistive device. The robot will be mobile, in that it will be motorized or attachable to a wheelchair. It will also have a controlling device to allow for speech input for voice control or through adaptive switches. The robot will include object recognition capability for items categorized according to environment (e.g, plate, spoon in cafeteria; tape recorder, book in classroom) and for human control of the robot (pre-sequenced series of events for cognitively impaired or young or total control of movement by high cognitive functioning users).

The panelists agreed that physically handicapped students would be the principal beneficiary population for this scenario. Other populations--including multiply handicapped, communication disordered, and visually handicapped--might also benefit. The panelists identified several activities related to the scenario which could help special education students. One would be to adapt the robot to assist visually handicapped persons to work in a complex environment (e.g., the robot would use vision and locational capability to retrieve necessary objects). Another would be manipulating print or electronic media resources, and a third would be the use of a robotic arm on a wheelchair for manipulation of multiple objects in the library, a laboratory, or the student's desk.

The length of time before such activities might be performed would depend, according to the panelists, on the further development of robots for commercial purposes. Even assuming such private development, the robot might not be available to ten percent of the relevant population earlier than five to nine years from now. Two of the panelists estimated a significantly longer time--from fifteen to nineteen years. The panelists generally agreed that the time would be driven by commercial applications, not activities within special education per se.

All of the panelists agreed that the cost of developing this robot would exceed $500,000, although they did not estimate the total cost beyond that. However, the panelists' comments indicate that the cost would be "massive," because the development of the robot would require the solution to "huge" engineering problems and the development of another generation of robots, and not just an adaptation of the present generation. Of course, related to these comments, the panelists also believed that cost and technical problems would be the primary inhibitors to the development of the scenario. The high cost and technical barriers are due to the need for a new generation of robot, which would require extensive developments to occur in other sectors, before the robot would be possible for use in a special education setting.

Comparison with Industrial Counterparts

Each of the three scenarios just discussed has an industrial counterpart--that is, an application which currently operates in a setting other than education, and upon which the scenario was based. The panelists rated the industrial robotics applications on the same dimensions as they did the scenarios. This subsection compares the ratings of the scenarios (done by five panelists) with the ratings of the industrial applications (done by ten panelists), and then summarizes the panelists' ratings of the applications themselves.

Comparing Scenario and Industrial Application Ratings. The panelists rated Scenario 1A--object and mechanical device manipulating robot--much as they had the industrial application upon which it was based. This application can be summarized as follows:

Application 1: Material Handling Robot

> "SCARA" is a multi-purpose robot, used in a small metal-working shop, for such things as the manufacture of the metal boxes that house computers. A human operator places metal computer housings on the work table and activates the robot. The robotic arm swings over the housings, sprays oil on the target hole, lowers, removes the metal from around a pre-drilled hole, and repeats the operation until the metal has been removed from around all designated holes.

For both Scenario 1A and Application 1, the panelists believed that the primary beneficiary populations would be physically and multiply handicapped students. The activities described in the scenario are consistent with those in the application--both involved students manipulating objects in their environment. Most of the panelists estimated the costs associated with developing the application as slightly lower (i.e., $100-200,000) than they did for the scenario (i.e., $200,000-300,000). There was also a difference in that most of the panelists believed that it might take less than four years to develop the application, whereas the majority of the panelists believed it would take at least from five to ten years to develop the scenario. Finally, for both the application and the scenario, the panelists cited costs and technical barriers as the chief impediments to future development and use with special education students.

The panelists agreed that both Scenario 2A--welding robot--and the industrial application upon which it was based were likely to be of quite limited usefulness to special education students. This application can be summarized as follows:

Application 2: Welding Robot

> The "Unimation 7000" is an electrically powered robot equipped with a positional sensing system, that is used in a manufacturing plant to make nuclear waste storage containers. A human operator places and secures two metal pieces on a work table and activates the robot. The robotic arm lowers and begins welding, while the sensing system constantly monitors the arm's position in relation to the target weld and adjusts the arm when it is off course. When the weld on one side is complete, the operator turns the piece over, and the sequence is repeated.

For both Scenario 2A and Application 2, the panelists believed that any benefits from welding robots would only occur in a training or vocational setting, and that the nature of the robot itself (i.e., heavy and cumbersome) would preclude its transferability to serve other functions.

The panelists differed somewhat in their ratings of Scenario 3A--multiple environment assistive robot--compared to the industrial application upon which it was based. This application can be summarized as follows:

Application 3: Machine Vision Robot

> "BinVision" is a robot, interfaced with a vision system, that is used to identify and select jet engine parts on a moving conveyor belt in a large manufacturing plant. A human operator dumps parts onto the conveyor belt that passes under the robot's vision system. The vision system

> identifies the required part and sends its locational coordinates to the robot's controller. The controller directs the robot's arm to pick up the part. The robot places the part on a table for use by the next robot in the work station, and then identifies, selects, and places another part.

For the application, the panelists believed that the primary beneficiary population would be visually handicapped students. For the scenario, they identified physically handicapped students as the primary beneficiaries. Further, the panelists were more optimistic about the required time and cost investments that would be required to benefit from the application, than from the scenario. Specifically, the majority of the panelists believed that the application might be developed and implemented to help special education students in less than four years and at a cost ranging from $100,000-300,000. For the scenario, these same estimates were for at least five to nine years and at a cost exceeding $500,000. The principal barriers--cost and technical difficulties--were the same for both the application and the scenario.

Ratings of Industrial Applications. The panelists identified two special education populations as the most likely beneficiaries of the robotics applications: physically handicapped/other health impaired and multiply handicapped. Other populations, including severely, multiply, and visually handicapped, were also identified as potential beneficiaries, depending of course on the specific robotics application. Several activities were identified as ones which might be accomplished or facilitated by the robotics applications. These include:

- Selecting, loading, and re-storing floppy discs in a computer laboratory;
- Contributing to independent living skills such as eating and food preparation and cleanup;

- Conducting laboratory experiments;
- Drawing and writing;
- Turning the pages of a book; and
- Identifying and selecting objects (when robots have machine vision capability).

The panelists believed that the applications could yield some benefit to ten percent of the relevant special education populations in the immediate future. This near-term timeframe is due, in large measure, to the vocational uses for which the applications are relevant today. The uses of specialized features of the applications, such as those equipped with vision systems, would require a much longer time horizon--over twenty-five years, according to some of the panelists. The costs estimated for developing the robotics applications ranged from under $100,000 (for the currently available vocational uses), to over $500,000 for systems where specialized development needed to occur. As one panelist noted, "Almost nothing new in robotics R&D can be done for under $1/2 million. It would cost that much just to [think about a specific use] and do the field testing."

Finally, the panelists agreed that cost and technical barriers would be the two biggest obstacles to developing and implementing the applications for special education students. These barriers would be greatly reduced when robots are more routinely used in other settings (i.e., are widely available commercially) and if robotics applications were more routinely used in other human service settings.

Summary

Three scenarios of the use of robotics in special education settings, along with their industrial counterparts, have been reviewed. The expert panelists who rated the scenarios agreed that physically handicapped and other health impaired students would be the primary beneficiary population from the robotics scenarios, and that multiply handicapped students might also benefit, but to a lesser extent. The panel judged that the robotics scenarios would take from five to nineteen years to implement and would cost from $100,000 to over $500,000 (in 1984 dollars). For each scenario, this development cost was seen as the primary barrier to implementation.

Of particular promise, according to the panelists, might be the robot described in Scenario 1A--object and mechanical device manipulating robot. The panelists believed that this robot might help physically and multiply handicapped students to better interact with their environment. The students might benefit from a pilot version of the robot in as little as four to nine years, with an investment of about $300,000. The panelists did not believe that the other two robotics scenarios held any near-term promise for aiding special education students.

V. THE DEFINITION AND STATE-OF-THE-ART OF ARTIFICIAL INTELLIGENCE

Capsule Definition of Artificial Intelligence

Artificial intelligence (AI) is both a field of study and a technology. In either situation, the topic involves:

> The use of the computer to conduct the types of problem solving and decisionmaking faced by human beings in dealing with the world (Gevarter, 1983a).

The field has undergone several fluctuations over the past thirty years. Paradoxically, despite the presumed capacity and power of contemporary computers, AI researchers have yet been unable to replicate the basic common sense reasoning and logic virtually taken for granted in human beings.

Discussion of Artificial Intelligence Definition

Changes in Artificial Intelligence Over the Past Thirty Years. One set of insights into the distinctive features of AI is provided by the historical development of the field, which began in the mid-1950s. At that time, "...it was assumed that intelligent behavior was primarily based on smart reasoning techniques and that bright people could readily devise ad hoc techniques to produce intelligent computer programs" (Gevarter, 1983a, p. 5). Among the most prominent accomplishments during this period, the program ELIZA was created (by Joseph Weizenbaum at The Massachusetts Institute of Technology--MIT), which operated as a non-directive psychotherapist. Early programs such as this overlooked the vital role of an extensive knowledge base, only focusing on the need for the smart reasoning techniques. In addition, the importance of heuristic search--i.e., one that would evaluate feedback and be "self-educating"--was not fully understood.

In the 1970s, some of these problems were addressed by new AI research. For instance, the search techniques began to mature, and attempts were made to develop programs for language processing, speech understanding, computer vision, and computer programs that could perform like experts. This progress led, in the 1980s, to the proliferation of expert systems, used for medical diagnosis, chemical and biological synthesis, mineral and oil exploration, circuit analysis, tactical targeting, and equipment fault diagnosis. An excellent example of this is an expert system that serves the function of a locomotive mechanic--i.e., putting a "computerized expert" at every railroad repair shop (Pratt, 1984a). (See Application No. 10 in Appendix A.)

Currently, the major AI program languages are LISP and PROLOG. The LISP language was initially developed by John McCarthy at MIT, and takes the form of symbolic expressions that are stored as list structures (Gevarter, 1983a, p. 33). The development of this language led to the further development of several different "LISP dialects," each with different levels of documentation and relevant for different kinds of hardware. A good example of this is "Golden Common LISP," based originally on the "Common LISP" language created by Patrick Winston (director of the AI laboratory at MIT) but adapted for microcomputers by the Gold Hill Computers, Inc., of Cambridge, Massachusetts. The PROLOG language has undergone similar developments, and is a logic-oriented language first developed in 1973 at the University of Marseille by A. Colmerauer and P. Roussel.

As for future developments, of particular interest is the Japanese plan to create a "fifth generation computer." The Japanese effort started in 1982, and is an attempt to install AI into computers. The intended features of the computer are that "...it is to have 1) intelligent interfaces (speech, text, graphics, etc.), 2) knowledge base management, and 3) automatic problem solving and inference capabilities" (Gevarter, 1983a, p. 11). These are the very features that define the essence of AI.

Artificial Intelligence Distinguished from Traditional Computer Programming. In the broadest sense, the definition of AI may be applied to all computer programming. However, the essence of current AI research and technology can be differentiated from traditional computer programming in at least three ways:

1. AI programs involve the manipulation of symbolic processes, and not merely numerical processes;

2. AI programs utilize heuristic search processes (based on rules) rather than algorithmic processes (based on formulas); and

3. AI programs call on large knowledge representation bases, containing information separate from the control languages and processes used by the program.

These three differences may be further described as follows.

First, with regard to the use of symbolic processes, the important characteristic is that the computer's architecture (i.e., the structure of the machine that permits it to be programmed) provides for internal representations that refer to other things--i.e., symbolic behavior (Research Briefing Panel, 1983). The symbol systems can be complex and abstract, far beyond the simple representation of numerical values in the traditional computer program.

Second, the use of heuristic search processes means that computer problemsolving can be based on general rules coded into the computer, as well as feedback about the success or failure of the search to that point. The processes are therefore able to deal with more complex problems than with traditional computer programming where search routines were defined in a "blind" or mechanistic manner. One by-product of the heuristic search process may be the creation of several, and not just singular solutions to a problem, and this again distinguishes AI from traditional computer programming.

Third, the knowledge representation bases are distinctive due to their broad domains and large sizes. Whereas the traditional approach to intelligence, for instance, had been based on the assumption that human reasoning follows complex and insightful processes coupled with only narrow knowledge bases, recent developments with AI have suggested the reverse. Thus, human common sense appears to be based on elementary reasoning coupled with massive amounts of experiential knowledge.

All of these contrasts between AI and traditional computer programming may be summarized by the following observations (Watt, 1984):

- "In AI, you don't tell the computer program what to do, but what to know."
- "In AI, the computer must be able to explain *why* it reached a conclusion."
- "In AI, you let the knowledge stay in the knowledge base."

Artificial Intelligence Distinguished from Other Technologies. The use of an artificial intelligence language and program can be combined with virtually any other sensory/motor device. Thus, AI overlaps with other technologies whenever this type of combining takes place--as in the example where an AI system may be used in part to control the functional behavior of a robot. Whereas the creation of the robot itself--emphasizing its motor abilities--may be considered an achievement of the robotics field, the development of the computer component may be a reflection of advances in AI.

Subcategories of Applications in Artificial Intelligence

Current AI applications can be divided into five major subcategories, which reflect those used by the American Association for Artificial Intelligence:

1. *Expert Systems*--intelligent computer programs, using knowledge and inference procedures to solve difficult problems (Feigenbaum, 1982); examples are (Waldrop, 1984):
   -INTERNIST-1, to diagnose internal medicine;
   -DELTA/CATS-1, to repair diesel locomotives; and
   -DEBUGGY, to tutor students in a form of "intelligent CAI" in which the student is able to ask questions and receive intelligent responses;

2. Sensory Information Processing (Research Briefing Panel, 1983)--including: a) computer vision or visual perception systems (Kinnucan, 1983) as well as b) speech recognition systems (Elphick, 1982);

3. Natural Language Processing, in which natural languages can be used to: a) communicate with computers and therefore to gain access to large databases stored in mainframe computers (Davis, 1984; and Gevarter, 1983b) or b) translate foreign language texts;

4. Speech Synthesis, or speech output from a computer (Elphick, 1981); and

5. Planning Systems, in which computers are used to select and connect individual actions into sequences, in order to achieve desired goals (Wilensky, 1983).

State-of-the-Art of Artificial Intelligence Based on Applications Reviewed

In all, 20 industrial applications of artificial intelligence were reviewed--five were part of the in-depth reviews and 15 additional ones in an inventory. (The reader is referred to the "Identify Uses of the Technologies" subsection of Section I for a description of the in-depth reviews and the inventory. Summaries of the information collected during the in-depth reviews are included in Appendix A and are referred to in this report as "applications.") From the analysis of these applications, the following conclusions were drawn:

1. AI programs represent very complex activities;

2. Expert systems are the most prevalent type of AI program;

3. Some AI programs, once written, can be readily adapted for use in other settings, and thus subsequent versions are relatively inexpensive to develop and operate; and

4. AI programs often rely on mainframe computers for efficient operation.

Table 9

VIGNETTES OF ARTIFICIAL INTELLIGENCE USES*

"Voice-Recognition Robot." A robot, equipped with a voice-recognition system, is being developed to perform the activities of daily living, such as serving food and water (e.g., to a disabled person) and painting for recreation. It also is being developed to perform other work tasks such as retrieving a file from a drawer and removing paper from the file. The robot is a Puma 250 that is equipped with an 8-bit microprocessor.

"RTC Project." This Radar Target Classification system uses rules for identifying ships--e.g., distinguishing among types of destroyers, cruisers, and aircraft carriers. Using a vision expert system, the features of an unknown ship are extracted and matched to the features of three-dimensional models of ships in the system's memory.

"EXPERT." This expert system is a generalized scheme for building expert reasoning models which can be used with individual problems, testing, and analysis on large numbers of cases, and work with large size models. The system has been used by specialists in medicine, biochemical modeling, and oil exploration to capture problem-solving expertise.

"EMYCIN." This is a system for building other expert systems (it is the MYCIN expert system minus the medical knowledge). To build an expert system using EMYCIN, an analyst must encode and add the knowledge base.

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* These vignettes were not the subjects of indepth review. They have been taken from a separate study document, "Inventory of Applications," by Robert K. Yin, Gwendolyn B. Moore, Elizabeth A. Lahm, and J. Lynne White (COSMOS Corporation, Washington, D.C., November 1984).

Complex Activities. The AI applications were used to represent the most complex of human activities--problem solving. AI programs were routinely used for such purposes as diagnosing medical illnesses, evaluating the molecular structure of chemicals, and analyzing geologic formations. AI programs generally represent vast amounts of knowledge, rules, and "if-then" statements, that actually allow the programs to make judgments and draw conclusions that heretofore would have been the sole domain of humans. In addition, AI applications have established planning sequences, recognized objects, synthesized speech, and recognized speech.

AI applications were also used in conjunction with other technologies, such as the vision system in the BinVision robot (see Application No. 3 in Appendix A) and the voice recognition system used with a robotic arm being developed by the Veteran's Administration Hospital in Palo Alto, California (see "Voice-Recognition Robot" in Table 9).

Expert Systems Predominate. Expert systems were the most prevalent type of AI program in regular use. In fact, examples of use of other types of AI programs--e.g., voice recognition and planning--were difficult to find, and they tended to be less well developed than their expert system counterparts. A number of technical barriers appear to be hampering the development of other types of AI programs. For example, certain types of sensory information processing systems (e.g., see "RTC Project" in Table 9) require massive amounts of information to be processed, which takes hours to run even on the largest and fastest mainframe computers.

As another example, speech recognition systems generally recognize the voice of only one person, and that person must enunciate his or her words in the same manner each time to be recognized. This is a significant obstacle, because if a person cries "stop" in a panic situation, and thus is not using his or her normal tone of voice, the speech recognition system will not recognize the word. This poses a severe safety threat if, for example, a speech recognition system were used to control the movements of a robot. Also, speech recognition systems tend to have very limited vocabularies (e.g., 50-100 words).

Adaptability of AI Programs. AI programs are relatively easy to adapt from one purpose to another. For example, the INTELLECT natural language processing system (see Application No. 8 in Appendix A) contains the basic rudiments of the system, and each new user simply adds a lexicon of terms specific to their situation. Also, certain expert systems programs, (see "EXPERT" and "EMYCIN" in Table 9), provide the structure within which to develop other expert systems--that is, they represent the "system" without the "expert." Because these types of AI programs were used as tools for developing additional applications, subsequent versions are relatively inexpensive. This adaptability was not the case for all AI programs however, such as vision recognition systems and planning systems.

Reliance on Mainframe Computers. Many AI programs were developed either on mainframe or minicomputers, and are only now being modified to run on microcomputers. Some AI programs will only be run on mainframe computers, because of the massive amounts of information they are required to process. Such reliance on large computers introduces a significant cost barrier to the use of some AI programs.

VI. FUTURE USES OF ARTIFICIAL INTELLIGENCE IN SPECIAL EDUCATION

The expert panelists developed and rated five scenarios describing the possible future uses of artificial intelligence in special education (refer to Section I for a description of how the scenarios were prepared and rated). The ratings identified the most likely beneficiary population, the activities that would be facilitated for the population, the length of time and costs which might be required for the benefits to be realized, and the barriers which might impede development and use of the technology in a special education context (see Appendix B for the questionnaire used for these ratings).

This section contains the information and data upon which the findings, conclusions, and tables in Section II of this report are based. Specifically, this section: 1) presents the analysis of the panelists' ratings of the scenarios; 2) compares their ratings of the scenarios with their ratings of the industrial applications upon which each scenario was based; and 3) presents the analysis of the panelists' ratings of the industrial applications themselves.

Ratings of Scenarios

Five artificial intelligence scenarios were rated by the expert panelists: 7A, screening and evaluation system; 7B, interactive diagnostic/treatment tool; 8A, resource database retrieval system; 9A, curriculum planning system; and 11A, mobility aid. The ratings for each one follow.

The first artificial intelligence scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 7A: Screening and Evaluation System

This diagnostic expert system will be used in school settings to assist in the screening and evaluation of mildly and moderately handicapped students. Some data are input by a clinician (e.g., demographic information) and other data are input by the student (e.g., touch tablets

> are used for motor functions such as copying shapes, writing, etc.). The system analyzes the data and prepares a diagnosis in narrative form, including an estimation of deviation from the norm and recommendations regarding treatment.

This system might be applicable to most all special education populations, but the panelists believed it would be of most benefit to mild and moderate mentally handicapped and learning disabled, and physically handicapped and other health impaired students. School personnel would use the system to screen, diagnose, and place students. For example, the system might be used with a non-vocal, motor-impaired student for diagnosing and identifying the appropriate curriculum and prosthetic materials to best meet the student's needs. One panelist believed that the system described in the scenario might be an efficient tool for curriculum planning, but another one questioned the emphasis of the system on normative data and visual skills only.

The panelists varied widely in estimates of how long it would be before the system might be available for use by school personnel. Three of the five panelists believed that ten percent of the relevant special education populations could benefit from the scenario in fewer than four years. However, the other two panelists did not believe that any students would benefit for at least ten years, and then in only a limited version. With regard to cost, all but one panelist believed it would cost in excess of $500,000 to implement the system, with one estimate as high as $3 million. The estimate of less than $500,000 was premised in the elimination of certain features of the system (e.g., graphics). Much of the cost of the system would be dedicated to the development of overt behavior norms to be used as diagnostic tools. (This concern over norms has been dealt with in other systems used in medical and clinical settings.)

Technical difficulties were mentioned most frequently by panelists as the factor that would inhibit the implementation of the system. The need for training of school personnel was the second most frequently cited factor. Overcoming the technical difficulties, according to the panelists, could be accomplished through a substantial funding program.

The training needs could be met through the use of demonstration projects, good documentation, and a technical hotline.

The second artificial intelligence scenario can be summarized as follows (see Appendix D for the full scenario):

> Scenario 7B: Interactive Diagnostic/Treatment Tool
>
> GRAPHCOM operates in a clinical setting concerned with language communication disabilities, where alternative communication channels must be tapped and mapped into "normal" language. The system operates as an interactive diagnostic/treatment tool. Its operation is based on the use of visual symbols in place of written and spoken language, where the system matches the symbols with its database, and communicates the symbols--but in normal English--from the user to others and back again.

Scenario 7B would benefit communication disordered and speech and language impaired students, and would be used by students to communicate, interactively, with others. Despite this possible use, three of the five panelists questioned the overall value of the tool. These panelists did not believe the tool reflected an appropriate or beneficial use of the technology, and challenged whether or not the scenario was realistic.

The panelists differed with regard to the amount of time it would take for the tool to be developed and implemented. One panelist did not believe that the scenario was desirable because he saw no benefit to it. Two other panelists believed it would be many years before the scenario would occur--one thought at least twenty-five years and the other at least fifty years. At the same time, the two panelists who believed that the tool might be technically possible in as little as five to fourteen years questioned the validity of the tool in the first place. In addition to all these qualifications, the panelists further agreed that the cost of implementing such a scenario would be in excess of $500,000. Much of the cost of the scenario would be, in the panelists' judgments, required for validating the concept underlying the scenario, not in the cost of technical development.

Although not the most costly item, technical developments would be the biggest barrier, according to the panelists. To overcome these barriers, the panelists cited the need for advances in linguistics and artificial intelligence "authoring" systems. The need for training of parents and students was also cited as a barrier, although the panelists commented that the extensive amount of training that would be required for the scenario might make its actual use quite unrealistic.

The third artificial intelligence scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 8A: Resource Database Retrieval System

> This system would be used by professional staff to query a database that stores information on resources, both instructional and physical. Resources are keyed to instructional goals and special education populations. The output of the system includes descriptive and prescriptive information.

This scenario represents a system for use by administrators, placement teams, and professional staff for planning and delivery of services to a range of special education populations (three populations were most frequently mentioned by the panelists: mild and moderate mentally handicapped/learning disabled, physically handicapped and other health impaired, and multiply handicapped). One panelist noted that the system might make the decisionmaking of professional staff easier, but questioned whether it would improve the care or education of students. Others noted that the system would be of only indirect benefit to the students, and that its benefits would be highly dependent on the quality of the information available in the database. Further, two of the panelists noted that the scenario may more closely resemble a standard database research problem than a true artificial intelligence application.

All but one of the panelists agreed that the system could be implemented--to a limited degree--in fewer than four years, although one believed that implementation could not occur for at least ten years. The majority of the panelists believed that it would take at least twenty years before the use of the system would be widespread. The cost of the system would be highly dependent on the scope of the database; moreover, to be most effective, the database would need to be extensive. Therefore, the cost of the system could be expected to exceed $500,000. As with the screening and evaluation system scenario, one panelist estimated that the costs of the system might be as high as $3 million.

The primary barrier to implementation of the system, according to the panelists, would be the training of school personnel. The overall cost of developing the database also was seen as a significant barrier. The training barrier could be reduced by assuring good system documentation and developing self-paced training modules. The cost might be reduced by establishing certain centralized, or "core" portions of the database.

The fourth artificial intelligence scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 9A: Curriculum Planning System

> This system is used by school personnel in curriculum planning. Data about the student's handicapping condition(s), mental and physical capabilities, and interests are put into the system. The system's database includes information about resources available in a given school, and generates a curriculum plan that best meets the student's learning needs.

This scenario involves the use of a database of existing special education resources to meet students' needs. The majority of the panelists challenged the basic premise underlying this scenario--i.e., matching student's needs with <u>existing</u> resources--as they felt the premise violated the clear intent of P.L. 94-142. P.L. 94-142 requires the specification of students' needs first, and then the identification of resources to meet those needs. Because the scenario describes a contrary situation to this, the panelists believed that no attempts should be made to implement the system described in the scenario.

Further, the scenario does not take advantage of the true properties of the artificial intelligence planning program upon which the scenario was based. In light of these strong concerns by the panelists, other information about the implementation of the scenario--e.g., time, cost, and barriers--are not reported here.

The fifth and final artificial intelligence scenario is summarized below (see Appendix D for the full scenario):

Scenario 11A: Mobility Aid

> This sensory-information processing system (SIPS) is used by visually impaired individuals as a mobility aid. The system not only detects objects, but it also determines what these objects are. The SIPS interprets sonar-type signals that the system sends and receives from a small processor carried on the user's belt. The system not only detects when an object is in the user's path, it also determines what the object might be and informs the user verbally as to the nature of the object.

Scenario 11A would be used to help students move around in their environment and to identify and avoid obstacles and objects. For example, it might allow a blind student to walk and talk with someone else, without either "holding on" or devoting all of his/her efforts toward locomotor guidance. The aid would be of primary benefit, according to the panelists, to visually handicapped students, although some believed that it might also be useful to multiply and physically handicapped students.

This aid, however, would require the use of artificial intelligence technology which far surpasses the current state-of-the-art of the technology. As a result, the panelists generally believed that it would be many years before the aid could be developed, and that development would be very expensive. Specifically, the panelists' estimates of the time before the aid might be available ranged from ten to twenty-four years. The panelists estimated that the cost to develop the aid might exceed $20 million. This high cost reflects the need to overcome immense technical obstacles, such as the miniaturization of the database. One panelist believed that the investment required to develop the aid might be better spent to develop an effective means of replacing the function of the defective sensors--i.e., the eyes.

Comparison with Industrial Counterparts

Each of the five scenarios just discussed has an industrial counterpart--that is, an application which currently operates in a setting other than education, and upon which the scenario was based. The panelists rated the industrial artificial intelligence applications on the same dimensions as they did the scenarios. This subsection compares the ratings of the scenarios (done by five panelists) to the ratings of the industrial applications (done by ten panelists), and then summarizes the panelists' ratings of the applications themselves.

Comparing Scenario and Industrial Application Ratings. Two of the artificial intelligence scenarios--7A and 7B--are based on the same industrial application. This application can be summarized as follows:

Application 7: Clinical Diagnostic Expert System

> Micropuff operates in a clinic of a 300-bed hospital, where it is used to analyze and diagnose the pulmonary functioning of patients. Some 30 variables are put into the system from an instrument that analyzes a patient's breath, and from a questionnaire to which the patient provides verbal responses. The system analyzes the data and prepares a diagnosis, written in narrative form.

The panelists rated Scenario 7A much as they had Application 7. For both, the panelists believed that a number of different special education populations would benefit through use of the system by administrators and school personnel. The activities foreseen were essentially the same (e.g., screening, diagnosis). The time required before the activities might be performed to the benefit of fifty percent of the relevant population(s) was seen as about the same for both the application and the scenario (i.e., between ten and nineteen years), although the estimate of development costs was greater with the scenario (over $500,000) than with the application (all but one of the panelists estimated the cost to be under $400,000). The panelists also identified technical difficulties as the greatest barrier to implementing the industrial counterpart to Scenario 7A. Cost and the need for training school personnel would also be significant barriers, according to the panelists.

The panelists rated Scenario 7B much differently than they had its counterpart, Application 7, clinical diagnostic expert system. With the scenario, the panelists indicated that communication disordered and speech and language impaired students would be the primary beneficiaries, but for the application they identified mild and moderate mentally handicapped/learning disabled as the principal beneficiaries. The panelists had raised questions about the utility of the scenario, but they did not pose any similar questions for the application. The panelists generally thought that the costs of implementing the scenario would be higher than for its industrial counterpart, and that the time before implementation might occur would also be considerably longer. The barriers to implementing both the scenario and the application were similar--i.e, technical difficulties, cost, and the need for training school personnel.

The panelists differed somewhat in their ratings of Scenario 8A and its industrial counterpart. This application can be summarized as follows:

Application 8: Natural Language Processing System

> INTELLECT is a natural language processing system that is used by staff in a large corporation to query a personnel database. Human operators enter requests on a keyboard using common English sentences. The system interprets each query and provides immediate responses to the questions, based on information included in the database.

The panelists identified administrators as the primary users of Scenario 8A, thus benefiting all special education populations equally.

For the application, the panelists were split, with half identifying mild and moderate mentally handicapped/learning disabled as the primary beneficiary population, and the other half suggesting that the primary use of the application would be by administrators. The panelists' ratings of the time it might take before the application could be implemented to benefit ten percent of the relevant population was slightly higher than it had been for the scenario--i.e., almost all of the panelists said implementation of the application could occur in fewer than nine years compared to their rating of fewer than four years for the scenario. The cost of developing the application, according to the panelists, was less (i.e., 70 percent of the panel estimated that the cost would be less than $300,000) than for the scenario (i.e., in excess of $500,000). Finally, the panelists were consistent in their identification of barriers: for both the application and the scenario, they identified the need for training of school personnel and cost as the main barriers. For the application, the panelists also added technical difficulties to this list.

The panelists' ratings of Scenario 9A, in which they challenged the premise of the scenario, were similar to their ratings of its industrial counterpart. This application can be summarized as follows:

Application 9: Planning System

> DEVISER is a planning system that was designed to arrange and schedule numerous operations, in their appropriate sequential order, to be carried out aboard an unmanned spacecraft. Human operators give an objective to the system, then the system refers to its 50-page information base and checks the status of shared resources. Based on available information, the system produces a set of instructions for producing the objective.

Although some of the panelists believed that the planning system application might have some applicability to special education students, most did not. The time before the application might be found in a special education setting was estimated to be at least ten to twenty years, and at a cost exceeding $500,000. The panelists generally agreed that major technical barriers would need to be surmounted before the application might be of benefit in special education.

The panelists' ratings of Scenario 11A and its industrial counterpart were similar. The application can be summarized as follows:

Application 11: Sensory-Information Processing System

> HASP/SIAP is a sensory information processing system used by a military service to detect the presence of ocean vessels by analyzing signals received from hydrophone arrays hidden in the ocean. The hydrophone sends digitized signals to the system. The system sorts the signals, and by using its knowledge base about the environment, ocean vessels, interpretation rules, and how to use other knowledge, it determines what vessels, if any, are moving in which areas of the ocean. The system produces a "current best hypothesis" about a specific vessel at a particular place at a particular time.

The panelists agreed that visually, hearing, and communication disordered students were likely to be the primary beneficiaries of Scenario 11A and Application 11. However, for the application as well as the scenario, some of the panelists questioned whether or not it would ever be possible to aid students with the technology described. The panelists believed that both would take many years--from five to twenty--before benefits might be observed, even with a limited percentage of the relevant populations. Further, most of the panelists believed that the costs for both would be the same, i.e., over $500,000. Finally, the panelists also agreed that the barriers to the development and implementation of both the scenario and the application would be technical obstacles and the costs associated with overcoming them.

Ratings of Industrial Applications. The range of capabilities of the artificial intelligence applications resulted in the panelists identifying several special education populations which might benefit from the applications. The population identified by panelists most frequently was mild and moderate mentally handicapped/learning disabled students. In addition, many of the panelists noted that the artificial intelligence applications may be especially appropriate for use by administrators and other school personnel, and as such, might be used to the benefit of all special education populations.

The artificial intelligence applications, according to the panelists, might help special education students in many ways. Examples of possible activities include:

- When used by administrators, clinicians, and other school personnel:
    - -to screen, diagnose, prescribe, and identify resources for individual students;
    - -to identify specialized curriculum materials available in a curriculum bank;
    - -to facilitate records management and custom scheduling of individual treatment programs; and
    - -to interpret speech patterns of students.
- When used by students:
    - -to identify and correct systematic cognitive errors (e.g., in learning math or in learning to talk);
    - -to demonstrate and practice important language concepts;
    - -to develop problem-solving skills by "asking" the student to clarify ambiguous or irrelevant questions;
    - -to provide access to reminders, procedures, and skills data;
    - -to plan trips or sequence other activities; and

-to discriminate among objects in student's environment and to help identify specific objects.

The panelists generally agreed that ten percent of the relevant population might begin to benefit from the artificial intelligence applications in fewer than four years. There was considerable variability in the panelists' ratings as to the time that would be required for larger percentages of students to benefit, with estimates ranging from five to over twenty-five years. Such a wide range reflects the variability of the artificial intelligence applications. Similarily, the panelists were divided on the costs for developing the applications to meet special education needs. The costs, like the time required, had a wide range, from under $100,000 to in excess of $500,000.

The panelists agreed, however, on two primary barriers which would impede the development of all of the applications: cost and technical difficulties. (The need to train school personnel and the commercial availability of applications were also seen as important barriers.) The two primary barriers, according to the panelists, would be reduced when the applications were more widely used in other settings.

Summary

Five scenarios of the use of artificial intelligence in special education settings, along with their industrial counterparts, have been reviewed. Based on the ratings of the expert panelists, five special education populations were identified as potential beneficiaries of the scenarios. The panelists also believed that it would take from five to twenty-four years for implementation to occur. The greatest barriers to implementation would be technical difficulties, needs for training, and cost. The cost for all but one of the scenarios would be in excess of $500,000.

Three of the five scenarios represent use of the technology by special education administrators and school personnel, rather than the students themselves. One of these--Scenario 8A, resource database retrieval system--seemed to panelists to hold the most promise for aiding special education students in the future. The panelists identified a number of problems associated with implementing the other scenarios, which suggests the need to examine the scenarios further before any implementation efforts were to occur.

VII. THE DEFINITION AND STATE-OF-THE-ART OF COMPUTER SIMULATION

Introduction to Computer Simulation

The "traditional" definition of computer simulation is quite broad, and encompasses the routine use of computer simulation techniques in over 70 fields, spanning ambulance dispatching, consumer behavior patterns, financial forecasting, harbor design, manpower planning, water resource management, educational funding, aircraft design, and urban development (Bronson, 1984). (For specific examples, see Anderson, 1983; Levy, 1983; and Patil, Janahanlal, and Ghista, 1983). Further, the history of computer simulation begins in the early 1950s, when aerospace engineers conducted simulations using analog computers (Pratt, 1984b). Finally, computer simulations also are currently used in educational settings--e.g., VOLCANO is a simulation that teaches students the geology and other forces related to volcanic activity.

Thus, a difficult challenge was faced by the project team: to develop a definition of computer simulation which would be relevant within the context of the present study, and yet one which was sufficiently narrow to be manageable in light of resource constraints.

Traditional Computer Simulation

Definition. Computer simulation is generally defined as: The representation of a system by a set of computer-based instructions that create a model whose behavior can be observed; the model's behavior is considered sufficiently close to that of the actual system that properties of the system can be inferred from the simulation (Dertouzos and Moses, 1979). The "system" can be any organism, process, organization, or situation that exists or is imagined ("The Society for Computer Simulation," no date). Computer modeling--representation of systems by mathematical formulas--is the heart of computer simulation.

Current Research. The majority of the activity in the computer simulation field today is in the use of proven computer simulation techniques by practitioners in problem-solving situations. There are relatively few people engaged in the "pure science" (Bronson, 1984) aspects of simulation--i.e., those who develop simulation languages and statistical tests.

Types of Simulation, Simulation Models, and Simulation Languages.[1] Two types of simulation are traditionally practiced: discrete and continuous. Discrete simulations deal with queueing system problems, where the prime interest is in the efficient processing of service recipients (e.g., customers in a store, airplanes at an airport). Discrete simulations address questions of how long a customer might have to stay in line (the queue) or the length of the queue given the number of service providers. Such problems are anchored in probability. Two further characteristics define discrete simulations: 1) the units moving through the system are measured as integers, and 2) there are large blocks of time in which the underlying system does not change.

Continuous simulations deal with systems that change constantly with respect to time--e.g., the trajectory of a rocket in flight. Thus, with continuous simulations the primary interest is the time-varying behavior of all quantities within the system. Because continuous simulation problems are generally governed by rates of change, the relevant mathematical models are based on differential equations; the only technique available for solving most differential equations is numerical integration, which is the core of continuous simulations. It is not always clear whether discrete or continuous simulation techniques are most appropriate, and in fact some forms of hybrid simulations--encompassing elements of both types of simulations--have emerged.

Two types of models are employed in simulation.[2] Analog models "act like" the systems being represented but are quite different in appearance, and are employed in discrete simulations (e.g., a service provider in a store would be represented by the value of 1 when busy, or by the value 0 when free). Abstract models are sets of mathematical equations for quantities in the system being studied. Abstract models of differential equations are the basis of all continuous simulations.

General purpose computer languages, such as FORTRAN, can be used for running computer simulations, although most practitioners prefer to use a specialized simulation language. There are two types of languages, corresponding to the two types of simulations. Discrete simulation languages are numerous, and include: SIMPAS, CAPS, DEMOS, GPSS, SIMSCRIPT, GASP, and SLAM (SLAM allows for some continuous simulation activities to be performed as well). Continuous simulation languages are based on numerical-integration routines for solving sets of first-order differential equations (both linear and nonlinear). These languages include: CSMP, CSSL-IV, ACSL, EASY5, DARE, and DYNAMO.

Simulation languages were originally designed to run on mainframe or minicomputers. Recently, however, new languages have been introduced to allow both discrete and continuous simulations to be run on microcomputers (e.g., micro-DYNAMO, SIMAN, and MicroNET).

A Focused Definition of Computer Simulation

The traditional definition of computer simulation is exceedingly broad, and includes applications in all aspects of problem solving in the physical sciences, as well as in the social sciences, economics, and education. As previously noted, it was necessary, for the current project, to develop a more narrow definition of computer simulation, to identify a manageable set of computer simulation applications. Thus, for the present study, computer simulation will be regarded as:

> A computer-controlled sensory or motor experience, providing an individual with exposure and involvement in an artificial environmental setting.

A computer simulation would thus include at least two components: 1) direct control of the activities of the simulation by a computer; and 2) some device to provide the sensory or motor experience--e.g., video display, sound, or movement. This definition would, therefore, exclude simulations conducted for analytic purposes, such as problems of natural resource supplies, population growth, assembly line functions, and the like. This definition also excludes simulations used as CAI tools, such as those currently used for teaching chemistry, physics, geology, and the basic skills.

Computer Simulation Distinguished from Interactive Videodiscs

Certain interactive videodisc applications closely resemble some computer simulations, as defined for this project. In fact, videodiscs are even used as the visual element in some simulations. Interactive videodiscs have been classified by their "levels of interactivity" (Thorkildsen and Friedman, 1984, p. 93), as follows:

> Level 1--the videodisc player is controlled manually with remote control device; the flow of logic of the videodisc is controlled by the user.
>
> Level 2--the videodisc player is controlled by a microprocessor built into the videodisc player; the flow of logic of the videodisc is controlled by the microprocessor.
>
> Level 3--the videodisc player is controlled by a computer program in an external computer, and by input from the user via the computer's keyboard; the flow of logic of the videodisc is determined by the computer program.

Level 3 interactive videodiscs, if they provide sensory or environmental experience, are considered simulations in the context of the present study; Level 1 and Level 2 interactive videodiscs are not.

Subcategories of Applications in Computer Simulation

Computer simulations may be divided into the subcategories commonly used by the Society for Computer Simulation, the primary professional association for computer simulation. These subcategories include:

- Physical and engineering sciences;
- Chemical sciences;

- Energy, resource management, and environmental sciences;
- Biomedical simulation;
- Management and the social sciences; and
- Training and research simulations.

These subcategories are relevant to the traditional definition of computer simulation; for the focused definition used in the present study, only the last subcategory--training and research simulations--is relevant.

State-of-the-Art of Computer Simulation Based on Applications Reviewed

A total of 13 industrial applications of computer simulation were identified--six were part of the in-depth reviews and seven more are included in an inventory. (The reader is referred to the "Identify Uses of the Technologies" subsection of Section I for a description of the in-depth reviews and the inventory. Summaries of the information collected during the in-depth reviews are included in Appendix A and are referred to in this report as "applications.") From these applications, the following conclusions have emerged:

1. Computer simulations have been used to replicate even the most complex, real-life situations;
2. Computer simulations are invaluable for depicting, without risk to a simulation's participants, life-threatening situations and high-risk environments;
3. Computer simulations are an effective training tool; and
4. Computer simulations are very expensive to develop.

Table 10

VIGNETTES OF COMPUTER SIMULATION USES*

"Lube Oil Plant." This operator-training simulator is a replica of a lube oil plant control room, where the simulation transmits information to and from the trainee station exactly as the process would. The simulator consists of an advanced simulation computer, instructor station, trainee stations, and simulation software.

"Trauma I." This educational simulator provides practice and reinforcement for paramedics to use "antishock trousers" (a device that looks like a rubber suit), that are put on trauma victims to stabilize broken bones, control bleeding, and prevent shock. The simulation has preprogrammed steps that must be followed before a student will meet with success, and only a minimal number of wrong branches are allowed before the "patient" dies.

"GULFSTREAM III SIMULATOR." This simulator provides pilots with a realistic flight environment, for a business turbo-jet, including both vision and motion. A complex mathematical model depicts the full range of aircraft functions, including the use of long-range navigation and weather radar.

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* These vignettes were not the subjects of indepth review. They have been taken from a separate study document, "Inventory of Applications," by Robert K. Yin, Gwendolyn B. Moore, Elizabeth A. Lahm, and J. Lynne White (COSMOS Corporation, Washington,, D.C., November 1984).

Replication of Complex Situations. Existing computer simulations have replicated the most complex of real-life situations, including operating chemical plants, flying jet aircraft, handling health emergencies, and making management decisions (see "Lube Oil Plant" and "Trauma I" in Table 10). One characteristic of computer simulations is that they often replicate a situation in "real time"--that is, the same as someone would experience in the real world. Further, many simulations, such as those used for training pilots, were so realistic that pilots were even given flight-hour credit for "flying" the simulation (see "Gulfstream III Simulator" in Table 10). Many of these simulations involve the use of an exact replica of the system it is modeling--e.g., an airplane's cockpit.

Duplication of Dangerous Situations. Computer simulations were particularly useful as a way of experiencing or examining life-threatening situations or high-risk environments without risk to human life. Such simulations may involve combat conditions, chemical spill clean-ups, and nuclear accidents (see Application No. 13 in Appendix A). Simulations were especially useful for training individuals to operate complex systems, such as airplanes, cargo ships, or certain types of processing plants. Learning these complex systems with a simulator allowed trainees to experience "accidents" and other problems without danger either to the human or to the system itself (see Application No. 17 in Appendix A).

Effective Training Tool. Because computer simulations can replicate such a vast array of real-life situations, they have been used as a training tool. This type of training was especially valuable in dangerous situations or when access to the real system was not feasible for training purposes. In the former situation, trainees experienced situations that would be prohibited otherwise, such as learning how to clean up oil spills. Simulations allowed trainees to experiment with a number of different methods and sequences of handling problem situations in a self-directed manner (see Application No. 14 in Appendix A).

Thus, trainees have been able to learn the consequences of their actions in situations replicatcng real life. Finally, because training using computer simulations does not pose a risk to trainees or to the systems about which they are learning, trainees have experienced and practiced certain types of activities which would be otherwise precluded (e.g., what to do during a nuclear plant accident).

Cost. Despite their many benefits, computer simulations have been very expensive to develop, especially when they involve the replication of a real-life system. For example, nuclear control room simulators must all be custom-built, because no two nuclear plants are alike. A nuclear control room simulator reviewed here cost about $7 million, including all hardware and software (see Application No. 13 in Appendix A). Other types of simulations, which are primarily software-based (e.g., see Application No. 16 in Appendix A), cost approximately $250,000.

NOTES TO SECTION VII

[1] This section draws heavily on an article by Richard Bronson, Farleigh Dickinson University, Teaneck, N.J., published in BYTE in March 1984. The authors also extend their appreciation to Bronson, for his willing exchanges regarding the computer simulation definition.

[2] There is also a third type of model, although it is not used in simulation. It is an iconic model, or one which looks identical to the system it represents (e.g., a mock-up of an automobile).

VIII. FUTURE USES OF COMPUTER SIMULATION IN SPECIAL EDUCATION

The panelists developed five scenarios of how computer simulation technology might be used to benefit special education populations in the future (refer to Section I for a description of how the scenarios were developed and rated). The ratings identified the most likely beneficiary population, the activities that would be facilitated for the population, the length of time and costs which might be required for the benefits to be realized, and the barriers which might impede development and use of the technology in special education (see Appendix B for the questionnaire used for these ratings).

This section contains the information and data upon which the findings, conclusions, and tables in Section II of this report are based. Specifically, this section: 1) presents the analysis of the panelists' ratings of the scenarios; 2) compares their ratings of the scenarios with their ratings of the industrial applications upon which each scenario was based; and 3) presents the analysis of the panelists' ratings of the industrial applications themselves.

Ratings of Scenarios

Five computer simulation scenarios were rated by the panelists: 12A, mobility training simulator; 14A, kitchen training simulator; 14B, object recognition and task-sequencing simulator; 16A, personal management training simulator; and, 16B, facility management training simulator. The ratings for each one follow.

The first computer simulation scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 12A: Mobility Training Simulator

> Beyond providing a very realistic simulation of equipment in operation, this application could be used to provide mobility training and wheelchair independence activities. This simulator could be used to help "fit" a future robotics/-wheelchair device. For simulating mobility and

> robotic wheelchair applications, instructors would be able to select features or options for the device, to program an interface structure (e.g., voice, touch, etc.), and to set mobility goals. The student could practice a wide range of features and environments, and could modify the configuration as needed, prior to fabricating the actual mobility device.

The panelists agreed that physically handicapped and other health impaired students would be the primary beneficiary population for this scenario. However, the panelists did not believe that the simulator addressed a real problem because mobility and orientation training is currently conducted in a effective manner, and thus, the costs of a simulation for the same purpose would not be well spent. Despite this essentially negative reaction by most of the panelists, one believed that the simulator might be useful as a diagnostic tool or to provide profound mentally handicapped students with "experience" in the environments in which they would someday be required to operate. In this same regard, the other panelists believed that the simulator might be of importance in training students how to use a "stair climbing" wheelchair, where mistakes could be dangerous. Further, the simulator might be helpful in diagnostic settings, such as in fabricating a "best" wheelchair for an individual.

If the simulator were to be developed (recall that the panelists did not believe it would address a need of the beneficiary population), it could be available to a limited number (i.e., ten percent) of the students in ten to fourteen years. One panelist noted that such an estimate assumes the availability of a good driver-education simulator, upon which the mobility training simulator could be based. The cost estimates for developing the simulator ranged from $300,000 to $1 million; however, the panelists noted that the limited usefulness of the simulator would make any level of investment not cost-effective. This lack of cost-effectiveness was also seen as the primary barrier to the development of the simulator.

The second computer simulation scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 14A: Kitchen Training Simulator

> "COOKER" is a videodisc software simulation of events and processes in a typical kitchen, where learning-impaired individuals can practice the planning and control of preparation tasks. In a typical sequence of usage the student would be assigned (or self-select) a food preparation (or service) objective. The system would follow or prompt for planning information and then simulate the processes requested (complete with appropriate visual imagery). If, for instance, an item is "overcooked," visual indications would be presented and corrective advice could be given. Performance can be quantified and used as a report card.

The primary beneficiary population for this scenario would be mild and moderately handicapped and learning disabled students. Other groups--including communication and behavior disordered students--also might benefit, according to the panelists. The simulator could aid students in learning and "experiencing" activities related to cooking, or other home economics or independent living tasks. One panelist did not agree that the cooking simulator as described would be beneficial to special education students; the panelist believed that cooking did not pose dangers to students, and that the inconsistency of the layout in kitchens would make the simulator of limited utility.

The majority of the panelists agreed that the simulator might be available to ninety percent of the relevant population in fewer than nineteen years. All agreed that it could be available to a more limited percent of the population--i.e., ten percent--in fewer than nine years (some believed that it might be available in less than one year).

All but one of the panelists believed that an investment of $200,000 to $300,000 would be required to develop the simulator. One believed that the cost might be as high as $1 million for the first setting, with subsequent modifications substantially less costly. This higher cost estimate was associated with the need for electronics interfaces to provide kinesthetic experiences.

The panelists cited cost and the need for training as the two primary barriers to implementation. The cost of implementation, according to the panelists, could be reduced through more widespread availability of similar simulations in other settings. Further, the simulator could help all students, not just special education ones, as well as individuals in institutional kitchen settings. To this extent, the development of the simulator might depend on its use in other settings before it is available to any special education population. To meet the training needs, panelists noted the importance of good documentation and the need for release time to train teachers in the use of the simulator.

The third computer simulation scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 14B: Object Recognition and Task-Sequencing Simulator

> This system allows the student to recognize the physical components of a particular vocational application setting, and practice the common sequences of steps used in that setting. Many such settings exist. Examples include: titration in a chemistry lab, proper use of a computer printer, a "car cockpit" and how to drive, etc. The student responds to text-based questions by entering a response or by touching the screen monitor. The system matches the student's input to an expected answer or sequence, and provides feedback. The system can determine when a student is ready to practice in a real environment.

The panelists identified mild and moderate mentally handicapped and learning disabled students as the primary beneficiary population for this scenario. However, several other populations were also cited as beneficiaries: behavior disordered and emotionally disturbed, physically handicapped, hearing handicapped, and severe and profound mentally handicapped. Two panelists also identified visually handicapped students as possibly beneficiaries of the scenario, but the other panelists questioned how this population could benefit from a video-based simulation. The scenario could be developed to provide a variety of experiences, including physically handicapped students doing physics and chemistry experiments, multiply handicapped students learning functional life skills, or mild and moderate mentally handicapped students preparing for vocations.

The panelists noted that the simulations like the one described in the scenario could be used with special education populations almost immediately and with very little cost (i.e., less than $100,000), because such similations already exist and are being used in other settings (e.g., chemistry lab video-based similations in schools and military vocational training simulations). However, for the simulator to be adapted to meet a particular need of special education students, it may take as many as nine years and cost as much as $1 million, according to the panelists.

The panelists believed that cost would be a significant barrier to implementation, and that the cost would be offset by having the simulations used by non-special education populations before adapting them to the particular needs of special education students.

The fourth computer simulation scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 16A: Personal Management Training Simulator

> This simulator provides a "game" of a variety of personal management problems that must be "solved" by the student. Depending on the degree of independence and specific problems being encountered by individual students, the simulator is programmed by the teacher to represent situations where the student must take some form of "interpersonal" action and then witness and evaluate the consequences. Feedback is given by the device and by the teacher.

For this scenario, all of the panelists agreed that mild and moderate mentally handicapped and learning disabled students would be the primary beneficiary population. Others, however, might also benefit:

communication disordered and speech and language impaired, behavior disordered and emotionally disturbed, and multiply handicapped. The simulator might not only teach students about personal management, but also could be modified to teach them about money management, mobility within the community, shopping, work habits and behaviors, or buying a meal in a restaurant. The technology required for the simulator is already available and being used in other settings. Thus, three of the panelists believed that the simulator could be implemented in fewer than four years. However, the other two panelists believed that, although the technology is available, the simulator might not be developed for five to nineteen years. This longer time horizon was seen as necessary if the simulation was to be adequately realistic (i.e., incorporate real scenes and objects, and not just computer-generated pictures).

The panelists estimated the range of costs for developing the simulator from $200,000 to $500,000. The panelists added a caveat, however: the quality of the actual simulation would be a direct function of cost--i.e., as the reality of the simulation increases, so does its cost. In the same vein, cost was seen as the greatest barrier to implementing the simulator. Certainly, the literal investment required to develop the simulator is not high--compared to the costs associated with other technologies. However, the panelists saw cost as a key factor because the use of the simulation by special education students might first require its use in non-special education settings. Other factors identified as possibly inhibiting the implementation of the simulator included the need for training students and school personnel. The panelists believed that the cost of the simulator might be reduced if similar types of simulators were more routinely used in other settings. Training barriers might be reduced by utilizing product demonstrations.

The fifth and final computer simulation scenario can be summarized as follows (see Appendix D for the full scenario):

Scenario 16B: Facility Management Training Simulator

> This simulator provides training to special education administrators in managing the complex variables in a service facility. Variables such as number of pupils, ages, types of handicaps, physical plants, and community attributes could be included to provide problem-solving settings.

The panelists agreed that all special education populations might benefit from this scenario, but indirectly, through more effective administration of special education facilities. The simulator might be used to help administrators be more effective in crisis management situations, to manage service delivery, and to experiment with different mixes of services and students. Similar types of exercises could be developed for teachers.

All of the panelists believed that the simulator could be developed and of benefit to at least ten percent of the special education administrators in fewer than nine years. Some estimates of the time required were much lower than that, since the technology required for the simulation--i.e., the "Anevent" program--is already available. The cost of developing the simulation would range between $200,000 and $400,000, according to the panelists. However, the cost, they noted, would depend directly on the comprehensiveness of the final simulation and whether it would be video-based.

Cost again emerged as the primary inhibiting factor in the development of the simulator. And, as with the previous computer simulation scenarios, the panelists believed the cost would be reduced by the use of this type of simulation in other settings.

Comparison with Industrial Counterparts

Each of the five scenarios just described had an industrial counterpart--that is, an application which currently operates in a setting other than education, and upon which the scenario was based. The panelists rated the computer simulation applications on the same dimensions as they did the scenarios. This subsection compares the ratings of the scenarios (done by five panelists) with the ratings of the industrial applications (done by ten panelists), and then summarizes the panelists' ratings of the applications themselves.

Comparing Scenario and Industrial Application Ratings. The panelists rated Scenario 12A--mobility training simulator--must as they had the industrial application upon which it was based. This application can be summarized as follows:

Application 12: Simulated Cockpit

> The MAGIC Cockpit is used by human factors engineers at a large military base to study questions of man/machine interface in advanced aircraft being designed for future use. Human operators perform a variety of specified tasks in the cockpit, using specially designed controls and displays (e.g., to test the ability of humans to recognize different patterns of dots, configured in the shape of ships, tanks, and bridges). The system collects and analyzes a wide variety of data for answering man/machine interface questions such as the feasibility of using voice control and "touch screen" technologies in cockpits.

For Scenario 12A and Application 12, the panelists identified physically handicapped/other health impaired as the primary beneficiary population. The panelists identified a number of activities the application might aid students in performing, while they questioned the overall utility of the activities described in the scenario. The panel believed that the application would be available to the relevant populations in less time (i.e., fewer than nine years for ten percent of the population) than they did for the scenario (i.e., ten to fourteen years for ten percent of the population). Similarily, the costs associated with the development and implementation of the application were lower (the majority of the panelists estimated less than $400,000) than for the scenario (estimates were as high as $1 million). For the application, the panelists believed that high costs would impede its development, and that the use of similar simulations in other settings would reduce the cost barrier. For the scenario, cost was also a primary barrier, but more with regard to its overall cost-benefit than to the development costs per se.

Two computer simulation scenarios--14A and 14B--were based on the same industrial application. The application can be summarized as follows:

Application 14: Video-Simulated Cockpit

> The "S3A" interactive videodisc pilot training system introduces trainees to the rudiments of flying in the S3A aircraft (the system was developed by the same company that produces the S3A flight simulator). The system presents detailed knowledge of the knobs, dials, and meters in the cockpit of the S3A; provides practice locating specific items in the cockpit; and provides experience in making decisions and taking actions. The human operator responds by entering information into the system using a touch screen monitor and a keyboard. The system evaluates the human operator's performance and provides immediate feedback.

The panelists rated Scenario 14A similarly to its industrial counterpart. In particular, the panelists identified the primary beneficiary population for both Scenario 14A and Application 14 as mild and moderate mentally handicapped/learning disabled students. The panelists believed that the application and the scenario might be available to special education students in about the same amount of time--i.e., to ten percent of the relevant population in less than nine years. In addition, the panelists believed that both the scenario and the application might be available for about the same investment of development and implementation costs: all but one of the panelists believed that the cost would be under $400,000 for the application, and from $200,000 to $300,000 for the scenario. Finally, the panelists also identified cost and the need for training as barriers for both the scenario and the application.

For Scenario 14B and its industrial counterpart, video-simulated cockpit, the panelists' ratings were essentially the same on every dimension. Their ratings were the same in terms of the primary beneficiary population, the cost required to develop scenario and the application, the length of time before they would be available to aid special education students, and the barriers which may impede development and subsequent implementation.

Both Scenario 16A and 16B were based on the same industrial application. This application can be summarized as follows:

Application 16: Video-Simulated Store

> The "Cashier Plan" simulation is used to train supermarket personnel how to manage the checkout and grocery bagging processes. The simulation is "played" like a video game. Each player acts as a store manager, and enters data about a number of variables (e.g., staff and store schedules, staff jobs to be performed). The system graphically depicts the store setting, the player assigns staff jobs and schedules, and the system executes the decisions and provides feedback on their effects. Players observe the effects and make changes accordingly. The system produces a printed record of the player's performance when finished.

The panelists rated Scenarios 16A much as they had its counterpart application. The panelists identified mild and moderate mentally handicapped/learning disabled as the primary beneficiary population for both the scenario and the application. The activities associated with both the scenario and the application (e.g., personal and money management) were similar, according to the panelists' ratings. The majority of the panelists believed that the application could be available to ten percent of the relevant population in less the four years, which is similar to the judgment of most of the panelists regarding the scenario. The panelists estimated a similar range of costs for development and implementation of the scenario and the application (i.e., from $200,000 to $500,000). Also, the panelists identified similar barriers to implementing both the scenario and the application. These barriers included the development costs and the training of students and school personnel.

Finally, the panelists' ratings of Scenario 16B and its industrial counterpart application, video-simulated store, differed in some respects. First, for the scenario, the panelists believed that all special education students, through use of the scenario by administrators, would benefit. For its counterpart application, the panelists believed that the population which was most likely to benefit was mild and moderate mentally handicapped/learning disabled, followed by behavior disordered/emotionally disturbed. The ratings were the same with regard to the time before benefits might accrue to the relevant special education population--i.e., in fewer than nine years. In the same regard, the costs of both the scenario and the application were rated as similar, in both cases less than $400,000. Finally, the primary barrier to developing the scenario and the application was also the same: cost. For both, the panelists believed that the cost would be reduced when similar types of simulations were used more routinely in other settings.

Ratings of Industrial Applications. The panelists most frequently identified mild and moderate mentally handicapped/learning disabled students as the primary beneficiaries of the computer simulation applications, although they also identified other populations as beneficiaries, including: communication and behavior disordered, and physically, severely, and multiply handicapped. The panelists identified a range of activities the applications might help students perform, including:

- Training students to use motorized wheelchairs;
- Testing the appropriateness of different configurations of interface options (e.g , speed, size, complexity) for adaptive aids;
- Selecting optimum symbol systems used in teaching and communication aid devices;
- Designing and testing specially adapated "workstations" for students;
- Teaching of procedure-based skills (i.e.,

anything that requires a series of steps to be performed);

- Replicating vocational settings for training purposes; and
- Providing "experience" with independent living activities (e.g., catching a bus, shopping, working).

The panelists believed that ten percent of the relevant special education populations might benefit through these activities in the near future--e.g., in less than four years. The panelists agreed that the applications might be developed and implemented with special education students at a cost of less than $500,000.

The panelists identified the costs of the computer simulation applications as the primary barrier to their development and implementation with special education students (this was especially true of simulations requiring full-scale replicas). As with both robotics and artificial intelligence applications, the panelists believed that the cost barrier would be greatly reduced when the technologies were used more widely in other settings and were commercially available.

Summary

Five scenarios of the use of computer simulation in special education, along with their industrial counterparts, have been reviewed. The expert panelists who rated the scenarios indicated that mild and moderate mentally handicapped and learning disabled students would be the principal population to benefit from the computer simulation scenarios. Additional benefits might be derived by physically handicapped and other health impaired students, and by special education administrators. The scenarios, if implemented, would help students to better understand and "experience" their environment. The scenarios, according to the panelists, might be implemented in five to fourteen years, at a cost ranging from under $100,000 to over $500,000. The main barriers to implementing the scenarios were cost and the need for training.

Of particular promise, among the computer simulation scenarios, might be Scenario 16A, the personal management training simulator. The panelists identified a number of activities this simulator might aid students in performing, and believed that it might be available in fewer than four years at a cost of less than $500,000.

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Appendix A

SUMMARIES OF INDUSTRIAL APPLICATIONS FOR WHICH IN-DEPTH REVIEWS WERE CONDUCTED

APPLICATION 1: Material Handling Robot

SCARA is a materials handling robot that is used in a metal-working "job shop." The robot can be easily reprogrammed to perform a variety of tasks as new jobs come in. This reprogramming occurs as often as three times per week and generally no less than once every two weeks. Frequently, new tools, end effectors, or table mountings are also required.

One example of SCARA's use is its role in the manufacture of the metal boxes for computer housings. In this situation, the metal boxes are manually placed on the work table and secured with air pressure clamps. The robot is fixed to the same work table. When the operator activates the robot, the arm swings over the boxes, sprays oil on the target hole, lowers, and removes the metal around a hole (so that a rivet, inserted later by a human operator, can be recessed to sit flush with the surface). This operation is repeated until all of the pre-programmed holes are completed. The arm then swings back to its initial position, strikes a switch on a mechanical counter to indicate that one box is completed, and shuts itself off. SCARA can perform this operation on 60 boxes per hour, which represents a 200 to 300 percent increase over manual operations. The robot generally runs for two, eight-hour shifts per day. Accuracy has greatly increased as well, as the robot does not miss any of the holes.

The SCARA system consists of two major components: 1) an IBM 7535 robot with 2-1/2 axes that cost $30,000 in 1982; and 2) a custom-made input/output interface to provide feedback to the robot controller. Development and materials of the interface cost approximately $1,000. Additionally, three support systems are needed: 1) compressed air is required for the clamps; 2) a mechanical counter is incorporated for counting parts; and 3) an IBM Personal Computer is used for writing the robot programs. A key to SCARA's flexibility is the availability of a machine tool shop on the premises, to custom make adaptive end effectors.

APPLICATION 2: Welding Robot

The Unimation 7000 robot is an electrically powered robot that is used in a large, southern manufacturing plant to make nuclear waste storage containers. The robot does MIG (metal inert gas) arc welding, and is very precise because it utilizes a sensing system that measures the relation of the welding point to the parameters of the weld being made. The sensing system obtains information about the weld through the arc itself, and if a weld is out of line, the welding point is automatically adjusted.

The robot functions as follows: 1) a human operator positions two pieces of metal on a work table, secures them in place, and activates the robot; 2) the robot arm lowers, begins the weld, constantly monitors its position, and adjusts when off course; 3) the welding material is automatically fed into the robot's welding gun from a spool mounted on the side of the robot arm; 4) when the weld is complete, the robot shuts itself off; and 5) the operator turns the piece over and restarts the process on the second side.

The robot can operate continuously, over three shifts, and can weld 115 parts per shift. It is currently running at less than capacity because of reduced demand for the part it welds. The robot accounts for high precision of welds, due in large measure to its sensing system, as well as increased speed, consistency, and quality of welds.

The Unimation 7000 robot consists of four components: a gantry (i.e., a metal track, fixed above the robot, across which the robot moves); the Unimation 7000 robotic arm; the MIG arc welding end effector; and a conventional programmable controller. These components cost $140,000 in March of 1984. No modifications were made to perform the task as described, with the exception of the programming. Two special work tables, which cost $60,000 in March of 1984, are also used, and these are controlled by the robot controller. When special fixtures are required, additional engineering and drafting time is needed. The skills and facilities used are standard in this type of manufacturing setting.

APPLICATION 3: Machine Vision Robot

The BinVision robot uses a vision system to identify and select parts from a conveyor belt. The robot is used at a large manufacturing plant in New England to help produce jet engines for airplanes. The BinVision robot works in concert with six other robots, and distributes to each one--at a rate of one part every 15 seconds--the parts they need for the manufacturing process. This is accomplished in the following sequence: 1) a human operator dumps parts onto a conveyor belt that passes under BinVision's cameras; 2) the camera identifies the required part, and sends its locational coordinates to the robot's controller; and 3) the controller directs the robot's arm to pick up the part and place it on a table, to be subsequently picked up by one of the other six robots.

The BinVision robot is unique in that it can identify and select from randomly placed parts on a moving conveyor belt. The use of the robot has helped to increase productivity, by making consistent the time needed to perform specific manufacturing activities. In addition, the efficiency of the production has increased because the BinVision robot has facilitated the combination of several activities into one workstation.

The BinVision robot consists of four components: 1) a General Electric model P50 robot, including a manipulator for grasping the parts and a controller; 2) an Optomation II vision system and two cameras; and 3) a NEMA 12 factory enclosure for safety. The software to direct the robot's activities cost approximately $25,000 to develop; the associated hardware cost approximately $95,000 (robot, manipulator, and controller, $55,000; vision system and cameras, $39,000; safety enclosure, $1,000). The hardware required little modification, with the exception of a custom-made end effector for the robot. The software for the vision system and the programmable controllers was developed by the manufacturing firm using the BinVision robot.

APPLICATION 4: SCARAB X-1

SCARAB X-1 (Self-Contained, Automatic Robotic Assistant Bartender) is an entire bar and cabinet console, including a robotic arm, that prepares and serves alcoholic beverages. It was designed to be used in a private home or small club setting. The arm, upon voice command, will retrieve a glass, collect ice if necessary, rotate to another area where the appropriate fluids are squirted into the glass, and place the filled glass on a bar--while announcing the name of the drink through a voice synthesizer.

The arrangement of the entire console, including the construction of the robotic arm, includes an Apple IIe microcomputer. Because of the slowness of the Apple IIe, the robot cannot simultaneously take voice commands and also make drinks. This inability results in a slow presentation of drinks, although the advantages of using the system are still the consistency and reliability of the "bartender." The system can keep track of all liquors dispensed, and can therefore eliminate the typical slippage or losses in supplies due to employee errors. At the same time, the manufacturer of SCARAB X-1 has designed newer versions of the same robotic arm, to be used in commercial settings and with greater productivity savings (e.g., a hospital console that can concoct 480 non-alcoholic drinks per hour, for patients; and a possible retriever of drugs to be used in a hospital pharmacy).

The entire console and robotic arm have been developed by a single firm. The arm is reprogrammable in the sense that different kinds of mixed drinks--using different combinations of liquids--can be devised. The cost of the entire console is very high (about $250,000 for a prototype, as no mass production has yet occurred), but the console is completely self-sufficient and requires no special support systems.

APPLICATION 5: Circuit Board Assembly

This robot is used in a manufacturing plant in the South, to assemble electronic circuit boards. The robot places electronic components (as small as 3/8") onto pre-printed circuit boards. To perform this function, the robot: 1) applies a two-part aerobic adhesive to columns of the circuit board; 2) "registers" the location of the robotic arm relative to the surface of the board; 3) picks up a component using vacuum suction; 4) inspects the leads of the component (if any lead is defective, the robot records the imperfection, puts the part aside, and proceeds to the next component); 5) places the component on the circuit board in a pre-programmed location; and 6) repeats the cycle. The number of components placed per circuit board varies with the type of circuit board being produced.

The robot operates in a normal manufacturing environment on the factory floor, although some lighting control is required. The robot can operate for three shifts, and it produces one completed board every 40 minutes (humans performing the same function used to complete one board every 40 hours). The accuracy and consistency of the robot far exceeds the capability of human operators.

The robot consists of several component technologies: 1) a Seiko RT-3000 robotic arm; 2) specially developed end effectors for placing the components and applying the adhesives; 3) an X-Y table; 4) a Hewlett-Packard A-600 computer; and 5) an Automatics Autovision system for visual inspection, utilizing above- and below-table cameras. Six of the robots are currently in operation; each system is estimated to cost $300,000, exclusive of the investment in R&D. The system took approximately four months to develop, and involved eight to nine individuals.

The system requires that some special grounding precautions be taken; needs an uninterrruptable power source, for "swallowing" power surges and providing transition power in the event of power outages; and uses compressed air for applying the adhesive.

APPLICATION 6: Spray-Painting System

On an assembly line, five hydraulically powered robots are used to blow pockets of water off a tractor chassis and then to spray paint it. As each chassis progresses along the conveyor, switches are tripped to signal the start of a robot routine. The chassis's paint and model code are communicated to the robot via the plant's computer and the robot system's I/O interface and controller.

Two robots then blow water pockets off the chassis, and after proceeding through a dryer oven, three additional robots paint the chassis. Using continuous path movement, one robot sprays the bottom from a pit, and two others paint the right and left sides. Human painters touch-up missed and hard-to-reach spots, before the chassis enters the bake oven.

This robot spray-painting system operates in a specially designed manufacturing environment. The robots are housed in booths to control paint fumes. At full capacity, the system could paint over 100 chasses for every 8-hour shift. It is currently running at about one-third capacity.

The major advantages of the system are in the reduction of labor and paint costs, savings realized from the displaced need for fresh air supplies in the booths, and the increased quality of the paint job. Additionally, the robots have been very reliable, resulting in minimal downtime.

The system integrates several component technologies: 1) five, 6-axis DeVilbiss TR3000 Trallfa robots; 2) a flipper head added to each robot as a seventh axis; and 3) a Modicon 484 I/O interface which was modified by DeVilbiss to interface all five robots. Each TR3000 robot costs $78,000, exclusive of the flipper arms and I/O interface.

This five-robot system does not require special support systems other than compressed air guns and electrostatic airless paint dispensers for the paint guns.

APPLICATION 7: Clinical Diagnotic Expert System

Micropuff is an expert, artificial intelligence system. The system analyzes and diagnoses the pulmonary function of patients. Such functions are initially recorded by: a spirometer, which assesses about 30 variables characterizing a patient's breath; and a questionnaire, to which the patient provides verbal responses. (The questionnaire data also include some judgments by the technician, regarding the patient's reliability and effort in doing the spirometer tests.)

The expert system, based on about 300 rules reflecting the clinical judgments of a single clinician, is then applied to these recorded data. The product is a narrative diagnosis, similar to that written by a clinician, indicating the patient's condition. The diagnosis presents an estimation of the normality-abnormality of the patient, the characteristics and likely causes of any abnormality, and the suggested treatment. A real clinician reviews the results, making corrections or changes if necessary.

The use of the Micropuff system allows a clinic to test and process about two to three times as many patients as under the previous, "manual" system. About 2,500 patients per year are analyzed at the 300-bed, West Coast hospital where Micropuff is used.

Micropuff's expert system language is LISP-based, with the software having been developed originally for a minicomputer (PDP-11) version of the system, known as "PUFF" and based on Stanford's MICIN program. Currently, Micropuff uses a Tektronix microcomputer workstation, with the spirometer's test results being electronically transmitted to the microcomputer system. The other major data entry, from the questionnaire, is done through a keyboard by the technician. In all, there are three such workstations in the clinic, one being connected to a Qum printer.

The Micropuff system does not require any special supporting facilities, in terms of utilities or other resources. However, the clinician who originally helped to develop Micropuff does continually update the 300 rules, based on the experiences from new cases or the learning of new medical methods. In addition, the system is being expanded to include more variables--primarily from the results of patient's physical exercise.

PUFF, upon which Micropuff is based, took a few months' staff time to develop (a programmer and the clinician); Micropuff was converted by the programmer to LISP language to run on the microcomputer.

APPLICATION 8: Natural Language Processing System

INTELLECT is an artificial intelligence, natural language processing system, that is used by staff in a large corporation to query a personnel database. The system allows operators to make requests, using common English sentences (e.g., "How many employees were hired in 1981?" or "How many employees have advanced college degrees?"). The system is used primarily for answering non-routine questions related to personnel, such as those which may arise during labor negotiations. Approximately 100 queries a week are put to the system, by the ten people who have access to it.

The INTELLECT system eliminates the need for extremely time-consuming manual searches of personnel records or the need for computer specialists to interface with users. Users are able to obtain information from the database without having to learn the complex control languages and request sequences normally associated with the use of computers. It also provides immediate responses to questions, and allows a user to feel free to ask as many questions as might be of interest. Finally, the system allows top-level managers to evaluate sensitive questions confidentially (e.g., "How many people would lose health insurance benefits if the policy were changed?"), because they can seek the necessary data themselves without the services of technical personnel.

The INTELLECT software is written in the PL-1 language, and is designed to resolve the ambiguity of questions put to it by analyzing the context of the questions. The system does this by using data from its lexicon and from the database itself. For example, take the question "Are there any baker's below 42nd Street in New York?" Two items are ambiguous in this question: is "baker" a person's name or a profession, and is "New York" the city or the state. Because "street" is a jurisdiction-specific concept, the system would "assume" that "New York" was the city. Further, if the particular database contained both "baker" as a name and "baker" as a profession, then the system would ask the user which "baker" was desired. If the database only contained one "type" of baker, the system would provide the answer. The ability of the program to resolve ambiguities makes it an advanced artificial intelligence system, and reflects the linguistic system and the basic elements of language structure contained in the program.

The INTELLECT program was developed by a commercial firm, and a full, life-time license to use it--which includes annual updates as the program is revised and refined--costs $50,000. The program can run on any mainframe computer.

APPLICATION 9: Planning System

DEVISER is a planning system, developed by a national research laboratory, whereby operations aboard an unmanned spacecraft can be carried out in the appropriate sequential order. For example, if the objective is to photograph a satellite at a certain time during the spacecraft's flight, DEVISER produces the instructions for: 1) pointing the camera, 2) turning it on, 3) setting the filters, 4) assuring that tapes are available for recording, 5) starting the tape recorder, and possibly half a dozen other discrete steps needed to achieve the objective.

DEVISER is an artificial intelligence system because it to arrange and schedule numerous operations. The simultaneity of the operations may involve shared resources that must also be accounted for. This type of system should be distinguished from the traditional, hard-coded planning systems on other spacecrafts, which simply pursue a linear set of instructions and not this interactive, dynamic activity. DEVISER involves a 9,000-line LISP code (set of rules), operating on a knowledge base of about 50 pages of information describing the spacecraft.

The prototype of DEVISER is now being tested on the Voyager mission to Uranus, in which DEVISER's performance will be compared to that of human (manual) operators, who have traditionally calculated the appropriate planning sequences. The human activity is deemed routine and rather boring, and DEVISER may be able to displace this activity and perform, in eight hours, what humans would have taken three to four weeks to do.

DEVISER has been under development since 1981, and is not electronically linked to the actual instruments aboard the spacecraft (the output is a written set of commands which then must be conveyed by a human operator to the spacecraft). In addition, DEVISER does not yet have any feedback connection, to determine whether the desired action actually occurred properly (this software is under development). DEVISER operates best on a Symbolix 3600 minicomputer, which has the LISP language hard-coded into its CPU. Such hard-coding has meant a programming time of ten minutes for what may have taken two hours on a PDP-10, but the Symbolix 3600 (a 36-bit machine) is expensive: over $100,000.

APPLICATION 10: DELTA/CATS-1

DELTA/CATS-1 is an expert system developed to assist in the diagnosis and repair of diesel-electric locomotives. It is used at several repair shops across the country. The system contains a knowledge base of locomotive engineering facts and 420 "if-then" rules for diagnosing multiple engine problems. This knowledge base represents the collective expertise of senior field service engineers.

The system detects engine malfunctions by leading the user through a series of detailed questions and solutions. The user is also able to access diagrams and detailed drawings of the locomotive and specific repair instructions and procedures. Any novice engineer, by using the computerized system, can identify the source of problems and make needed repairs.

The expertise provided by the system has reduced total repair times from two hours to an average of 20 to 30 minutes, and eliminated the need to transport locomotives to distant repair shops. Use of the system has minimized repair costs and increased maintenance productivity.

DELTA/CATS, written in a version of FORTH, runs on a Digital Equipment PDP 11/73. The system also utilizes a 10 mega-byte Winchester disc, a VT100 terminal, a Selanar graphics board, and a Sony laser-video-disc player with color monitor. The entire system is packaged in a steel box with a front of high impact Lexan plastic for protection from the locomotive maintenance work.

APPLICATION 11: Sensory-Information Processing System

HASP/SIAP is a sensory information system intended to analyze large and complex arrays of signals. The signals come from hydrophone arrays, concealed in the ocean, that detect the sounds of ocean vessels. The hydrophones convey digitized data to a central source, and the analyst must sort these data to determine what vessels, if any, are moving through which areas of the ocean.

The sorting of these signals is a complicated task, done in the past by human analysts. With HASP/SIAP, a knowledge base with the following types of information had to be constructed: knowledge about the environment (e.g., common shipping lanes, known maneuver areas, and the location of the hydrophone arrays); knowledge about vessels (e.g., their component parts and acoustic signatures, range of speed, and home base); interpretation knowledge (e.g., the rules used by the human analysts in the past); and knowledge about how to use other knowledge. The analytic routine involves a hierarchy of levels of analysis. The outcome of each analysis is a "current best hypothesis," regarding the likely identity of a specific vessel at a particular place at a particular time.

HASP/SIAP took nine years to develop, with support from the U.S. Advanced Research Projects Agency. The evaluation of the system showed that the program reduced computation costs by two to three orders of magnitude over conventional methods. The program is said to be applicable to other problem topics where large amounts of signals must be sorted and translated into meaningful information--e.g., the interpretation of speech and other acoustic signals, x-ray and other spectral data, radar signals, photographic data, or the maintenance of global plotboards in air traffic control centers.

APPLICATION 12: Simulated Cockpit

The MAGIC cockpit (Microcomputer Applications of Graphics and Interactive Communications) is used by human factors engineers to examine questions of man/machine interface relating to cockpit controls and displays. This computer simulation is used by engineers, in a research laboratory, at a major U.S. Air Force base in the Central United States. The MAGIC cockpit is generic, in that it does not represent any particular aircraft, but rather represents various features of possible future aircrafts. In this sense, the simulator is quite flexible and with minor modifications can be used to test different aspects of man/machine interface. For example, the simulator has been used to test the ability of humans to recognize different patterns of dots, configured in the shape of ships, tanks, bridges, etc. The concern was to determine which specific pattern was the most readily recognizable as symbols on an aircraft's control panel. The simulator has also been used to test voice control and "touch screen" technologies for future use in aircraft.

The MAGIC cockpit is controlled by a modular software package, written in Digital Research's Pascal MT+86 and 8086 Assembler. The modular construction allows several programmers to simultaneously work on the software, thus facilitating software changes. The cockpit mock-up itself is a single-seat fighter cockpit approximately the size of an F-15, built principally from plywood. The MAGIC cockpit simulation is run by four CompuPro microcomputers, with a total of 1.4 megabytes of random access memory. The system also uses the INRAD-II real-time graphics system; a Lenco, Inc., color encoder; and four Pioneer videodiscs. The system is used, on average, for eight hours per day. The development of the software and concepts behind the MAGIC cockpit took approximately four person-years, and the hardware components cost $200,000 to $250,000.

APPLICATION 13: Nuclear Control Room

A computer simulation of the operations of a nuclear power plant is used for: 1) training plant operators, 2) conducting operator licensing examinations, and 3) conducting tests of guidelines and procedures for operating the plant. The computer simulation is an exact replica of the control room of an actual, operating nuclear plant, that is located in the South-Central United States. The simulator is housed in a training facility, about one mile from the actual nuclear plant.

The simulator is a valuable training and testing tool because trainees and operators can "experience" situations which could not be safely replicated in a real plant setting. Also, the simulator provides an opportunity to test new procedures and practices without any risk or plant downtime. The simulator is used an average of 12-16 hours per day, and could be used 24-hours per day if necessary.

The simulator is controlled by a complex software program, that exactly duplicates the operations of the nuclear plant, and can produce over 1,000 routine and emergency conditions which might occur in a "real" nuclear plant. The simulator is controlled by four, SEL-3255 minicomputers. The simulator was custom-designed for the plant it replicates. The simulator is quite large, and requires a gymnasium-sized facility to house it. The only other special facilities required are the temperature and humidity requirements of the minicomputers. The simulator, including all computer software and hardware, was purchased in 1982 at a cost of approximately $7 million.

APPLICATION 14: Video-Simulated Cockpit

A "Level 3" interactive videodisc system is used for training people to fly the S3A carrier-based, submarine-hunting aircraft. The system is being marketed by an East Coast company which also sells an S3A aircraft flight simulator. The videodisc system provides trainees with: 1) detailed knowledge of the knobs, dials, and meters in the cockpit of the S3A, using a format where the trainee "asks" the system for information; 2) practice in locating specific items in the cockpit, where the system "asks" the trainee to identify objects; and 3) experience in making decisions and taking actions, in response to malfunctions presented on the videodisc.

The videodisc system is self-paced, can be used in ordinary office or classroom settings, and is used in conjunction with printed materials. The use of a touch-sensitive screen on the videodisc monitor is a significant feature of the system, and one which makes the system particularly adaptive to the needs of trainees. Trainees use the videodisc system for mastering the rudiments of the S3A aircraft, before they begin actual practice in the S3A flight simulator. Such sequenced training is especially appropriate because of the high cost of time in the flight simulator.

The videodisc system is based on a software program, written in Pascal, that combines instructional sequences, presented along with pictures of the workings of the S3A cockpit (the photography for the videodisc was actually done using an S3A simulator, and not an actual aircraft). Also part of the system are: 1) an IBM personal computer with two floppy disk drives; 2) a SONY laser scan videodisc player; 3) a high-resolution color monitor, with a touch-sensitive screen and screen controller; and 4) a controller for the interface between the microcomputer and the videodisc player. The instructional programming costs were approximately $45,000; the hardware elements cost approximately $15,000. No special support systems or facilities are required for using this system, although the S3A flight simulator was needed to make the videodisc in the first place.

APPLICATION 15: COMDAC Ship Bridge

This computer simulation is a full scale mock-up of the COMDAC (COMmand, Display, And Control) electronic control system used onboard medium endurance Coast Guard cutters. The simulation is operated in a training facility located at the software developer's lab, and it is used to train operators in the use of the system. Trainees first use the simulator to familiarize themselves with the specific components of the COMDAC console, and then they are presented with scenarios of real-life situations which include radar, navigation, and speed information. The data are displayed on one of four monitors in the console in two forms: computer generated maps with location and target information plotted, and numeric information listed by variables.

The trainee is expected to navigate the ship, pinpoint the target, and activate sensor/weapon systems using the controls on the console. A steering and propulsion simulator automatically feeds data back into the system as the trainee manipulates the controls. Immediate feedback is provided to the trainee--the position of the ship visually moves on the map and the numerical values dynamically change.

Groups of 14 operators are trained using the simulator in a four-week course. Four specific benefits of the simulation are: 1) reduced cost from not having to designate an entire ship for the purposes of training; 2) reduction of boredom related to previous methods of teaching (lecture followed by on-site training); 3) enhanced learning because of the immediate feedback provided to trainees; and 4) the ability of the system to simulate motion.

The COMDAC computer simulation training system consists of three major components: 1) the COMDAC system; 2) the steering and propulsion simulator; and 3) the computer system that runs the simulation software. The COMDAC system includes several parts: a bridge console, command support console, and eight equipment racks. These racks contain three AN/UYK-20 computers, three scan converters, four graphics generators, and other I/O interfaces. The entire system was custom designed using standard military components when possible, and cost $7 million as a whole. The hardware and development costs of the steering and propulsion simulator totaled $300,000. The simulation computer system consists of a fourth AN/UYK-20 computer at $80,000 and a Model 4-E teletype terminal at $7,000. Including the COMDAC system, the entire application was six years in development.

The simulation training program will be moved to a military training facility soon. It does not require any special support systems for its operation.

APPLICATION 16: Video-Simulated Store

The Cashier Plan computer simulation will be used to train supermarket personnel how to manage the check-out and grocery bagging process, to minimize both the cost of staff salaries and customer wait time. The simulation was jointly developed by a simulation specialist, a Canadian national research council, and a supermarket chain. It will be placed in general use in the supermarket's 75 stores within the next several months.

The simulation is "played" like a video game. It operates at 60 times real time, so that a 10-hour day can be simulated in 10 minutes. Simulation "players" take on the role of a store manager, scheduling and deploying up to 30 staff, trying to achieve the best "final score." Players begin by entering data about a number of variables, including projected customer arrival rates; store opening and closing times; staff arrival, break, lunch, and departure times; and average price per item purchased. The player also defines a number of staff jobs, e.g., operating the cash register, bagging groceries, retrieving shopping carts, or straightening the magazine stand.

The simulation graphically depicts the check-out counters and the queues of customers that form at each counter. The player must assign staff to different functions, for specific starting and ending times. As staff deployment decisions are made, the player is able to observe the effect of the decisions on the queues of customers. At the end of the simulation, the player receives a printed record of his/her decisions, and other information such as the day's total sales, number of customers served, and average customer wait time. Information about staff utilization is also provided--e.g., the time staff spent performing different functions, including breaks and "unassigned," non-productive time. The simulation can also be used, in addition to training, to develop staff schedules to reflect minimum costs and customer wait times.

The simulation software uses "Anevent," an interactive form of a discrete/continuous simulation package, written in Fortran. Its design was adapted from GASP II. The simulation software was developed after an analysis of the operations of actual supermarkets. The program runs on an IBM-PC, with two disc drives. Software development costs have been approximately $120,000; an estimated $80,000 will have to be incurred in addition to finalize the program. The development has occurred over an 18-month period.

APPLICATION 17: On-Scene Commander

The On-Scene Commander computer simulation is used, by a major oil company, to train personnel in the actions to take to control oil spills. The simulation can also be used at an actual spill site, to correlate all of the available information for prompt implementation of the optimum cleanup strategy.

A 48-hour scenario is simulated in four hours of actual time, during which the On-Scene Commander responds to the spill situation by requesting weather information, spill trajectories, deploying booms and skimmers, and solving other problems in a time-pressured situation. All commands are input through a touch-sensitive screen, eliminating problems experienced by users unfamiliar with a keyboard. At the end of the simulated response, data are provided on the amount of oil recovered, the amount of shoreline oiled, and the total cost of the cleanup. The trainee can then evaluate his or her actions as recorded by the computer throughout the simulation and as presented to him or her in the form of graphs at the end of the simulation.

The simulation is written in Control Data Canada's PLATO language. It runs on a CDC 110 Viking terminal, which has a touch screen capability. This portability is especially useful, because the oil company's personnel are often located in remote areas. The simulation has been validated by conducting numerous pilot projects with experienced oil spill response personnel. Early pilot programs demonstrated the problems of using telephone connections; now the program runs on a disk drive microcomputer unit, which eliminates the need for a telephone line.

Appendix B

QUESTIONNAIRE FOR EXPERT PANELISTS

QUESTIONNAIRE FOR EXPERT PANELISTS

1. Please enter number and name of application being rated:

____

2. Please rank order the three special education populations you believe would most benefit from this application (1 = most benefit; 2 = second most benefit; 3 = third most benefit).

_____ Mild & moderate mentally handicapped/learning disabled
_____ Communication disordered/speech & language impaired
_____ Behavior disordered/emotionally disturbed
_____ Physically handicapped/other health impaired
_____ Severe & profound mentally handicapped
_____ Visually handicapped
_____ Hearing handicapped
_____ Multiply handicapped
_____ Other, specify: ________________________________

Comments, if any:

3. Please estimate the approximate investment (1984 dollars) that will be required before any special education population will benefit from this application. Indicate your estimate by checking one range in the table below.

	Check Only One
Under $100,000	
$100,001-200,000	
$200,001-300,000	
$300,001-400,000	
$400,001-500,000	
Over $500,001	

Comments, if any:

4. Please estimate the approximate number of years required before 10%, 50%, and 90% of any special education population will benefit from this application. In the table below, enter "10%" by the range of years when you believe 10% of all students in any special education population will benefit from the application. Enter "50%" by the range of years when you believe 50% of all students in any special education population will benefit from the application. Finally, enter "90%" by the range of years when you 90% of all students in any special education population will benefit from the application.

	Enter 10%, 50% & 90%
0-4 years	
5-9 years	
10-14 years	
15-19 years	
20-24 years	
25 years +	

Comments, if any:

5. Please briefly describe at least one specific activity, that would occur in a school setting, that indicates how the application will help special education students (e.g., moving in a cafeteria line and filling a tray with food; turning the pages of a book, while seated at a desk; or gaining a better understanding a new setting or problem).

Comments, if any:

6. Check the two activities you believe the application will help special education students to accomplish.

___ Writing
___ Moving about
___ Understanding
___ Eating
___ Talking
___ Reading
___ Seeing
___ Other, specify: ________________
___ Experiencing
___ Manipulating
___ Playing

Comments, if any:

7. Please rank order the three factors, from the list below, that you believe will inhibit the use of this application in special education (1 = greatest inhibiting factor; 2 = second greatest inhibiting factor; 3 = third greatest inhibiting factor).

____ Cost
____ Federal government policy
____ State and local policy
____ School setting
____ Need for technical assistance by students and parents
____ Need for technical assistance by school personnel
____ Technical difficulties
____ Training of students and parents
____ Training of school personnel
____ Behavior of private industry
____ Commercial availability
____ Other, specify: ____________________________

Comments, if any:

8. For the three factors you identified as inhibitors in question 7, please briefly state how the factor could best be eliminated or neutralized. PLEASE BE AS PRACTICAL AS POSSIBLE. Enter your responses in the table below:

Write in Factor From Question 7	What would eliminate or neutralize this inhibiting factor?
1st ranked:	
2nd ranked:	
3rd ranked:	

9. What is your level of confidence in the judgments you have made about this application and its potential usefulness to special education? Please circle one number on each of the two scales below.

a. With regard to the <u>technology</u>:

1	2	3	4	5
I know nothing about the technology and am not at all confident about my projections.				I am very well-versed in the technology and am exceedingly confident about my projections.

b. With regard to <u>special education</u>:

1	2	3	4	5
I know nothing about the implications for special education, and am not at all confident about my projections.				I am very well-versed in the implications for special education, and am exceedingly confident about my projections.

Appendix C

INSTRUCTIONS TO PANELISTS FOR DEVELOPING SCENARIOS

SCENARIOS

You are being asked to write two scenarios, to represent your view of how the current applications might be used in special education in the future. You have been assigned application A, and may choose application B or C, to base your scenarios:

A. ______________________
B. ______________________
C. ______________________

The scenarios should reflect two assumptions:

- The current applications will need to undergo modifications to be applicable in a special education setting.
- The new applications in special education will occur in settings like those that exist today in schools.

Further, the scenarios should:

- be consistent with your questionnaire responses for the application--e.g., the scenario should reflect your prior judgments about the cost and time required for the application to be used, etc.
- reflect your vision of the use of the application, as if it were actually observing the "transformed" application in a special education setting.

Finally, the scenario is be presented in the same general form as the "extracted information" on each of the current applications, and should be written clearly or typed on the "Scenario" sheets provided. Nevertheless, please try to provide as much detail about each topic as possible. Thus, your scenario of the future use of the application in special education will be represented by the following information:

1. The function(s) being performed, the population being served, the date the scenario takes place, and the setting within which it is occurring;
2. The way the new application operates--i.e., the steps or activities one must perform to use it;
3. A description of the benefits or drawbacks of the application (either as compared with previous methods of performing the same function, or as a totally new capability); and
4. The support systems, including needed training and technical assistance, and cost you believe will be incurred to develop the new application.

Appendix D

SCENARIOS OF TECHNOLOGIES IN SPECIAL EDUCATION

SCENARIO 1A: Object and Mechanical Device Manipulating Robot

Technology: Robotics

Function: Manipulation of objects (toys, tools, etc.) by robot; operation of mechanical devices.

Population: -Multiply handicapped, physical/OMI, severe mentally handicapped

Date: 1986

Setting: -Classroom

Operation:
-Teacher sets up table with robot, objects
-Student operates robot by English commands, voice or keyboard input
-Robot performs commands or built-in programs

Benefits:
-Physical function of robot allows student to experience tasks beyond unaided capability
-Robot is easily adaptable to variety of functions

Drawbacks:
-Each task must be setup or tooled before use
-Operation should be monitored for safety

Support systems: -Training

Cost:
-$200,000 to select system hardware and develop software and curriculum
-Each station should cost no more that $25,000

NOTE: This scenario assumes some robot other than IBM 7535, but presently commercially available.

SCENARIO 2A: Welding Robot

Technology: Robotics

Function: A systematic reference point for vocational education in special education. It will provide two roles: (1) an operator and programmer role, and (2) a robot assistant role.

Population:
- -Mobility impaired (physically impaired) - operator role
- -Mildly handicapped - robot assistant role

Date: 1988

Setting: -In special education work study, in any factory that has equipment and supports the integration of the handicapped in the work place

Operation: -As presently used with some minor modifications to allow wheelchair-based operators to access control and programming devices

Benefits:
- -Allows the robots physical power to complement the abilities of the physically handicapped
- -Allows for the establishment of a stable, simple task for the assistant

Drawbacks: -None, when compared with similar equipment operation roles in industry

Support systems: -More concerned with social and safety factors than operator skill support

Cost: -None--above present

SCENARIO 3A: Multiple Environment Assistive Robot

Technology: Robotics

Function: The modified BinVision robot will be utilized as a multiple environment (different rooms/stations), single setting (single school), manipulating assistive device. The system will have to have both hardware and software modifications. Hardware modifications are primarily in making the device mobile (motorized, attachable to wheelchair) and adapting the controlling device (speech input for voice control, controllable through adaptive switches). Software modifications include object recognition for items categorized according to environment (e.g., plate, spoon in cafeteria; tape recorder, book in the classroom) and for human control of the robot (pre-sequenced series of events for cognitively impaired or young or total control of movement by high cognitive functioning users).

Population: -Severely motorically (minimally upper extremity handicapped) with or without cognitive disabilities

Date: Early 1987

Setting: -Barrier free school

Operation:
-Operator controls movement of robot within and between environments
-Operator selects category of objects (or environment) that robot will manipulate
-Operator selects object to be manipulated via voice or adapted input
-Vision system identifies object and sends location coordinates to controller
-Controller directs robot to pick up object
-Operator selects/controls sequence of operations to be performed by robot

Benefits:
-This system will enable severely disabled individuals to interact in a more "normalized" environment with significantly reduced dependence on attendants
-The system will provide a significant increase in technology applications in the changing environments found in a school setting

Drawbacks: -The major drawbacks of this technology involve the size and ackwardness of the hardware (lack of easy transportability out of a setting) and the need for extensive support systems (software and hardware)

Support systems: -Training for users and professional staff
-Technical assistance for software/hardware adaptations and development as well as initial assessment and application with users
-Basic software and hardware development and maintenance

Cost: -$55,000 for robot and controller
-$39,000 for vision system
-$50,000 for adapting hardware to mobile application
-$ 5,000 for speech/adaptive controller hardware
-$50,000 for software development
-$50,000 for technical assistance

SCENARIO 7A: Screening and Evaluation System

Technology: Artificial Intelligence

Function: The diagnostic expert system will be used in school settings to assist in the screening and evaluation of mildly and moderately handicapped students.

Population: -Mildly and moderately handicapped children (LD, MR, ED)

Date: Early 1986

Setting: -Clinical evaluation setting in the school

Operation:
- Examiner keys in demographic data
- Using a graphics or touch tablet students perform motor tasks (copying shapes, writing, etc.) which are machine analyzable
- Student and/or examiner keys in evaluation answers
- The system analyzes the data and prepares a diagnosis, written in a narrative form
- The diagnosis includes an estimation of deviation from the norm, prepares a profile of student achievement, and makes initial recommendations regarding treatment (disability, placement, strengths and weakness')
- Evaluator reviews results and makes corrections or additions as necessary

Benefits: -This system will enable for increased efficiency (number of students screened) and increased reliability (computer reliability in evaluating directly input data) in the initial assessment of children referred to special education

Drawbacks: -The major drawbacks of this technology involve the need for norming the use of the technology for motor tasks, the size of the database necessary (potentially solvable by networking to hard disk or a mainframe)

Support systems:
- Training for users and professional staff
- Technical assistance for software/hardware adaptations and development as well as initial assessment and application with users
- Basic software and hardware development and maintenance

Cost:
- $ 10,000 for hardware and networking capabilies
- $250,000 for software development
- $ 50,000 for technical assistance, training

SCENARIO 7B: Interactive Diagnostic/Treatment Tool

Technology: Artificial Intelligence

Function: GRAPHCOM operates in a clinical setting concerned with language communication disability (dyslexia; aphasia;...) where alternative communication channels must be tapped and mapped into "normal" language. The system operates as an interactive diagnostic/treatment tool.

Population: -There are over 400,000 communication impaired people who might benefit from the existence of such a system

Date: -R&D for this application could begin immediately
-Clinical study could begin in one to two years
-Widespread availability (10 percent) is feasible by 1989

Setting: -R&D requires tight coupling between a technical groups and a clinical group

Operation: -Operation is based on the use of visual symbols in place of written and spoken language
-Images created by the student are analyzed for feature extraction and associative meaning
-Symbolic manipulation and "database: building" parallel guidance by a human communication "expert/clinician"
-Results are codified as a translation schema from the user to others and back again (i.e., sketch--english--sketch)

Benefits: -With viable communication education can proceed

Drawbacks: -Human therapists would have to learn to use the new computer based tools

Support systems: -This is essentially a software development that will (in 1989) require no more than a high end personal computer

Cost: -The development, test and diffusion sequence will require about $600,000 over 4 years

SCENARIO 8A: Resource Database Retrieval System

Technology: Artificial Intelligence

Function: The system would be used by professional staff to query a database which stores information on resources, both instructional and physical. Resources are keyed to instructional goals and special education populations. Outcomes include descriptive data and prescription. (Could be used in conjunction with IEP.)

Population: -Users of the application would mainly be special education professionals; resulting information could be used for any special education population addressed in the database

Date: -Limited resources for one or two populations: Sept. 1986
-Large resource base for many populations: 1988

Setting: -In the office of a guidance counselor or special education professional

Operation: -Human operates ask questions (typed in English with some restrictions on vocabulary and syntax) relating to resources available, efficacy, etc.
-System interprets each query; ambiguities are resolved by the system asking the user questions
-System responds with descriptive information or prescription. Alternative prescriptions may be provided if more than one is appropriate, or no one prescription is "best"

Benefits: -Reduce time for accessing wide array of information
-Printed reports automatically generated
-Reduce liability for not using available resources

Drawbacks: -Requires frequent updates of the database

Support systems: -Large networked (i.e. shared and updated) data would be ideal for this application, although small local databases could be used
-Training program for users would be needed
-Periodic data base updates

Cost: -For a simple system using a local data base (i.e. off-line and school specific) for one or two populations, using an IBM PC with hard disk: $75K for development, $10K for 2 stations
-For a large networked data base: 250K for development, 100K for implementation, 50K per year for maintenance, 50K per year for hardware & network access

SCENARIO 9A: Curriculum Planning System

Technology: Artificial Intelligence

Function: Curriculum planning for handicapped students that accounts for available resources, prostheses, and the students mental and physical capabilities and interests.

Population: -All handicapped

Date: 1990

Setting: -School serving any handicapped population, especially those needing technology-based aides

Operation:
-School personnel input courses, specialized training available, etc.
-School notes classes of handicaps serviced in each course
-School inputs the types of technology available
-Student is questioned by computer about interests
-Student is given any performance tests required
-A curriculum plan is created and modified with student and school input

Benefits:
-More efficient training, less loss of time, less frustration
-Faster institutionalization of technology
-Gets around school training roadblocks

Drawbacks: -Lots of school planning is required

Support systems:
-Technical support to schools
-Continued updating of system

Cost:
-R&D cost - $2,000,000
-Cost of production item - $2,500 personal computer

SCENARIO 11A: Mobility Aid

Technology: Artificial Intelligence

Function: The Sensory-Information Processing System (SIPS) is used by visually impaired individuals as a mobility aid. This system not only detects objects, it also determines what these objects are.

Population: -Visually Impaired

Date: 2005

Setting: -The environment in which the user normally travels

Operation: -The SIPS sorts out sonar-type signals that the system sends and receives from a small processor carried on the individual's belt. The system not only detects when an object is in the user's path, it also determines what the object might be. The system verbally informs the user as to the hypothesized object.

Benefits: -The system provides the user with specific information about obstacles encountered in one's environment with a portable device

Drawbacks: -The system must have the knowledge-base which describes objects entered for each object
-The system is not intelligent enough to define and remember new and unknown objects

Support systems: -Minaturized processor that can be carried by the individual. Ideally, the processor should be no larger than current portable radios (i.e., Sony Walkman).

Cost: -$750,000 - $1,000,000

SCENARIO 12A: Mobility Training Simulator

Technology: Computer Simulation

Function: Beyond providing a very realistic simulation of equipment operation, this application could be used to provide mobility training and wheelchair independence activities. This simulator could be used to help "fit" a future robotic/ wheelchair device.

Population: -Primarily physically handicapped and mild/moderate mentally retarded

Date: 1990

Setting: -Traditional training facilities and physical therapy locations

Operation: -For simulating mobility and robotic wheelchair applications, instructers will be able to select features or options for the device; program in interface structure, (i.e., voice, touch, etc.) and set mobility goals. The student could practice a wide range of features/environments and could modify the configuration as needed, prior to fabricating the actual mobility device.

Benefits: -Permits a wide range of configurations and collects a great deal of data as to how students use the various simulated devices

Drawbacks: -Cumbersome to configure and difficult to easily introduce new groupings of interface and simulator for mobility settings

Support systems: -Constant programming of new types of equipment and environments.

Cost: -$300,000 (?)

SCENARIO 14A: Kitchen Training Simulator

Technology: Computer Simulation

Function: COOKER is a video-disc software simulation of events and processes in a typical kitchen where learning impaired individuals can practice the planning and control of preparation tasks (quickly, softly and in response to errors).

Population: -Learning and memory impaired individuals

Date: -An R&D effort starting today would yield workable prototypes in one year

Setting: -The development and evaluation of a prototype system would take place where technical and clinical resources are effectively integrated

Operation: -In a typical sequence of usage the student would be assigned (or self select) a food preparation (or service) objective
-The system would follow or prompt for planning information and then simulate the processes requested (complete with appropriate visual imagery). If, for instance, an item is "overcooked," visual indications would be presented, corrective advice could be given.
-Performance can be quantified and used as a report card

Benefits: -The primary benefits include: safe operation; a chance to accelerate time; an ability to measure performance objectively; a practice for emergency situations

Drawbacks: -Professionals in the special education environment must learn to use a new tool

Support systems: -The technology will be equivalent to a mixture of home computers and video disc players

Cost: -The first demonstration project would be done for as little as $150,000 in one to two years

SCENARIO 14B: Object Recognition and Task-Sequencing Simulator

Technology: Computer Simulation

Function: This system allows the student to recognize the physical components of a particular vocational application setting, and practice the common sequences of steps used in that setting. Many such settings exist; examples include: titration in a chemistry lab; proper use of a computer printer; a "car cockpit" and how to drive; etc.

Population: -Mildly mentally retarded; visually impaired and physically handicapped; specific population would be particular to each vocational setting chosen

Date: -First setting could be produced and in use by Sept. 1986.
-Future settings could be produced

Setting: -In a semi-private learning carroll, often in library or instructional resources center

Operation: -Each setting teaches visual recognition of objects, and practice of sequence tasks
-The student responds to text-based questions on the screen by entering a text response, or by touching the screen monitor
-The system recognizes both types of input with the widest possible range of tolerance
-The system matches student input to expected answer or sequence and provides feedback
-The system can determine when student is ready to practice in real environment

Benefits: -Provides (practice) access to a variety of settings with only one "station"
-Offers risk free introduction to possibly dangerous environment
-Provide variable amount of practice in a "patient" environment

Drawbacks: -Lack of fine motor control may inhibit use of keyboard; or fine discrimination on touch panel

Support system: -Training students to use the system
-Some minimal technical assistance to the staff

Cost: -Development of each setting would cost between 80k and 300k
-Producing several settings in a coordinated effort could reduce production costs 20 percent, as well as reduce number of discs (e.g., increase number of settings on a disc)
-Cost per student station could be as low as $5,000

SCENARIO 16A: Personal Management Training Simulator

Technology: Computer Simulation

Function: Providing a simulation "game" of a variety of personal management problems that must be "solved" by the student.

Population: -Mentally handicapped students

Date: 1988

Setting: -Schools that are providing training for students that are nearing a point where they can begin assuming responsibility for their interactions with others outside of the institution

Operation: -Depending upon the degree of independence and specific problems being encountered by individual students, the simulator is programmed by the teacher to present situations where the student must take some form of "interpersonal" action and then witness and evaluate the consequences. Feedback is given by the device and the teacher.

Benefits: -Provides guided practice in very "dynamic" settings.

Drawbacks: -Students may have difficulty relating the "game" to the real setting.

Support systems: -Programming support to provide various simulation topics.

Cost: -$400,000 (?)

SCENARIO 16B: Facility Management Training Simulator

Technology: Computer Simulation

Function: Train special education administrators in managing the complex variables in a service facility.

Population: -All populations of special education students

Date: 1987

Setting: -Preservice and inservice training programs for special education administrators.

Operation: -The "Anevent" program development package would be used to model a special education program
-Variables such as pupil number, ages, types of handicaps, physical plants,and community attributes could be variables to provide problem-solving settings

Benefits: -Reduce the possiblity that the administrator would learn on the job, at the expense of handicapped children and their families

Drawbacks: -This is a well-developed technology
-It has limited use in education because of budgets and lack of educators trained in the use of simulation

Support systems: -Minimal

Cost: -2 years at $120,000 per year

RELATED PUBLICATIONS
by COSMOS Corporation

The following publications may be of further interest to the reader, and are available from COSMOS Corporation.

Yin, Robert K., and J. Lynne White, "Microcomputer Implementation in Schools: Findings from Twelve Case Studies," in Milton Chen and William Paisley (eds.), Children and Microcomputers: Formative Studies, Sage Publications, Inc., Beverly Hills, Calif., 1985. (Available from Sage)

Yin, Robert K., Case Study Research: Design and Methods, Sage Publications, Beverly Hills, Calif., 1984. (Available from Sage)

Yin, Robert K., and Gwendolyn B. Moore, Planning and Implementing an Automated Office, COSMOS Corporation, Washington, D.C., December 1984. ($10.00)

Moore, Gwendolyn B., Robert K. Yin, Claire B. Rubin, and Peter G. Bateman, Local Initiatives for High-Technology Development: Analysis, Case Vignettes, and Bibliography, COSMOS Corporation, Washington, D.C., May 1984. ($12.00)

Yin, Robert K., and J. Lynne White, "Federal Technical Assistance Efforts: Lessons and Improvements in Education for 1984 and Beyond," COSMOS Corporation, Washington, D.C., December 1983. ($2.50)

1735 Eye Street, N.W. • Suite 613 • Washington, D.C. 20006 • (202) 728-3939