A comparison of traditional, simulation and virtual reality training methods

by

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INTRODUCTION

> Virtual Reality, as described by Howard Rheingold, is an experience in which a person is surrounded by a three-dimensional computer-generated representation and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it. (Cruz-Neira, 1993, p. 1-2)

Computer applications such as computer-assisted training, simulations and virtual environments have the potential to increase worker efficiency, decrease equipment maintenance costs and deliver training to large numbers of individuals. Virtual reality has been used in military applications since 1979 (Pimentel & Teixeira, 1993, p. 36). The U. S. Army claims that training in simulators while using components of virtual reality cuts training costs (Gourley, 1995). Cray Research Incorporates "Combustion Engineering Group" claims that a four-to-six year automotive engine development cycle can be reduced to six months using 3-D software that is also used in creating virtual environments (Sawyer, 1994, p. 36).

Simulations and virtual reality's positive attributes, including delivering training at an individualized pace and giving immediate feedback, are drawing the attention of technical trainers as well. Interactive video disks, computer simulations, and virtual reality are being examined for potential use in business and industrial environments. Why can't the same positive results reported by the military and robotics companies be achieved in industrial training applications?

Computer power is increasing rapidly. McCraken, of Silicon Graphics Incorporated, claims that in the 1990's computer power relative to price is increasing 10 fold every 3 1/2 years. That is significantly faster than the tenfold increase in computer power relative to price every 7 years in the 1980's and every 10 years in the 1970's (Winter, 1994). As the power of computers increases, the cost of high-end applications, such as computer aided drafting and 3-D modeling, requiring memory and fast computational times, is decreasing. Human-computer interfaces including joysticks, keyboards, pinch gloves, voice commands or graphical displays, allowing humans and computers to interact, are becoming more user friendly. Applications for virtual reality are appearing as fast as people can create them with development time ranging from months to years. Financial backing, available personnel, performance specifications and level of detail will all affect development time.

Rationale

Training professionals indicate that major changes will be made in the way business and industry conducts training over the next few years. New models for learning will be combined with new technologies while experimentation with local and decentralized training will continue (Training & Development, May, 1994, p. 30-31). A changing workforce, global economies and rapidly advancing technologies are impacting what will be learned and how it will be learned. Stan Davis and Jim Botkin predict that :

> corporate training will yield increasingly to individual learning. The main reason for this shift will be information technologies that allow such things as desktop learning and just-in-time learning. . . Learning will be delivered to homes, offices and neighborhood stores via CDs, satellites, cellular, and twisted pairs, and along the information superhighway. (Davis & Botkin, 1994, p. S34)

Examination of current industry practices and problems shows that Davis and Botkin may be correct. A shrinking labor pool, globalization of commerce and rapidly advancing technologies will make it necessary for companies to increase training programs for their employees. These training programs will be necessary to help companies and their employees stay competitive in this changing market.

Shortage of trained workers

The Secretary's Commission on Achieving Necessary Skills (SCANS) Report makes compelling arguments about America's failure to keep up with rapidly advancing technologies and the globalization of commerce and industry. SCANS estimates that fewer than half of the students leaving high school have achieved the minimum reading and writing skills needed to succeed in the workplace. Even fewer students have the mathematical and communication skills vital to workplace success. SCANS further reports that American productivity has slowed and sometimes declined since 1973. Median family income has declined since 1979. High paying manufacturing jobs are being replaced by lower paying service jobs (Secretary's Commission on Achieving Necessary Skill, 1991). An industry report by *Training* Magazine found that 43% of the companies they surveyed offered remedial education in reading, writing and math. Sixty percent of the employees entering these programs have a diploma from a U.S. high school (The Three R's, 1995, p. 66).

The Workforce 2000 study, completed by the U.S. Department of Labor, indicates that "the workforce will grow slowly, . . . (become) older, more female, and more disadvantaged" (Employment and Training Administration, 1987, xiii). Service industries will create new jobs that will require above-average math, language and reasoning skills while the labor pool to recruit from will shrink (Employment and Training Administration, 1987). "Except in a few companies, training is confined mostly to the top and bottom ranks of employees, with little systematic effort to insure that all workers are constantly reinvesting in themselves to avoid obsolescence" (Employment and Training Administration, 1987, xxv).

The reality of the SCANS and Workforce 2000 report is evident in existing training articles. Carnevale and Carnevale report a 45 percent increase in formal company training programs from 1983 to 1991 (Carnevale & Carnevale, 1994, p. S22). *Training* estimated that more than 47 million people received formal training from their employers in 1993. This was a gain of 15 percent over 1992 and topped the 11% gains reported in 1990 and 1992 (Froiland, 1993, p. 53). Industry reports from 1996 indicate that 58.6 million people received some type of formal training (Industry Report, 1996, p. 38).

Rapidly changing technologies, high school students and minorities lacking basic workplace skills, a shrinking labor pool to recruit from, an aging workforce, and other factors make it necessary for business and industry to train or retrain employees on a regular basis. While these factors make it a challenge to bring quality training to a large but diverse group of American workers, it also provides an opportunity for training personnel to develop more effective methods of workplace training.

Workplace training

Underskilled people can experience success when they enter the workplace and can find a company willing to train them for a specific job. An employee who is retrained instead of laid off can also find success. Nancy J. Perry states that:

> seventy-five percent of the people who will be working in the year 2000 are already on the job. . . . As the country's 77 million baby-boomers work their way toward retirement . . . (companies) are concentrating on the 75% of high school students who do not plan to attend a four year college. (Perry, 1991 pp. 68-69)

With the labor pool shrinking and training programs increasing, it would seem as if more people are getting some training.

Closer examination reveals that this is not the case. Ronald Henkoff , reporting figures from the American Society for Training and Development (ASTD), states that 0.5% of American employers account for 90% or $30 billion spent on training every year (Henkoff, 1993, p. 62). It is apparent by these figures that a small number of companies account for the majority of formal training in American business and industry.

The picture becomes bleaker when looking at *Training* Magazine's 1993, 1995 and 1996 annual reports. In 1993 more training was provided to all categories of employees than in other years but educated professionals, managers and salespeople received more hours of training than the lower skilled customer-service people, production workers and administrative employees (Froiland, 1993,

p. 54). The 1995 report indicates that professionals, managers and salespeople consume 66% of annual training budgets while all other workers split the remaining 33% of the budgeted training dollars (Who Benefits?, 1995, p. 46). *Training's* 1996 report demonstrates that these percentages remain stable (Who Benefits? 1996, p. 46). Carnevale, Gainer and Meltzer sum up the situation when they write:

> . . . the most devastating impact of basic workplace deficiencies falls upon the disadvantaged who are outside the economic mainstream, struggling to get in. For those attempting to enter the workforce and those who have been displaced from their jobs, . . . deficiencies inhibit entry into productive and well-paying work, pinning those disadvantaged at the bottom of the economic heap. (1988, p. II)

Thus, the people needing the most training are allocated a minimal amount of training time and money.

This lack of training creates a workforce with underdeveloped skills that corporations could use to their benefit. Training all workers has direct benefits such as shortening new product development cycles, solving business problems, improving processing or acting on new opportunities (Calvert, Mobley & Marshall, 1994). Indirect benefits to corporations and society as a whole might include increased charitable donations, individuals paying higher taxes or increases in safety (Bishop, 1993, p. 224).

Benefits of training

What benefits does training have for the current state of business and industry? Increased profits, less waste and lower employee turnover rates are a few examples. Ronald Henkoff claims that for every $1 Motorola spends on training there is a $30 return in productivity gain. Corning has cut defects by 38% (Henkoff, 1993). The military and large corporations have documented the fact that training employees increases productivity, cuts waste, decreases employee turnover, and reduces time lost for health reasons (Henkoff, 1993).

Employee training helps individuals. They see real benefits as increased education pays off with higher incomes or more prestige. Bishop claims that these social benefits known as "spillovers" or "externalities" are associated with a lesser likelihood of illness and absenteeism among workers, discoveries or artistic contributions that benefit others, more charitable donations and less financial burdens for government and insurance institutions. Bishop categorizes these real externalities as: performance attributable to good training, disasters attributable to poor training and general skills of value to other employers (Bishop, 1993, pp. 223-226). Effective training benefits the individual worker, the organization and society as a whole while ineffective training is costly in dollars lost and less "spillovers" produced.

Types of training

What kind of training do U.S. industries provide to their employees? Since no organized department in the U.S. government keeps track of training statistics, the most reliable industry data comes from *Training* Magazine's annual reports. With the advent of personal computers it makes common sense to see that basic computer skills tops *Training's* list of types of training provided by employers

(General Types of Training, 1996, p. 58). Over 90% of the organizations providing training include computer skills in their training programs. Management skills, technical skills, technical knowledge, communication skills, customer relations, new methods and procedures are offered in 80% or more of the companies surveyed. Executive training, personal growth, clerical skills, labor relations, customer education, wellness and sales are provided in over 50% of organizations ranging from 100 to over 10,000 employees (General Types of Training, October, 1995, p. 60). These numbers, like other training statistics cited, have remained fairly constant during the 1990s.

Specific training programs are dictated by the unique needs of the organization. They may include executive development, organizational transformation, employee orientation, skill training, sales training, intercultural training and many others. William R. Tracey categorizes over twenty types of formal training offered by business, industry, government and military institutions (Tracey, 1992, pp. 1-21). Organizations also add government-mandated training programs as needed. Hazardous chemical awareness and AIDS training are two specific examples of government mandated training programs recently required of organizations across the country. Each of these programs have varying trainee, trainer, time, budget and government constraints. Therefore, different training programs may require a unique training method for effective delivery.

Training methods

When choosing a delivery system a trainer must consider numerous factors. Training budgets, time, the trainees' role, the trainer's role, available technologies, desired outcomes and the level of trainee skills are a few examples. Tracey (1992, pp. 213-229) gives a good overview of the decisions a trainer must make when choosing a delivery system. These include cost, facilities, available equipment, trainee population, number and skill level of instructors, delivery options, and time restrictions.

New technologies are rapidly increasing the delivery options available to the trainer. Before the advent of television, VCRs, and multimedia, training was completed through lectures, demonstrations, and on-the-job training programs. Today's technologies allow for voice and video conferencing, simulations, computer-based training and more. Technologies such as CD ROM, video disks, and virtual reality are entering organizations as viable instructional methods. These instructional methods are changing rapidly. In 1993 Froiland noted that the top five methods of training included lectures, videotapes, one-on-one instruction, role playing and games/simulations. New to Froiland's list was interactive video used in 21% of the organizations providing formal training. Computer-based training was used as a training method in 58% of the organizations responding to *Training's* survey. Virtual reality was not listed as a training method (Froiland, 1993, p. 57). By 1995, with traditional delivery methods still entrenched in training programs, virtual reality entered the training market (Instructional Methods, 1995, p. 62). Virtual reality holds onto its niche in the 1996 market when *Training* reported that it was used in 3% of the organizations providing formal employee training (Instructional Methods and Media, 1996, p. 61).

Training effectiveness

Companies implement training programs to increase productivity, meet government mandates, ensure a safer workplace or improve product quality. Effectiveness, or success, of training programs can be measured by how well a training program meets its stated objectives, how much it increases productivity, or how it benefits the corporation (Tracey, 1992, p. 49). How effective are the training programs offered in business, industry and government institutions? Many companies use traditional methods of training, including lectures, videotapes, workbooks, and overheads (Instructional Methods, 1995, p. 62). Do these traditional methods produce the best training impact, such as the largest positive change in employee behavior, the highest long-term retention rate, or the biggest return on investment for the money spent, or are these methods easy ways to disseminate information quickly to large numbers of people?

Information suggests that less than 50% of companies providing training can answer these questions. Data measuring the return on investment is deemed too costly in time and/or money to collect and analyze. Research has shown that only twenty percent of organizations leading in training evaluated their programs using economic indicators effecting their organization (Carnevale & Schulz, 1990, p. S-2). Nelson, Whitener and Philcox (1995) use figures from the American Society for Training and Development to determine that organizations that conduct training assessments neither systematically identify inputs nor systematically evaluate outputs. Training needs assessments are conducted less than 50% of the time. Less than 50% of the organizations that did evaluate the effectiveness of training programs attempted to evaluate the impact training had on the organizational budget. Inputs that aren't systematically identified and outputs that are not systematically evaluated lead to a "random-in random-out" approach to training (Nelson, Whitener & Philcox, 1995, p. 27). Without objective needs analysis and evaluation components in place, training programs are not designed or refined to address the needs of corporations and employees. This leads to the random approach that Nelson et al. describe. Carnevale and Schulz (1990) found similar results and Paul Erickson contends that the pre-and post-tests used in industries to evaluate trainee learning are inadequate. They measure short-term learning and do not tell anyone if the trainee can apply the information on the job (Erickson, 1990, p. 57).

Finding ways to assess training impact is difficult. What if new production lines are added at the same time training occurs? How much of the productivity gain is a factor of training and how much of the productivity gain is a factor of new equipment? There are various ways to conduct training assessments. A significant number of articles have been published during the 1990's. The specifics of assessment techniques are beyond the scope of this paper. The point to be made is that extensive training is taking place in industry but its impact is not being measured.

Statement of the Problem

America's workforce is undergoing dramatic changes. It is aging and becoming more diverse both in gender and in cultural backgrounds. Emerging technologies used by corporations to increase productivity (such as lasers, fiber optics, and computers) require skilled operators. Communication technologies are enabling corporations to operate on a global scale. These changes make it necessary for companies to employ individuals who have the basic math, writing and communication skills that helps the organization remain competitive. Most of the American workforce that will be in place at the turn of the century is already there. Business and industry no longer has the luxury of picking employees they need from an abundant labor pool. They must use the assets they have to remain competitive. Current industry practices are not addressing these needs. Over half of the training goes to the educated professionals and managers or to those entering the workforce while high school graduates without a four year college degree remain an untapped resource that business and industry ignores (Who Benefits?, 1995, p. 46).

In addition to changing workforce demographics, companies have to cope with several other training issues. The first of these issues addresses training from the corporate level. How effective are training programs? Since objective evaluations of training programs are not typically conducted, many organizations would find it difficult to answer that question. *Training* Magazine reports that in organizations with 100 or more employees that conduct evaluations, 46% measure the impact training has on business results, 60% evaluate a trainee's change in behavior, 69% measure what was learned and up to 85% measure trainee reactions (Training Evaluation, 1995, p. 64). This means that in companies with 100 or more employees 54% cannot tell what impact training has on business, 40% don't know if training changes employee behavior yet 85% of these same companies can tell you if the trainees enjoyed the training or felt it was beneficial. These statistics show that many training decisions are being made on subjective rather than objective data.

Companies also need to address training from an individual employee's perspective. Ronald Henkoff accuses companies of using "the same antiquated passive teaching techniques that have failed so miserably in the schools" (Henkoff, 1993, p. 69). *Training* Magazine reported that 91% of companies responding to their yearly survey indicated that traditional classroom programs would be used for training within their company (Instructional Methods and Media, 1996, p. 61). These techniques ignore research on current learning theory. Research indicates that people acquire information in many different ways (Dunn and Griggs, 1988, p. 36). Luca Solõrzano (1992) claims that over 20 components make up an individual's learning style. Gaea Leinhardt (1992) claims that there multiple forms of learning and that learning builds on prior knowledge and within a social context. Over-utilization of traditional classroom programs may further prevent business and industry from utilizing their human resources to their fullest potential.

Effective training programs need to account for individual learning styles (Herrold, 1989 p. 39), be flexible to meet the needs of a diverse group of people, be compatible with organizational goals, have the ability to be assessable, and be cost effective. In the past, traditional methods have met these goals. Technological advancements and decreasing computer costs make alternatives appealing.

Virtual reality is an emerging technology which some industries and the military claim can be used as an effective and cost saving training tool. Creating, implementing and maintaining virtual environments in business and industry settings has been cost prohibitive until the last several years. Research into the effectiveness of virtual environments has therefore been very limited. Most virtual reality studies have been confined to specific applications such as architectural modeling, flight simulation, surgery simulation, aircraft construction and manufacturing environments (Holusha, 1993, p. F11).

Virtual reality has the ability to address several issues confronting trainers in business and industry. It has potential for addressing the needs of a variety of trainees (McLellan, 1994). Once developed, the virtual reality programs can be easily updated and potentially used anywhere at any time making them flexible and cost effective (Immersive VR tests best, 1994). Proper procedures or concepts can be demonstrated with immediate feedback from a computerized tutor and performance assessment can be built in and directly viewed by the trainee. The trainee immediately views the consequences of any action without endangering people or damaging equipment. These built-in training system attributes can help a trainee go from the slower, serial mode of controlled processing (remembering a phone number long enough to dial it) to the faster, parallel, automatic mode of processing (driving a car) as described by Schneider (Schneider, 1989, p. 3 & 4). Virtual reality can be used to train individuals on a single workstation or groups on local and wide area networks (Gourley, 1995, May and Alluisi, 1991 and McCarty et. al., 1994). Despite these positive attributes, virtual reality won't be accepted as a training tool until its effectiveness is demonstrated.

Purpose of the Study

Marketing virtual environments as a viable training method will be possible when its benefits and/or cost-effectiveness are demonstrated. Companies will not spend thousands of dollars on a custom virtual environment if an off-the-shelf computer tutorial, selling for less than $100, accomplishes the same end result. This study addresses that issue. The primary goal of this study is to:

1. Collect and analyze data to determine if there are significant cognitive or kinesthetic differences between individuals trained in a traditional (low immersion, to be defined), simulated (medium immersion) or virtual (high immersion) environments.

Secondary issues to be considered include:

1. Collect and analyze data to determine if there are correlations between learning style indicators and performance in traditional, simulated or virtual environments and whether these correlations vary.
2. Collect and analyze data that will serve as a starting point for further research into virtual reality. Data regarding the effect of

presence, immersion and learning styles on cognitive and kinesthetic gains will be measured and suggestions made for further research.

Thesis Organization

The Introduction outlines the rationale for this study. A shortage of trained workers, training in the workplace and benefits of training are reviewed. Types of training provided, training methods used and issues surrounding training effectiveness are highlighted. The "Statement of the Problem" section is laid out and followed by the "Purpose of this Study" section. After the organization of this thesis is laid out, terms used later in the paper are defined.

The Literature Review gives an overview of traditional, simulation and virtual reality training systems. A "trainee-trainer-technology" continuum is introduced to describe differences in training methods. Immersion, the degree to which a trainee becomes involved in their surroundings, and its impact on performance is discussed. Individual learning styles as they relate to training is also discussed.

Methods and Materials describes the three phases of recruiting, training and testing participants in this study. The population that was studied is described and the training and assessment materials used are detailed. The chapter closes with a description of the statistical analyses that were applied to the data.

Research Results describes in statistical terms the comparisons made during the study. Associations between the three methods used for training and participants' kinesthetic, cognitive and performance scores are compared. Associations between learning style and performance are examined.

Chapter Five, Conclusions, summarizes the findings of this study and provides recommendations regarding this study's results. Suggestions for further research is given.

Appendices included in the back of this thesis include the outlines for traditional lectures used in this study, directions for reproducing the final test environment, and assessment instruments. References to the appropriate sections are made throughout this paper.

Definition of Terms

andragogy: principles of adult learning. Some experts contend that adults learn differently from children. These differences arise because adults bring more life experiences into a learning situation, they are more self-directed in their learning, and they are more likely to be motivated by a desire for social change than are children.

cognitive: "knowing" or relating to factual knowledge.

computer-aided instruction: is one component of computer-based instruction which applies to "all systems that employ computers to aid the instructional process" (Blaiwess & Regan, 1986). It "involves the use of a computer to conduct, or assist in conducting, instruction" (Tracey, 1992, p. 273). Tutorials, drills, games, modeling, simulation, etc. are used to deliver instruction to individuals or large groups at stand alone workstations or through networks using high-storage-capacity computers (Tracey, 1992, p. 273).

computer-based instruction: "include all the learning systems and activities that have a digital computer or microprocessor as an integral component." (Tracey, 1992, p. 272) It includes hardware, software and the courseware to deliver training.

efficacy: "power to produce an effect" (Merriam Co., 1973, p. 362).

haptic: relates to the sense of touch or feeling pressures and textures.

head-mounted display: are displays, replacing computer monitors, that have been adapted to be worn on an individual's head. These displays give wide viewing angles and create a 3-D effect.

human-computer interfaces: the mechanical devices that allow human beings to input information into a computer as well as the computer hardware that allows human beings to receive information from the computer. Examples include keyboards, monitors, computer mice and head-mounted displays.

immersion: in virtual reality is when a participant or observer 'becomes totally involved in the displayed image through a feeling of "being there"' (Yamaguchi et al as cited in Rheingold, 1991, p. 234). In this study immersion refers to the degree to which a participant becomes involved in the training or testing environment. This degree of involvement will be measured using the U.S. Army's "Immersive Tendencies Questionairre" which is designed to measure how much control individuals feel they have in their training environment and how close the training environment mimics reality.

intelligent tutoring system: a computer keeps track of an individual's answers and repeats material as needed for reinforcement (Livergood, 1994).

kinesthetic: the movement and control of body parts.

presence: is "the subjective experience of being in one environment (there) when one is physically in another environment (here)" (Singer & Witmer, 1996).

simulation: "machine(s), device(s) or process(es) designed to assume the appearance, characteristics, or capabilities of a system or item of equipment on which training is required" (Tracey, 1992).

simulation training: using simulation to create a learning environment where trainees can practice on real or computer generated models of actual equipment. In this study simulation training refers to computer models only.

traditional training: the training and teaching method which uses the process of instructor-centered lectures. Trainees sit passively while the instructor disseminates information. Lectures may be supported by overhead transparencies or worksheets.

virtual environments: "the integration of computer graphics and various input and display technologies to create the illusion of immersion in a computer generated reality - Steve Bryson (Cruz-Neira, 1993)".

virtual reality: "real time, interactive, personal simulation of the content, geometry and dynamics of the environment. . . The users are immersed directly in an environment rather than placed in a vehicle simulated to be in an environment. Further, the hardware producing the simulation is more often worn than entered (Ellis, 1994, p. 18)".

LITERATURE REVIEW

Is virtual reality (VR) or computer simulation a viable training tool? In many cases it is hard to tell because safety and cost issues prohibit the testing of a control group against an experimental group. Many simulations and VR applications used to date were used to train individuals where safety and high-cost equipment were primary issues (Tapscott, 1993). It is not practical to study how astronauts or pilots can perform specific tasks without having had simulation or VR training. Power plant operators need to be competent for safe and efficient electricity to be delivered to the public (West, 1984, p. 52). Loss of life, costly shutdowns, ruined equipment and loss of expensive training time could be a result of inadequate training.

While searching for studies on the effectiveness of VR training, government and industry personnel told this author that VR applications were developed at the request of organizations for a specific need. The development of VR applications is driven by a consumer market and not by evidence of training effectiveness. This author knows of no study which compares performance of a control group without simulation or VR training against a study group which does have simulation or VR training. Jet aircraft, satellites, and power plants cost too much to run this kind of study. When looking at current applications one must ask, "Did the simulated or virtual reality experience make the difference in a trainee's successful or unsuccessful performance"? Were technical diagrams or an individual's past experience what made the difference between success and failure?

This study is designed to answer some of these questions. Are external variables, those delivery systems designed for training, or internal variables, those differences unique to each individual, responsible for training effectiveness? Knowledge acquisition, kinesthetic performance and external immersion scores among individuals participating in either traditional, simulated or virtual reality training environments is used to measure the impact external variables have on training effectiveness. Internal immersion scores and correlations between individuals' learning styles or major of study and the training method used will help determine the effect of internal variables on training effectiveness. This will be accomplished using traditional techniques, simulations and VR applications.

While often seen as distinct forms of training, traditional, simulation and virtual reality training methods are part of ever-evolving delivery systems. They can be envisioned on a trainee-trainer-technology continuum (see Figure 1.1) and are not separate and distinct forms of training. Examination of the continuum shows that as training becomes more individualized and more realistic the technological devices used to deliver training becomes more sophisticated. Trainee involvement, active participation in the learning-teaching process, increases as technological systems become more complex. Trainer involvement, active participation in the teaching-learning process, decreases with system complexity. This relationship can be envisioned as one examines the attributes of these training systems which are described on the following pages.

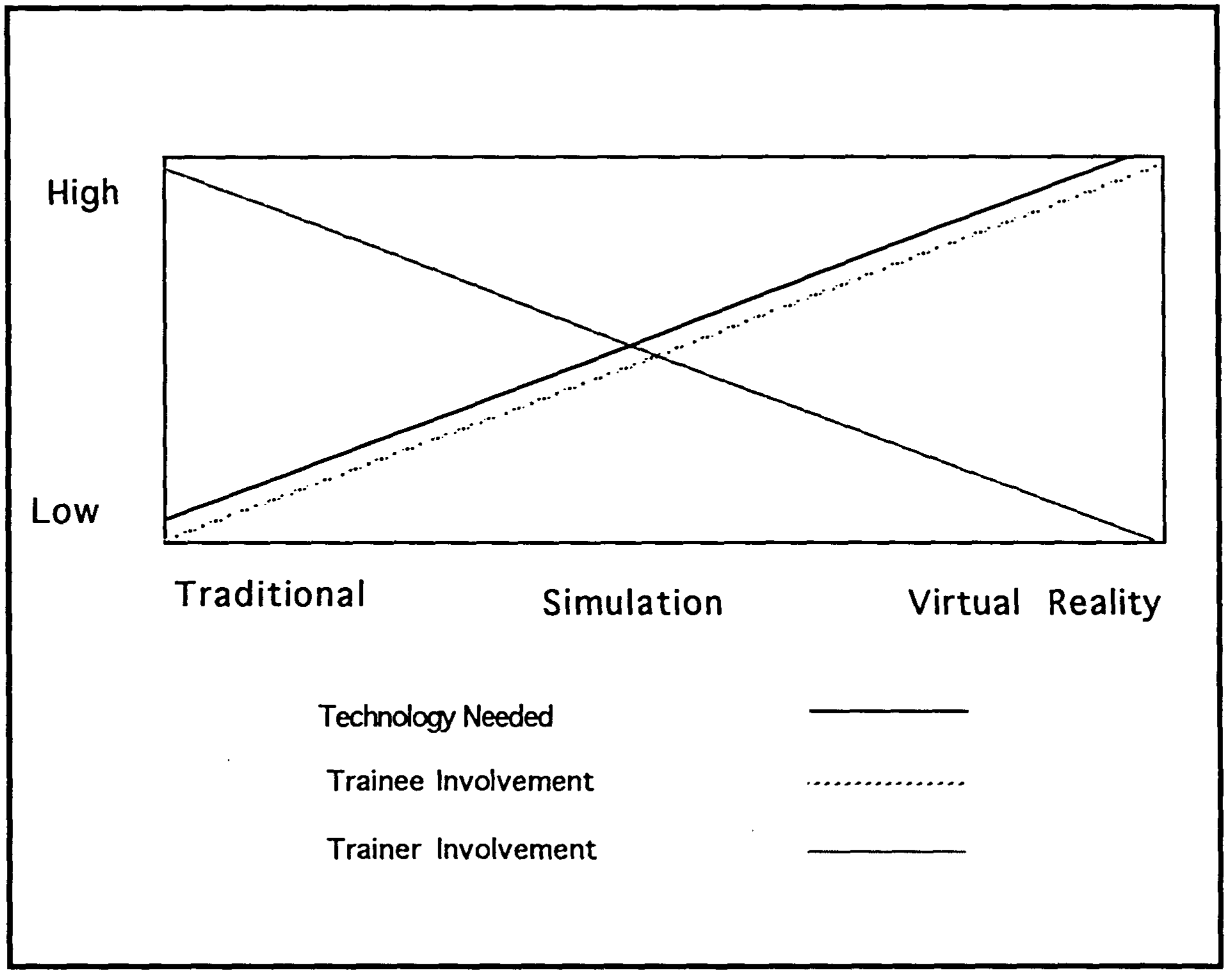


Figure 2.1 Trainee-trainer-technology continuum

Traditional Training Techniques

Traditional training methods were chosen as a "known quantity" against which other training methods can be judged. The standard instructor-centered, lecture-based method is one which has been used for years and which most Americans know well. It is the predominant method of teaching in the United States where individuals sit in their seats and take notes while a teacher lectures about a particular subject. Herrold describes this type of learning as being "brain-antagonistic" and uses Hart's examples (as cited in Herrold, 1989, p. 39) of traditional methods including:

> classroom assignments and physical arrangements better suited to administrative expediency than teaching or learning; the conviction that what is taught will be learned, and what is to be learned can be fit into neatly packaged, exactly timed courses; an overwhelmingly punitive rather than productive use of evaluation; and a curriculum filled with learning devoted to recall and right answers rather than that which is valuable for real-world application. (Herrold, 1989)

Traditional training techniques for skills and technical training include lectures, discussions or demonstrations supplemented by equipment, tools, mockups, models or other job aids (Tracey, 1992, p. 8). Traditional training may be delivered to large or small groups of people who progress at a rate determined by the instructor. A minimal amount of individualization in course structure and learning activities is present. Technologies used for presentations traditionally include blackboards, chalk, overhead projectors, paper and pencils.

Simulations as a Form of Computer Aided Instruction

Computer-based instruction including interactive video disks, computer aided instruction, and computer simulators have become more affordable and are used in many training settings today (Instructional Methods, 1995, p. 62). Computer systems have been developed to provide instruction in two-party negotiation situations (Jones & Hill 1994). James Hoffmann (1991) uses computer-aided instruction (CAI) to teach music composition, performance and listening skills. William Lee cites improved job performance, standardization of training and decentralization of training as benefits of computer-based training. He states that:

> Although hard data are difficult to find on the true effectiveness of such instruction, the positive response from employees who are trained by IVD (interactive video disks) should convince large corporations to invest in it. (Lee, 1990, p. 65)

While seemingly different, CAI applications and simulations use computers to deliver training. According to Blaiwes & Regan:

> computer-based instruction (CBI) is a term used to encompass all systems that employ computers to aid the instructional process . . . (These) classroom aids are important to the discussion of training devices because distinctions between simulator-based training, CAI applications, and other traditional classroom aids have begun to blur. (Blaiwes & Regan, 1986, p. 105)

While some authors cite the effectiveness of computer-aided instruction for training, others question its effectiveness as a training medium. Norman Livergood (1994) found that there was no significant difference in learning scores between undergraduate college students instructed in intelligent tutoring systems using printed material and those undergraduate students instructed using a computer-based multimedia program. Scores did increase significantly when an intelligent tutoring system (the computer keeps track of an individual's answers and repeats material as needed for reinforcement) was added to the computer-aided instruction (Livergood, 1994). Stephenson (1992) found that students engaged in computer-based instruction had higher performance scores when there was instructor-student interaction. Gist, Schwoerer and Rosen (1989) found that people with higher computer self-efficacy scores performed better than people with low computer self-efficacy scores during computer software training. Behavior modeling (trainees imitate a demonstrated skill) worked better than CAI for individuals with low computer self-efficacy (Gist et al., 1989). Reason (1987) argues that simulation is a better training tool than CAI. Reason paraphrases Brennan Kraje as saying that:

> a training program designed with simplistic exercises will produce simple-minded understanding. . .Simulation. . . may be the training technique that provides . . . complete exposure to a subject and is most closely aligned to the human brain's natural receptiveness to knowledge. (Reason, 1987, p. 75)

Simulation systems vary from large networked pieces of hardware to stand-alone computer stations. Standardization of content delivery and decentralization of training, the ability to deliver training at more than one site independent of instructor-led activities, results in lower training costs and are simulation's attributes (Gourley, May, 1995). Simulations may include individualized, self-paced instruction or networked group activities such as SIMNET (Alluisi, 1991 or McCarty et al, 1994). Trainees can see a "cause and effect" because simulation systems are able to react to individual inputs and provide immediate feedback. They help train individuals for dangerous situations without endangering lives (Gourley, January, 1995). Simulators can be adjusted for individual levels of expertise or programmed to deal with a specific training concern (Tracey, 1992, p. 273). Trainees can move from controlled to automatic processing faster because simulators can compress time giving trainees more chances to practice given skills (Schneider, 1989, p. 14). The technologies needed to make simulations effective include full scale models, electronic networks, computer models and human-computer interface devices.

A simulator, according to Tracey "is a machine, device, or process designed to assume the appearance, characteristics, or capabilities of a system or item of equipment on which training is required" (Tracey, 1992, p. 329). Simulations used in this study are a form of computer-assisted instruction (CAI) acting as an operational simulator as described by Tracey (1992, p. 273 & 329). A computer simulation is used because it is the "state-of-the-art" in 1997's technological terms. Simulations serve as a check point between traditional instructional techniques and virtual reality training methods.

Research has been conducted which demonstrates simulators can be a viable training tool. In 1984, West reported on a simulator that reduced the number of errors power plant operators made, reduced startup times, and improved plant safety (West, 1984, p. 52). Simulations can provide a record of performance to a trainee, log critical events and provide progress reports to trainers (Coffee, 1987). A study reported in *Computer Simulation* found that:

> In situations where the objective of instruction is to learn the facts without application or transfer, method of instruction is not a significant factor. However, if the educational goal is to transfer and apply the knowledge to real-world problems, then simulations integrated into class structure may be an effective learning strategy. Also, these activities should be based on guided exploratory learning and be designed to stimulate students' thinking processes. (Effectiveness of computer simulations for enhancing higher order thinking, 1996, p. 45)

If simulations work well for training individuals, then virtual environments, in which trainees interact directly with their environment, is arguably more effective.

Virtual Reality

Technologically more complex than simulations, virtual reality (VR) is described as:

> real-time, interactive, personal simulation of the content, geometry, and dynamics of the environment. This is directly analogous to the technology for traditional vehicle simulation. But unlike vehicle simulation, virtual environment simulation is typically unmediated. The users are immersed directly in an environment, rather than placed in a vehicle simulated to be in an environment. Further, the hardware producing the simulation is more often worn than entered. (S. Ellis, 1994, p. 18)

Virtual reality was chosen for this study because it is an emerging technology which may be tomorrow's preferred training method. It addresses corporate needs by being flexible, easily transported, safe and, as VR prices drop, cost effective (Immersive VR Tests Best, 1994). New training systems have advantages over traditional systems. Nina Adams claims in Cyber Edge Journal (1994) that VR systems can provide an individual "virtual lab" for each student, enabling them to have full and solitary access to all of the equipment, free of embarrassment or penalty for shyness (Immersive VR Tests Best, 1994). The trainer in this experience is nonexistent so trainees can manipulate and react to their environment on an individual level. Trainees can work at their own pace, gain immediate feedback, observe cause and effect and be actively involved in the learning process (Adams, 1995). Brown claims that:

> educationally speaking, this is a superior form of training, as the learner is placed into the actual environment of job performance rather than, say, reading about it. Virtual reality-based training systems will become more prevalent as the cost of the hardware decreases with market penetration. (Brown, 1992, p. 27)

Two attributes make virtual environments unique and different from simulations. This includes immersion where Yamaguchi et al. state that: '. . . the observer becomes totally involved in the displayed image through a feeling of "being there"' (as cited in Rheingold, 1991, p. 234). Larry Hodges et. al. who used

VR to successfully treat people's fear of heights claims that immersion or: 'the "sense of presence" in a virtual world elicited by immersive VR technology indicates that VR applications may differ fundamentally from those commonly associated with graphics and multimedia systems' (Hodges et al., 1995, p. 27).

Navigation, "moving your point of view through 3-D space" (Pimentel & Teixeira, 1993) is the second attribute of virtual reality that distinguishes it from simulations. McKinney and La Russa indicate that there is a 1.5:1 transfer of learning among boom operators (people who refuel aircraft in mid-flight) using a three-dimensional simulator. When the 3-D aspect of the simulation was removed, training effectiveness decreased significantly (McKinney & La Russa, 1981, p. 24).

Research comparing simulations with virtual reality is lacking at this time. Stephen Ellis (1994) claims that:

> A key element frequently missing in the research for many applications areas is a rigorous comparison of user performance with a head-mounted virtual environment display versus a well-designed panel-mounted substitute. Panel-mounted formats are publicly viewable, available with high resolution, and currently much cheaper than head-mounted virtual environment systems. Without such comparisons, the specific benefits of the new technology will remain unknown, and the market will wait on developments. (Ellis, 1994, p. 20-21)

Few studies have been done to date which analyze the transfer of training from virtual environments to real world applications. Kozak et al. (1993) tested a pick-and-place operation and found that learning did not transfer to real-world tasks. They concluded that: "the present results might appear somewhat disappointing for the application of VR technology. However, we believe that many of the present barriers to transfer are due to the technological state-of-the-art, rather than VR *per se* " (Kozak et. al. 1993, p. 783).

Since that study was completed, computer power relative to price has increased ten times (Winter, 1994). More recent studies have also indicated that there is some value in using VR as a training tool. Hodges et al. (1995) concluded that VR was useful in treating the fear of heights. Lampton et al. developed a set of tasks to measure human performance in virtual environments. Lampton concluded that although there was a lot of variation between individuals, virtual reality has "tremendous potential" for training (Lampton et al., 1994, p. 46 & 47).

What is VR's potential as a training method? Neither comparative studies between VR training and a control group nor a comparative study between VR and simulations could be found by this author. While Adams (1994), Brown (1992), Hodges (1995), etc. used VR applications successfully, Kozak found that learning didn't transfer from VR to real world applications (Kozak et. al., 1993). McLellan (1994) argues that VR can be used to promote learning to a diverse group of learners with no evidence to support the claim, while Stephen Ellis (1994) calls for comparative studies between VR and real mock-ups.

Who is right? Each of these cases provides conflicting information about the ability of VR and simulations to be used as an effective training method for skill acquisition. Additionally, VR's potential to address individual learning styles is only a theory at this point in time. This study examines internal and external variables associated with traditional, simulation and virtual reality training methods as described in the following pages.

Skill Acquisition

In order to measure skill acquisition, it has to be defined. Wheatcroft addressed this issue in 1973. He claims that the three components of skill include knowledge, knowing what to do and how to do it, dexterity, putting knowledge into practice at the right pace, and stamina, keeping up that pace (Wheatcroft, 1973). Time constraints prevent examination of the stamina issue but knowledge and dexterity can be addressed. Dexterity is the "process of improvement through practice" (Wheatcroft, 1973, p. 5). The more practice an individual receives, the more proficient they become at completing a task. Danger, difficulty and cost may prevent individuals from training on actual equipment.

Knowledge can be broken down into two components. Wheatcroft states that:

> Symbolic knowledge (such as 2+2=4) can be acquired on a theoretical basis, but sensory knowledge (such as recognizing the color changes of a chisel as it cools) requires direct sensory experience. For instance, one can describe the color blue by saying that it is one of the parts of the spectrum, but this information is meaningless to the hearer until he has seen the color with his own eyes. (Wheatcroft, 1973, p. 4)

The major thrust of this study determines whether the method of instruction, an external variable used for training, has a statistically significant impact on trainee learning. Null hypothesis 1.1 is designed to measure symbolic/cognitive knowledge gained during training using traditional, simulated and virtual reality methods. Null hypothesis 1.2 addresses whether the learning taking place is related to the task of robot operations or if learning is related to the training delivery system. The questions trainees ask about their learning environment is an indicator of "knowledge gained". Null hypotheses 1.3 through 1.7 examine kinesthetic gains among 36 trainees exposed to traditional, simulated and virtual training systems.

Hypothesis 1.1 There is no statistically significant difference in written post test scores after eliminating original differences in pretest scores between individuals trained in traditional, simulated and virtual environments.

Hypothesis 1.2 There is no statistically significant difference in the number of training questions asked by individuals exposed to traditional, simulated and virtual reality training environments.

Hypothesis 1.3 The amount of time needed to learn a specific task does not differ with statistical significance for individuals trained in traditional, simulated and virtual environments.

Hypothesis 1.4 There is no statistically significant difference in final performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots.

Hypothesis 1.5 There is not a statistically significant difference in the "total time" scores of individuals trained using traditional methods, simulations and virtual reality.

Hypothesis 1.6 There is not a statistically significant difference between task accuracy scores of individuals trained using traditional methods, simulation methods and virtual reality methods.

Hypothesis 1.7 There is not a statistically significant difference in the final performance scores of individuals trained using traditional methods, simulations and virtual reality.

Since immersion and 3-D attributes separate VR from simulation, this study tries to measure the effects of these variables as they relate to task performance. Null hypothesis 1.3 through 1.7 indirectly address this issue by assuming that the presence or lack of 3-D graphics during training will affect end performance scores much like McKinney and La Russa's study (McKinney & La Russa, 1981).

Another major part of this study looks for indicators between the type and degree of immersion during training and final performance scores in a real environment. Internal immersion (the amount of immersion an individual feels as the result of personal perceptions and experiences) and external immersion (the amount of immersion induced by external equipment and software) are measured using questionnaires found in the Virtual Environment Performance Assessment Battery (VEPAB) developed by the U.S. Army Research Instittue (Lampton et. al. 1994). The following null hypotheses were developed to asses how immersion, internal and external variables, affected trainees' final performance.

Hypothesis 1.8 There is not a significant correlation between an individual's internal immersion score and their final performance score.

Hypothesis 1.9 There is not a significant correlation between an individual's external immersion score and their final performance score.

Hypothesis 1.10 There is not a statistically significant correlation between an individual's total immersion score and the method of training they experienced.

This study started by examining the external variables affecting trainee performance. Null hypotheses 1.1 through 1.7 compare the effects of traditional, simulated and VR training environments. The results of these hypotheses may help organizations decide if the training benefits gained in VR or simulations, as described by Adams (1994), Schneider (1989) and Gourley (1995), are worth the development costs. Immersion, a variable induced by external equipment as well as individual perceptions is also examined in null hypotheses 1.8 through 1.10.

Internal variables are examined in the final part of the study. It will help determine if an individual's perceptions and expertise affect training performance. Justification for exploring this issue is presented in the following section.

Individual Learning Styles

Research into human learning is creating a debate about how people learn and how that learning should be assessed. Debates raging in the educational community may raise questions about which type of delivery systems are most effective in different training scenarios. These debates have implications that affect this study so they are highlighted here. The following literature review highlights questions being asked and research taking place.

The thrust of andragogy described by Malcolm Knowles in 1980 assumes that children and adults learn differently (Imel, 1989). As individuals mature they become more self-directed, have more experience to draw upon, become more concerned about their social roles and deal with problem-centered learning instead of subject-centered learning (Davenport & Davenport, 1985). Learner motivation, learning styles, self-directedness, and other questions were researched after Knowles' theory was proposed in 1973 (Feuer & Geber, 1988). Feuer and Geber sum up other researchers' ideas as follows: At Columbia University, Stephen Brookfield questions adult learner's self-directedness. Allison Rossett, of San Diego University, asks whether adults and children learn differently. Victoria

Marsick, also at Columbia University, claims that Knowles' adult learning theory focuses on the individual and does not account for the workplace environment (Feuer & Geber, 1988)

Studies by Gorham (as cited in Imel, 1989) found that even when instructors perceived a difference in learning styles between adults and pre-adults, directive teacher behavior remained virtually the same (Imel, 1989).

While Knowles' theory may have found strong dissention in the training community, it started to focus training on the needs of the learner. Ruth Stiehl, of Oregon State University, states that:

> there is nothing more important than understanding our learners, not just their instructional goals but their developmental stage. The more we know about them, the better we're able to put ourselves in their shoes and the better our instruction will be. (Feuer & Geber, 1988, p. 39)

Knowles' premise (as cited in Beder) led to the idea that:

> adult education should be learner-centered, and that the teacher should function as facilitator and guide rather than as conveyor and evaluator. Responsibility for learning, or the lack of it, clearly rests with the (receptor) rather than with the teacher or provider of education. (Beder, 1985, p. 14)

Charles Letteri echoes this idea when he writes that:

> learning is an activity of the brain, under the direct control of the individual, that must result in additions to and modification of long-term memory (LTM). Anything less is not learning . . . The responsibility for engaging in learning belongs to the individual . . . Learning is not automatic. Rather it requires a sustained and conscious effort on the part of the individual. (Letteri 1985 p. 113)

Naour also makes the point that as human beings we receive information through similar senses but everyone is unique in how they interpret the information and construct reality around those stimuli (Naour, 1985, p. 101).

Brain research and research into learning styles indicate that people learn in many different ways that are not fully understood. Dunn and Griggs (1988, p. 36) state that:

> Learning style is a biologically and developmentally imposed set of characteristics that make the same teaching method wonderful for some and terrible for others. . . Learning style also considers motivation, on-task persistence, or the need for multiple assignments simultaneously, the kind and amount of structure required, and conformity versus nonconformity levels.

Sternberg (1994) points out that learning styles are neither good nor bad but are fluid and change with different situations. Luca Solõrzano (1992, p. 27) argues that over 20 components have been identified that influence an individual's learning. An individual will perform best when the instructional method used to teach matches an individual's learning style. Armstrong (1993, p. 82) states that:

> According to Lowenfeld's research, approximately one-fourth of the population shows a clear preference for haptic (as opposed to visual-spatial) perception, while another third appears to have at least some access to its kinesthetic sensibilities.

In 1984, Gardner proposed that learners have seven interrelated intelligences that they use to solve problems (McLellan, 1994). McLellan (1994) suggests that virtual reality can engage all seven of Gardner's intelligences and thus promotes learning. Herrold (1989, p. 40) supports this idea when he writes that "the more senses we involve in the learning process the better it will be for the development of new (brain learning) programs."

Of particular interest for this study are the spatial (i.e. ability to think in pictures), bodily-kinesthetic (talent to control body movements), and linguistic (writing and speaking abilities) intelligences (McLellan, 1994). These may be indicators that determine whether trainees perform better in a traditional lecture style setting or in a virtual environment. Is it possible that training success is not tied to delivery techniques but rather is directed by internal factors within each individual trainee?

Finding internal variables, unique to each trainee, which might determine an individual's success in traditional, simulated or virtual training systems is a secondary goal of this study. Past studies, like this one, have used a relatively homogenous group of test subjects to conduct their research. Kozak et al. (1993) like Hodges et al., and this study, use volunteers from a university community. Military studies use military personnel. Volunteers were chosen from two different majors of study so that this question could be examined. Also, the university environment may attract people who learn best using traditional lecture methods with similar learning styles. In this case there would be no difference between the two groups. The null hypothesis designed to answer this question is:

Hypothesis 2.1 There is not a statistically significant difference between the final performance scores of individuals enrolled in Engineering and individuals enrolled in Industrial Technology courses at Iowa State University.

Learning styles are an internal variable that may affect final training performance. The null hypothesis indicating there is no relationship between learning styles and final performance is:

Hypothesis 2.2 Individual learning styles will have no statistically significant correlation with final performance scores among trainees participating in this study.

Is there are statistically significant difference in the learning styles of the Mechanical Engineering group and the Industrial Technology group? It may be reasonable to conclude that individuals are enrolled in a university and in a particular program because their learning style is conducive to success in this environment. An individual's major of study may relate to an internal variable which affects trainee performance. Null hypothesis 2.3 states that:

Hypothesis 2.3 There is not a statistically significant difference in "Learning Styles Inventory" scores for individuals enrolled in different "majors of study" at Iowa State University.

Figure 2.2 shows the relationship between the variables in hypotheses 2.1, 2.2 and 2.3. A hypothetical "Industrial Technology" group is shown while the "Engineering" and "Other" group are omitted for clarity.

The base of a cylinder is divided into three sections which corresponds to the three majors of study used in this study. A wedge-shaped piece for each "major of study" is located along the central axis of a cylinder at a height that corresponds to the transformed "final performance score". This shows the relationship between final performance scores and major of study as stated in null hypothesis 2.1. Each "major of study" segment is further divided into 25 sections which represents the 25 components measured in the learning styles inventory. The transformed "learning style" scores for each major of study are charted along the circumference of the cylinder. This shows the relationship between "individual learning styles" and "final performance scores" as stated in null hypothesis 2.2. The relationship between "learning style" scores and "major of study" can be seen when the 25 "learning styles" scores for all three majors are graphed around the circumference of the

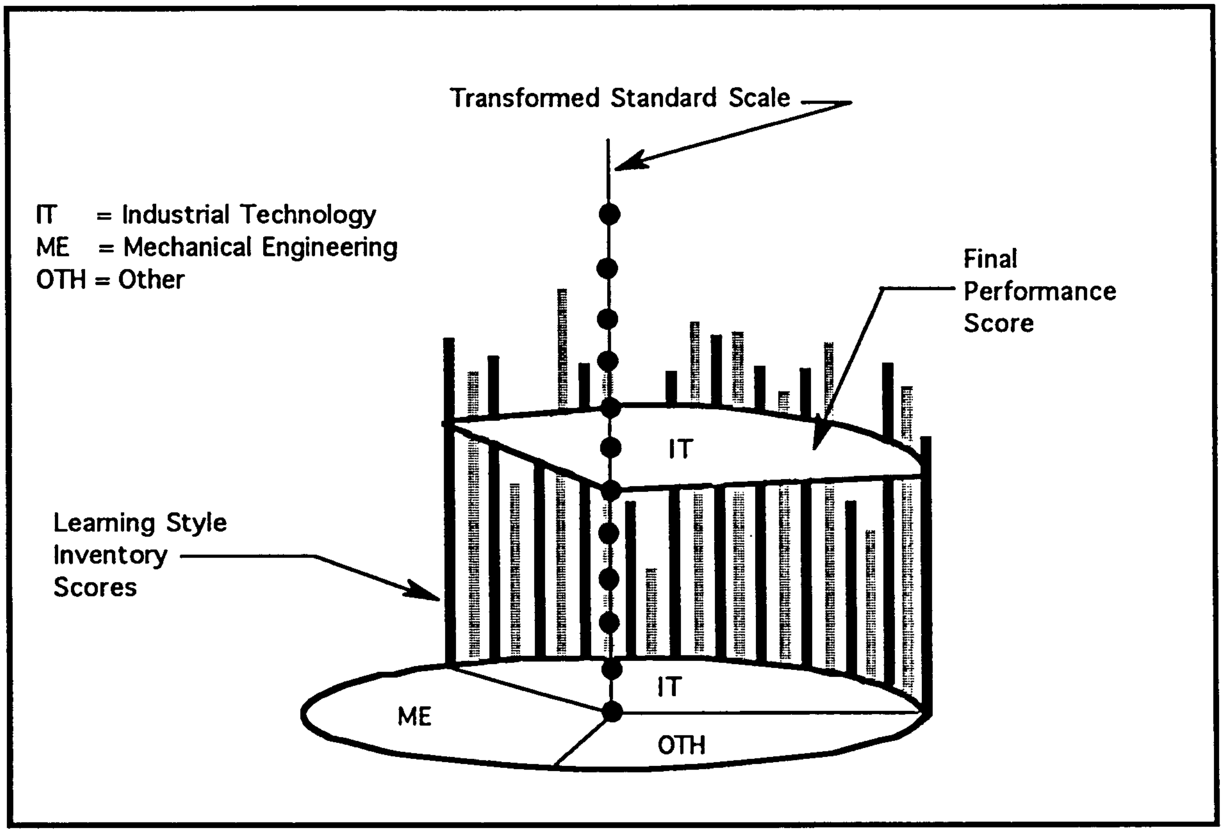


Figure 2.2 Learning styles, major of study and final performance scores

cylinder. By viewing the three-dimensional graph the "kinesthetic" learning style of the "Industrial Technology" group can be compared with the "kinesthetic" learning styles of the "Mechanical Engineering" and the "Other" group. The procedure can be repeated for the other 24 components of "learning style" measured in this study.

Is performance in a particular learning environment affected by internal variables such as an individual's major of study or a learning style? It is important to insure that success or failure in a particular training environment is the result of the training method and not the result of individual perceptions, learning styles, or area of expertise.

Assumptions of the Study

It is not possible to test all of the factors that affect a study. Some assumptions need to be made in order to test the desired variables outlined in a study. The following assumptions were made when this study was conducted:

1. Students put forth a sincere effort in completing training and performing robot tasks. No one purposely took more time than needed to conduct training so as to skew learning time.
2. The outcomes were specific enough to allow everyone in each learning scenario to put forth their best effort trying to learn the material presented.
3. Instructors in the traditional courses did not use any simulation or VR techniques nor was there crossover between simulation, traditional and VR techniques in any of the other training methods.
4. Training personnel delivered training in a uniform manner to each participant within a given training environment.
5. Participants were self-directed in their learning. They were able to determine if they needed more training time. Questions would be asked if there were problems with training delivery system or if training materials and objectives were not clear.
6. Presence of other individuals within the training environment, such as lab assistants or technicians, did not impact the learner.
7. Participants exposed to different training environments did not speak with one another regarding the study.

8. The recruiting process, training formats and assessment instruments provided an unbiased sample and an unbiased analysis.
9. Data is not biased by outside variables. Computer usage, age, gender, robot experience, reading levels or others did not significantly impact the performance measures used in this study.
10. Statistical assumptions were met for the methods of analysis utilized in this comparative study.
11. The measurements and data collected were accurate assessments of participants' abilities. There were no measurement errors on variables such as immersion, presence, cognitive gains or kinesthetic gains.
12. Conditions for internal and external validity were met.

Limitations of the Study

Traditional, simulation and VR training and test environments limited the study in several ways. Choosing participants with little or no VR and simulation experience before the study began was intentional. Other limitations resulted from the material, financial and human resources available to this investigator. These limitations are highlighted in the following paragraphs.

Participants trained using simulations and participants trained using VR were not exposed to their assigned training environment before instruction took place. It was impossible to limit participants' exposure to traditional training environments. Thus, study participants had to cope with, or learn, the training methodology as well as the subject matter. This was assumed to be a relatively easy and passive task for participants involved in the traditional lecture method of training. Participants involved in the simulation and VR methods of training may have had a more active role in learning and a more difficult time adjusting to the training methodology. Success using traditional, simulated and VR training environments may be limited by the individuals' ability to adapt within these differing training environments.

Over fifty participants were recruited for this study but only thirty-six participants provided usable data for the study. The sample sizes used for comparison were reduced to no more than 13 individuals as these volunteers were divided into three groups for exposure to different training environments. This small number of individuals exposed to traditional, simulation and virtual reality training environments may have affected the precision of this study's results.

Finding reliable and parallel materials for each training environment was important for consistency throughout the study. Rhino Robot Incorporated's training materials were used to train participants using traditional methods. Diagrams of teach pendants, hand-held boxes used to program robots, and robot diagrams from Rhino Robot Incorporated not only had been developed by the manufacturer but they matched the actual robots used in the final evaluation session. Variability in training materials was minimized by providing participants in simulation and VR training environments with the same printed materials as the individuals exposed to traditional training methods. The teach pendant modeled in simulation and VR environments duplicated the actual XR-3 teach pendant while VR and simulated robots used during training sessions were simplified computer models of the real XR-3 used in the final evaluation session. Time and budget constraints prohibited more detailed computer models. When designing computer images McCormick (1981, p. 49) argues that at the conscious level one only needs to include "information necessary to accomplish major training objectives such (as) navigating to a target" yet the discrepancies between robotic computer models and the actual robots may have skewed training results.

Technology is fallible and may contribute to a trainee's perceptions and performance. Computer technologies added limitations to this study when they were used to create an interactive robot model. A trainee's sense of presence and immersion are affected by acuity, color, frame rates, haptic and auditory feedback whereas skill acquisition is affected by a trainee's overall comfort and willingness to spend time in the training environment. Equipment breakdowns, heavy head-mounted-displays, peripheral cables, or other environmental factors may have varied enough to impact training effectiveness. While computer technologies may have impacted training, performance limits of the robots during the assessment phase may have impacted participants' training scores. Robots used in the final assessment portion of the study were older with some wear in the motors and gears. Accuracy scores were only as good as the robots' ability to make minute motor adjustments and the trainees' ability to recognize the performance limits of the robots.

Personnel administering the study and the participants involved in the study introduced human factors which may limit the results of this study. University students at Iowa State University represent a relatively localized and homogenous group of subjects for research. Although there are some differences in participants' age, gender, computer experience, etc. there are other factors such as the ability to learn, motivation and literacy levels that are similar. This homogeneity may make it difficult to predict training performance outside the scope of this study or outside the scope of university environments.

Training in traditional environments was administered by a student enrolled in an Industrial Technology program at Iowa State University while training environments utilizing simulations and VR methods were developed and implemented by a student enrolled in a Mechanical Engineering program at Iowa State University. A single, forty-five minute lecture to a large group was delivered by an Industrial Technology student to those participants exposed to traditional training methods. Short, individual, two-minute introductions on simulations or virtual reality was administered by a Mechanical Engineering student to those participants exposed to simulation and VR training methods. Consistency between training sessions may have been compromised by the use of two different trainers or the ability of trainers to remain consistent with one-on-one training sessions implemented over fifty times. Differing perspectives and training techniques utilized by the Industrial Technology student and the Mechanical Engineering student may have also impacted this study.

Participants' exposure to training methodologies, sample size, training materials used, the fallibility of technology and human factors may have impacted this study. This author believes that these limitations do not negate study results since similar variables are encountered in real-world training scenarios.

METHODS AND MATERIALS

Comparing trainee skill acquisition using traditional lecture methods, trainee skill acquisition using computer simulations and trainee skill acquisition using virtual reality is the primary purpose of this study. Wheatcroft (1973) defined the three components of skill as knowledge, dexterity and stamina. Knowledge acquisition and dexterity are measured in this study while time constraints prevented the examination of stamina issues. Secondary purposes of this study compare final performance scores with individuals' learning styles and major of study to determine if internal variables, unique to each individual, impact training effectiveness.

Training and Testing Environments

In other studies, such as Hodges et al. (1995) and Lampton et. al. (1994), participants were brought to a minimum skill level in virtual environments before they were asked to perform there. Business and industry can ill afford to develop trainee skill in simulated or virtual environments before delivering training. Training must include concurrent instruction in computer and VR skills as well as the intended content and skills for job productivity. Thus, computer skills, VR skills and content were taught at the same time in this study using the methods and materials described in the following pages.

Robots were used as the delivery vehicles in this study because of their ability to provide an environment where both cognitive and kinesthetic gains among trainees are measurable. Cognitive gains are measured using six part fill-in-the-blank pre-training and post-training assessments. Differences between participants' post-test and pre-test scores indicate individuals' cognitive gain. Kinesthetic gains are measured by participants' time and accuracy scores as they complete a pick-and-place operation using a robot. Simple pick-and-place tasks modeled in traditional, simulation and virtual training environments allowed participants to acquire robot skills while concurrently adapting to the specific training environment. These pick-and-place tasks also represent dexterity skills needed in today's business and industry. Since robots operate in a three-dimensional envelope they provide the opportunity to compare the assets of 3-D virtual environments with two-dimensional computer simulations and traditional training methods.

Three parallel training environments were developed for this study. One used traditional methods, another used computer simulation and the last used virtual reality training. A final test environment using a real robot, aluminum blocks and a model was also developed. These training and testing environments are described in the following paragraphs and found in the related appendices.

A traditional training lecture was created using robotic materials modified from Rhino Robot's "Student Workbook" (1986, 1-2 to 1-7 and 2-1 to 2-17). The traditional lecture included objectives of the training, a line drawing of an XR-3 Rhino robot and a line drawing of a Rhino Robot XR-3 teach pendant. Handouts of the objectives, robot parts and the teach pendant, as shown in Appendix B, were given to each participant.

Figure 3.1 Simulated Environment

Simulation and immersive virtual environments for this study were developed by Sasikumar Kutti, a graduate student under the direction of Dr. Judy Vance at Iowa State University. Major parts of the Rhino XR-3 robot were modeled for the simulated training environment, as shown in Figure 3.1, using Sense8's "World Up" software and Silicon Graphics Incorporated's Indy workstation with a single R4000 processor and 24 bit graphics hardware.

Simulated robots were controlled using a mouse to manipulate views of the robot and to point and click on a teach pendant which is shown in the upper left corner of Figure 3.1. A two-dimensional, color view of the environment was maintained with sound incorporated into the simulation. Paper copies of the objectives, robot parts and a teach pendant, like those given to the traditional lecture participants, were provided for individuals participating in the simulation training.

The immersive virtual environment, shown in Figure 3.2, was similar to the simulation with color and sound incorporated into the training environment. A three dimensional, robot image was viewed as participants donned an n-Vision VGA head mounted display with an Ascension "flock of birds" sensor attached. Views of the robot were changed as participants moved around the virtual robot by changing head angles or changing body positions. The teach pendant moved as the sensor attached to the participant's left hand moved. Another sensor attached to the Fakespace Pinch Glove, fitted to the participant's right hand, caused the virtual representation of the hand on the computer screen to move relative to the teach pendant. An interactive training environment, manipulated by body movements

Figure 3.2 Immersive Virtual Reality Training Environment

like those used in a real-world setting, was possible as peripheral computer hardware and sensors worked in unison with the computer software. Paper copies of the objectives, robot parts and a teach pendant were provided for individuals participating in this virtual reality training.

The final test environment, detailed in Appendix C, was adapted from the Utah State Office for Vocational Education (Utah State Office for Vocational Education, 1984, pp 1-13). Participants manipulated hollow, aluminum blocks from a masonite target area into a modeled truck using an XR-3 Rhino robot. Block placement and clear, acrylic sides on the edges of the truck bed forced participants to use all five axes of the Rhino XR-3 robot. Opposing corners of the aluminum blocks were painted yellow and blue so that accuracy of block placement on the truck bed could be measured in millimeters according to an X, Y, and Z coordinate system. Details of the information collected in these training and testing environments are provided in the *Research Design* section of this paper.

Population and Sample - Original Study

Availability of industry personnel, travel time, access to equipment, cost factors and time constraints made it necessary to recruit a sample of fifty participants from undergraduate Mechanical Engineering and Industrial Technology courses at Iowa State University in Ames, Iowa. Study results were then generalized from this sample population to the workplace. These students were targeted because they had little or no robot experience and because they represented two groups with the potential of demonstrating differing learning styles.

Student volunteers spent two to three hours participating in this study and were reimbursed at a rate of six dollars per hour for their time.

Thirty seven of the fifty original participants completed the study within the specified parameters. Eight of the original fifty individuals chose not to participate after the first introductory session. Two people failed to participate in the final evaluation session while two more people failed to provide enough data for comparison. The last individual eliminated from this study was exposed to both simulation and virtual reality training environments which violated the parameters of the study.

It is important to verify that the assumptions made regarding the thirty-seven participants in this study are accurate (see pages 40 and 41). Gist, Schwoerer and Rosen (1989) found that people with high computer self-efficacy, believing in one's ability to perform a task, performed better in computer software training than people with low computer self-efficacy. Robinson-Staveley and Cooper (1990) investigated how gender and the presence of other people affected an individual's performance in human-computer interactions. Correlating data gathered from the thirty seven remaining participants helped determine that the variations in this study resulted from differences in training methodologies or learning styles and were not the result of other factors like those in studies such as Gist et. al. (1989) and Robinson-Stavely and Cooper (1990).

Training time, final performance time, task accuracy, questions asked during training, and written scores, are subcomponents of every participant's final performance scores. The principal investigator employed these measures after speaking with industry and government personnel and reviewing performance indicators used in other studies. Factors indicative of participants' self-efficacy and possibly affecting performance scores includes gender, age, robot experience, and computer experience. These factors were examined for their affect on the study before further analysis of training and learning styles data was attempted. Results from this examination follow and are summarized in Tables 3.1and 3.2.

All participants had normal vision or corrected to near-normal vision with updated optical prescriptions. Every participant stated that they would wear their updated prescriptions with the exception of two male subjects who claimed that the glasses were not needed for the study. It was assumed that participants would take necessary measures to function within their designated training environments and no data analysis was conducted on the vision variables.

Six of the participants were female (16%) and 32 participants (84%) were male. This study assumed that gender was not a significant factor (at an alpha level of .90) for the number of questions asked during training, training time, written test scores, robot accuracy or for final performance times. The Kolmogorov-Smirnov test (Abacus, 1991, pp. 153 & 154) was applied to these variables and the results shown in Table 3.1. It can be seen that gender did not play a statistically significant role at the .90 significance level in any of the final performance subcomponent scores.

Correlations between age and final performance subcomponent scores, robot experience and final performance subcomponent scores and computer experience and final performance subcomponent scores were computed. The results of these correlations are shown in Table 3.2 while the demographics of the study participants are listed below.

Ages of the thirty seven final participants varied from 19 to 36 years with a mean age of 22.19 years. Twenty-eight participants had no robot experience while nine participants had robot experience ranging from 2 hours to 1 month. The average time of experience among participants was 2 1/2 days. Computer

Table 3.1 Gender versus final performance subcomponent scores

	Maximum Difference Between Means	Komogorov-Smirnov Chi Square	z score	Probability
Questions asked during training	.134	.363	.301	.7631
Time spent in training environment	.210	.884	.470	.6383
Identification of robot parts	.186	.707	.420	.6743
Task accuracy	.267	1.457	.604	.5462
Pick and place task time	.610	7.612	1.379	.1678

Degrees of freedom = 2

Male cases = 31

Female cases = 6

experience was indicated for IBM/DOS or compatible machines, Macintosh and SGI/Sun/UNIX machines. Participants had from 0 to 10 years experience using IBM/DOS machines with a mean of 4.12 years. Macintosh use ranged from 0 to 10 years with a mean of 2.31 years. SGI/Sun/UNIX experience ranged from 0 to 5 years with a mean of 7.5 months. Total computer experience, the sum of DOS, Macintosh, UNIX, etc. machines ranged from 0 to 18 years of experience with an average of 6.7 years. Correlation coefficients indicated that there was little if any correlation between a participant's age and the final performance score subcomponents, robot experience and the final performance score subcomponents or computer experience and the final performance score subcomponents. The decision was made to keep all thirty seven participants in place for analysis.

The final group of participants included 28 Mechanical Engineering students (76%), 4 Industrial Technology students (11%) and 5 individuals categorized as "Other" (13%). The "Other" category included one Environmental Engineering student, one Speech Communication major, one Electrical Engineering major, one Agricultural Engineering major and one Civil Engineering major. The original study was designed to compare "Mechanical Engineering" (ME) majors with "Industrial Technology" (IT) majors. The principal investigator formed a third "Other" category because a "Speech Communication" major didn't fit in either the ME or IT group. The principal investigator was also concerned that students enrolled in different types of Engineering majors might have different learning styles from one another. Instead of assuming that learning styles for all Engineering majors was similar, a third "Other" category was used.

Table 3.2 Final performance score subcomponent correlations - original study

	Age		Robot Experience		Computer Experience	
	Correlation	R^2	Correlation	R^2	Correlation	R^2
Questions asked during training	.116	.014	-.138	.019	-.291	.085
Time spent in training environment	.289	.083	-.163	.027	.041	.002
Identification of robot parts	.245	.060	-.286	.082	-.061	.004
Task accuracy	.295	.087	-.051	.003	-.196	.038
Pick and place task time	.046	.002	-.225	.051	-.204	.042

N = 37

Correlation = .00 to .30 (.00 to -.30) Little if any correlation (Hinkle et. al, 1994, p. 119)

.30 to .50 (-.30 to -.50) Low positive (negative) correlation (Hinkle et. al, 1994, p. 119)

R^2 = amount of "variance in *one* variable that is associated with the *other* variable" (Hinkle et.al, 1994, p. 119)

Assigning study participants to traditional, simulated or virtual training environments without bias was accomplished before continuing with this study. Participants provided their student identification numbers on a survey during the first introductory session. These surveys were arranged according to the student identification number from lowest to highest value and then assigned a number from Marija Norusis' (1990, p. 14) Random Number Table. The surveys, with their newly assigned random numbers, were arranged from the lowest to the highest random number and divided into one "traditional training" group containing 16 individuals, one "simulation training" group containing 17 individuals and one "VR training" group containing 17 individuals. Participants with the lowest random numbers were assigned to the "traditional" training method; participants with mid-range random numbers were assigned to the "simulated" training method; participants with the highest random numbers were assigned to the "VR" training method. After accounting for the participants who were removed from the study, fourteen participants participated in traditional training; eleven participants participated in simulated training; thirteen participants participated in virtual reality training. These participants spent between ten minutes and forty five minutes in training and from nine minutes to forty five minutes completing the final performance portion of the study. These variables are examined in detail as outlined in the *Research Design* section of this paper.

Research Design

Three phases of this study required different types of assessment and performance indicators. Existing assessment instruments were used when possible because the validity and reliability of these instruments had been tested. Other assessments were adapted from preexisting materials or constructed by the principal investigator.

The first phase included recruitment of participants for the study. Before training began, individuals met in a large group setting to complete a learning styles inventory and an assessment of robot operation and computer knowledge. The second phase was completed as individuals were assigned to one of three test groups: those who were exposed to traditional training techniques, those using a simulation, and those acquiring cognitive and kinesthetic skills in a virtual environment. The simulation is a two dimensional, workstation-based training environment whereas the virtual environment is fully immersive and three-dimensional. The third, and final, phase included a performance test of kinesthetic abilities and a cognitive test indicating what robot parts trainees could identify a week after training and two weeks after recruitment. The specific test instruments and details of each of these three phases is described below.

Phase I - Recruitment

A letter requesting that interested students participate in this study was sent to instructors of undergraduate students in Industrial Technology and Mechanical Engineering courses. Students agreeing to participate in the study attended one of four introductory meetings. Mechanical Engineering students were given introductory information in one of Iowa State University's Engineering buildings. The room was a conference room with moveable tables and chairs. A television and a VHS video cassette recorder mounted on a moveable cart were provided. Industrial Technology students were given introductory information in one of Iowa State University's Industrial Technology buildings. The room had both chairs and tables mounted to in a stepped, auditorium-type arrangement. A large screen at the front of the room descended for viewing the rear projected video cassette recorded images. While the environments differed, it was assumed that students would feel most comfortable in surroundings that were the most familiar.

Except for the physical surroundings, each of these evening introductory session was the same length and contained the same content. Students were introduced to the principal investigator, given contact and pay information, asked to sign a consent form, and to complete two assessments. This introductory material is included in Appendix A.

Introductory Surveys obtained background information on each participant. Data regarding participants' age, major of study, gender, eyesight, robot experience and computer usage was collected. A fill-in-the-blank inventory, adapted from Rhino Robot Ltd.. literature, was used to determine how many parts of a robot each participant could identify. This introductory score was used a the base line for "cognitive knowledge gained".

Learning styles for each participant was collected using the "Vocational Learning Styles Inventories" from Piney Mountain Press, Inc. (1994). The principal investigator chose this "learning style inventory" because it included a video tape and a written questionnaire which addresses several learning styles at one time. Responses were collected to seventy-five questions arranged in a four position, "Most Like Me" to "Least Like Me", Likert-type numerical rating scale. Responses to these questions were used to indicate an individual's learning style profile which included five major domains. The physical domain indicated how individuals retain information using kinesthetic, visual, tactile and auditory processes. Preferring to study in groups or individually is measured in the social domain. Environmental preferences such as design, light, sound and temperature are measured in the Environmental Domain. Mode of Expression indicates a preference for verbal or written expression. Preferences for working conditions such as working with people, data, things, indoors or outdoors, lifting or nonlifting, and sedentary or nonsedentary is measured in the Work Characteristics Domain.

This particular learning styles inventory was based on C.I.T.E. Academic Learning Styles and the Hendrix-Frye Vocational Learning Styles Inventories. Validity and reliability data, upon which the Piney Mountain Press inventory was based, were provided by the publisher. Piney Mountain Press's Learning Style Inventory was also accompanied by a video which provided a uniform delivery of the learning styles inventory and addressed the needs of individuals with auditory and visual learning styles (Piney Mountain Press, 1994).

Phase II - Training

Although there were three groups of participants, all being trained using different training methods, training was to be delivered in parallel formats. Each person received the training objectives, which were also read to them, upon entering either the traditional, simulated or virtual training environments. Participants then completed the "Immersive Tendencies Questionnaire" and a "pre-Display System Comfort Questionnaire", detailed below, so that the effects of internal and external immersion on final performance can be determined. These materials are enclosed in Appendix B (Lampton et al, 1994).

After filling out the "Immersive Tendencies Questionnaire" and the "pre-Display System Comfort Questionnaire", participants exposed to the traditional training method spent the next twenty six minutes listening to a lecture on robot parts and visualized moving a robot using a teach pendant. An overhead projector, overhead markers and paper handouts were used to supplement lecture training.

Participants exposed to the simulation training methods completed a short, several minute introduction on using a mouse, switching computer views, and navigating through the robot training environment. The objectives, robot diagrams and teach pendant diagrams given to traditional training participants were laid next to the training computer. The intention of the principal investigator was to give participants exposed to computer simulation training methods the same written materials, delivered in the same manner, that were given to the "traditional" group. Training objectives were to be read to the study participants. Lab personnel helping with this study did not understand the stated directions and the objectives were not read to the participant in the "simulation" group. Nevertheless, all of the participants using the computer simulation stated that they had seen and understood the training objectives.

Participants exposed to the virtual training environment went through a short, several minute introduction on using a data glove, adjusting the head mounted display, and navigating through the virtual robot training environment. The objectives, robot diagrams and teach pendant diagrams given to traditional training participants were laid next to the training computer. However, participants were immersed in the virtual environment and only two participants saw the training objectives. Lab personnel helping with this study did not understand the stated directions of the principal investigator so training objectives were neither read nor given to individuals immersed in the virtual training environment.

Data were collected during the training phase using observations as well as written assessments. Cognitive and kinesthetic gains among trainees were measured using the following methods.

Questions asked by trainees during training were used as an indicator of cognitive gains within the training environment. As subjects proceeded with their training, the questions they asked were classified under "robot", "computer/application" and "other" categories. The frequency of response scores were recorded and compared during the final analysis. Questions regarding training environments and robots were added to a final performance score since they indicate that learning is on task. Questions not related to robots or the learning environment were recorded separately.

Training time, the amount of time it takes an individual to complete training, was used to measure kinesthetic gains within the training environment. It was assumed that individuals would not continue to practice in the training environment when they felt comfortable enough to perform a task in a real environment. Instructors delivering traditional training recorded the start and finish times to the traditional lecture. Starting and ending times were also recorded for subjects trained using simulations and virtual reality. Time spent correcting hardware and software problems was also recorded and deducted from time spent "in training". These "down times" were recorded for future reference.

All participants, except those in the "traditional" group, were allowed to spend as much time as they felt was necessary to become competent in performing robot tasks. Trainees in the simulated environment said they felt confident about performing robot tasks and did not choose to spend any extra time in the training environment. Trainees in the virtual environment indicated that they were not sure what the reason for the training was and they quickly lost interest in what they were doing. As a result, this group had relatively short training times.

All participants completed the "Presence Questionnaire" and the "Post Display System Comfort Questionnaire" at the end of their respective training sessions. These materials, described below, are included with the rest of the training materials in Appendix B.

The **Immersive Tendencies Questionnaire** was designed by the United States Army Research Institute to assess how much presence individuals experience in an artificial environment. The thirty-four question instrument uses a

7-point scale based on the semantic differential (Singer & Witmer, 1996, p. 6). It is anchored at each end by opposing descriptors but unlike the semantic differential it is anchored at the midpoint as well. Eighteen items are used to indicate an individual's tendency to become immersed in an environment. Areas measured include "focus", "involvement" and "games". "Games" collects data on how involved individuals are with video games while "Involvement" measures the likelihood an individual will become passively involved in watching something. "Focus" asks questions which indicate how mentally alert an individual feels at the specific time of completing the questionnaire.

Reliability tests were performed on this 18 item questionnaire and resulted in a Cronbach's alpha of .81 (N=132) with a mean of 76.66 and a standard deviation of 13.61 (Singer & Witmer, 1996, p. 6). Since the "Immersive Tendency Questionnaire" is still being tested, sixteen additional items are included in the questionnaire for further study.

Presence Questionnaires were developed by the United States Army Research Institute to measure the extent to which an individual was involved in a virtual environment. The thirty two question instrument uses a 7-point scale based on the semantic differential (Singer & Witmer, 1996, p. 6). It is anchored at each end by opposing descriptors but unlike the semantic differential it is anchored at the midpoint as well. Nineteen items were used to measure an individual's sense of presence in a virtual environment. Areas measured include "Involved/Control", "Natural" and "Interface Quality". "Involved/Control" items measure how involved an individual became in the immersive environment. "Natural" items measure how consistent with reality and how natural the immersive environment felt. The "Interface Quality" items indicate whether the hardware used to produce an immersive environment was distracting.

Reliability tests were performed on this 19-item questionnaire and resulted in a Cronbach's alpha of .88 (N=152) with a mean of 98.11 and a standard deviation of 15.78 (Singer & Witmer, 1996, p. 6). Since the "Presence Questionnaire" is still being tested, thirteen additional items are included in the questionnaire for further study.

The **Pre-Display System Comfort Questionnaire** is part of the *Simulator Sickness Questionnaire* as described by Kennedy et al. (1992). This questionnaire, containing three items about individuals' health, is used to control variances in the *Post Display System Comfort Questionnaire.* Data were collected using this questionnaire for later analysis.

The **Post Display System Comfort Questionnaire**, also part of the *Simulator Sickness Questionnaire* as described by Kennedy et al (1992), asks sixteen questions about the physical discomfort an individual experiences during simulations. The *Simulator Sickness Questionnaire* is designed to identify problems with high-fidelity visual simulators. Although designed for military simulations, the questionnaire was administered to generate data for later analysis.

Phase III - Testing

All participants were tested at the end of this study for cognitive and kinesthetic gains made during training. This was done using both written and performance assessments. Data was also collected regarding the amount of "presence" participants felt when they were using a real robot and a modeled environment.

Testing took place in an Engineering facility at Iowa State University. Florescent lighting was located over five paired rows of tables mounted to the floor. Each pair of tables was separated by a six foot aisle with moveable chairs that allowed placement of, and movement around, the four foot by four foot test environment for kinesthetic gains. This "final performance" test environment is described below.

Participants entered the final performance session in fifteen minute intervals and spent between twenty minutes and one and one half hour in the test session. All participants went through the exit sequence in the same manner. Upon entering, participants were asked to complete an exit survey and read a handout on robot safety and "task scenario". The exit survey was an exact copy of the entrance survey. At least two weeks separated the entrance survey from the exit survey to help prevent memorization of the assessment items. After the exit survey was complete and the robot handout was read, participants received a verbal over view of robot safety and the task they were expected to complete. Any questions participants had were answered and participants began moving four blocks into position as per the directions given. Participants recorded their own starting and completion times when using the robot. The principal investigator monitored trainees performance to make sure the reported times were accurate. When an individual indicated she/he was done using the robot, accuracy scores were compiled by calculating how far away opposing corners of four aluminum blocks were from a prepainted "target" area.

A questionnaire requesting information and personal attitudes about the training methods used in this study was developed after several individuals stated that training would have been better had they been given the objectives for training. Since the stated objectives were supposed to have been given to all participants, the principal investigator became concerned about the implementation of the study and designed a questionnaire to collect the participants' views about the simulation and training environments. This information, while not included in the formal study, was used to find discrepancies between the designed study and the actual implementation of the study.

Time sheets were the last item collected from study participants. Times for recruitment, training and testing sessions were added together. Participants were paid $6 per hour and thanked for their time and help. The time sheets, exit surveys, questionnaires and other testing materials are detailed below and in Appendix C.

The **Exit Survey** was a six item, fill in the blank, written assessment that duplicated the fill in the blank questions on the "introductory survey". At least two weeks separated the "introductory survey" and the "exit survey" to minimize any memorization of the questions. The correct answers on the exit survey were compared to the correct answers on the introductory survey as an indicator of cognitive knowledge gained during training.

Task time was used to measure kinesthetic gains during training. Participants recorded their starting and ending times as they used the XR-3 Rhino robot to move four color coded aluminum blocks from a modeled accident site into a modeled truck. When blocks were tipped, jarred or dropped, participants were allowed to move the test block(s) in question back to their original starting position and begin again or to try and adjust the blocks using the robot. All participants were told to take as much time as the accuracy of the robot and their patience would allow. The assumption the principal investigator made was that people with the greatest robot skill would take the least time to manipulate the blocks. Therefore, time could be an indicator of kinesthetic skills gained.

Task Accuracy was measured using four rectangular 3/4" x 1 1/2" x 3" aluminum tubes. The length of one corner was painted yellow and the length of the opposing corner was painted blue. Starting positions for these blocks were painted on a 4' x 4' pressboard base. All were within reach of the XR-3 Rhino robot. Participants moved these four blocks to corresponding positions in the rear of a modeled truck. A clear acrylic box on the back of the modeled truck provided visibility but forced participants to use all of the robot's axis. Accuracy scores were derived by measuring, in millimeters, how far the corners were from the indicated positions in the rear of the truck. The x, y and z measurements were added together for the total error. Since the scores were inverted from lowest to highest in the measuring processes they were inverted mathematically for statistical comparison.

Presence Questionnaires used in the training environment were administered again in the test environment. No changes were made to the assessment instrument and participants were told to answer the "Presence Questionnaire" as it applied to the final test environment. The data collected will help answer questions as they relate to modeled data and individual perceptions of the "Presence Questionnaire". This analysis is beyond the scope of this paper.

Post Display System Comfort Questionnaire is the same instrument described in the"Training" section. The questionnaire was administered to generate data for later analysis.

Data were collected using these survey instruments and test environments over a three week time span. The resulting information was entered into computer scoring programs, spreadsheets and data bases for analysis as described in the following section.

Data Analysis

The data were analyzed using three separate computer programs. The VEPAB was provided with scoring instructions but were not computerized. The principal investigator used a simple spread sheet to compile scores as instructed in the VEPAB directions (Singer & Witmer, 1996).

The Learning Styles Inventory came with a computerized scoring system which was loaded onto a DOS machine (Vocational learning styles inventory media
kit, 1994). Participants in the study completed a bubble sheet and data from these sheets was entered into the computer by the principal investigator. Participants were not informed of their Learning Style Inventory results.

Statview for Students (Abacus Concepts, 1991) was used to compile and make comparisons between all of the data that was collected. This included time, accuracy, VEPAB and Learning Style Inventory scores. A summation of the comparisons is included in Table 3.3.

Is there a statistically significant effect of the method of instruction on trainee learning? Does the method of training have an effect on trainees' kinesthetic and cognitive performance? Will the degree of immersion a trainee experiences affect final training performance? Part one of the study attempts to answer these questions while part two of the study looks at the relationship between learning styles or major of study and overall performance. Statistical analysis of the data will demonstrate how effective training with traditional environments compares to training by interaction with virtual environments or simulations.

Alterations to the Study

The principal investigator became concerned when participants trained using virtual reality techniques indicated they had no clear idea of what the objectives of the study were. Further investigation revealed that the training

Table 3.3 Summary of statistical analysis

Hypothesis	Measuring Instrument	Analysis
Hypothesis 1.1 There is no statistically significant difference in written post test scores after eliminating original differences in pretest scores between individuals trained in traditional, simulated and virtual environments.	6 Question pre-test with identical fill in the blank post-test.	ANCOVA adjusts for initial differences.
	Measures cognitive gains	32 of 37 respondents had a a score of 0 on the pretest
Hypothesis 1.2 There is no statistically significant difference in the number of training questions asked by individuals exposed to traditional, simulated and virtual reality training environments.	Record the number of "training content" questions asked, the number of questions asked regarding "training environments" and the number of "other"questions asked.	One-way ANOVA between "content" questions and training method
		One-way ANOVA between "training environment" questions and training method
	Measures cognitive gains and helps differentiate between content skill acquisition and training environment skill acquisition.	One-way ANOVA between "other" questions and training method
		One-way ANOVA between the total relevant questions and training method

Table 3.3 (continued)

Hypothesis	Measuring Instrument	Analysis
Hypothesis 1.3 The amount of time needed to learn a specific task does not differ with significance for individuals trained in traditional, simulated and virtual environments.	Measured training time Measures skill acquisition per unit of time	One way ANOVA between training time and training method.
Hypothesis 1.4 There is no statistically significant difference in final performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots.	Measured performance time Measures skill acquisition	One way ANOVA between final performance time and training method.
Hypothesis 1.5 There is not a statistically significant difference in the "total time" scores of individuals trained using traditional methods, simulations and virtual reality.	Sum of training time and performance time Measures skill acquisition	Correlation coefficient and one way ANOVA between time scores and training method.

Table 3.3 (continued)

Hypothesis	Measuring Instrument	Analysis
Hypothesis 1.6 There is not a statistically significant difference between task accuracy scores of individuals trained using traditional methods, simulation methods and virtual reality methods.	Measured accuracy score Measures skill acquisition	One way ANOVA between accuracy scores and training method.
Hypothesis 1.7 There is not a statistically significant difference in the final performance scores of individuals trained using traditional methods, simulations and virtual reality.	Sum of training time inverted performance time inverted, accuracy scores inverted, questions asked and knowledge gained. All scores standardized	One way ANOVA between final performance scores and training method.
Hypothesis 1.8 There is not a significant correlation between an individual's internal immersion score and their final performance score.	VEPAB "Immersion Questionnaire" Sum of training time inverted performance time inverted, accuracy scores inverted, questions asked and knowledge gained. All scores are standardized.	Correlation Coefficient between final performance scores and overall "immersion" scores.

Table 3.3 (continued)

Hypothesis	Measuring Instrument	Analysis
Hypothesis 1.9 There is not a significant correlation between an individual's external immersion score and their final performance score.	VEPAB "Presence Questionnaire" Sum of training time inverted, performance time inverted, accuracy scores inverted, questions asked and knowledge gained. All scores are standardized.	Correlation Coefficient between final performance scores and overall "presence" scores.
Hypothesis 1.10 There is not a statistically significant correlation between an individual's total immersion score and their final performance score.	Sum of "Immersion" and "Presence" questionnaires. Sum of training time inverted, performance time inverted, accuracy scores inverted, questions aked and knowledge gained. All standardized.	Correlation Coefficient between the total immersion scores and final performance scores.
Hypothesis 2.1 There is not a statistically significant difference between the final performance scores of individuals enrolled in Engineering and individuals enrolled in Industrial Technology courses at Iowa State University.	Major of study Sum of training time inverted, performance time inverted, accuracy scores inverted, questions asked and knowledge gained. All standardized.	One way ANOVA between major of study and final performance scores.

Table 3.3 (continued)

Hypothesis	Measuring Instrument	Analysis
Hypothesis 2.2 Individual learning style will have no statistically significant affect on final performance scores among trainees participating in this study.	Learning style scores Sum of training time inverted, performance time inverted, accuracy scores inverted, questions asked and knowledge gained. All standardized.	One-way ANOVA between learning style scores and final performance scores.
Hypothesis 2.3 There is not a statistically significant difference in "Learning Styles Inventory" scores for individuals enrolled in different majors of study at Iowa State University	Learning style scores Indicated major of study	One-way ANOVA between major of study and learning style scores and

objectives had been laying next to the training computer but few of the participants saw the training objectives. Lab personnel failed to read or make participants aware of the objectives while participants were absorbed in donning VR equipment. Since this impacted how much participants trained and what they tried to learn, the need for remedial measures was indicated.

Population and Sample - Revised Study

Twenty one new participants were recruited from the Engineering and Industrial Technology departments at Iowa State University one month after the original study was completed. Students in these introductory courses were targeted because they had little or no robot experience, they provided consistency with the original study and could potentially demonstrate the effects that differing learning styles had on training. Student volunteers spent two to three hours participating in the study and were reimbursed at a rate of six dollars per hour for their time.

All new participants were assigned to the "virtual reality" group since these participants were the only individuals in the original study who were not aware of the training objectives. Objectives were read by the individual participants so they had a clear understanding of the training objectives. The trainer did not read the objectives aloud, as was originally designed, to maintain a similar format with the methods implemented in the original portion of the study. The data that was collected from the new participants was merged with the original data collected from participants exposed to "traditional" and "simulation" training environments. Descriptions for the newly merged sample are highlighted in the following pages.

Fourteen of the twenty one new participants completed the study within the specified parameters. Two participants were eliminated from the study because they were trained in a different version of the VR robot environment which violated the study parameters. One person gave incomplete data and four individuals failed to complete the study past the training portion. Thirty-eight individuals were left in place for the revised study.

The assumption made regarding the participants on pages 40 and 41 of this study were tested for this second, revised study. Correlating data from thirty eight participants helped determine that the variations in the study were the results of training methodologies or learning styles and not the result of other factors like those mentioned in Gist et. al. (1989) and Robinson-Stavely and Cooper (1990).

Factors indicative of participants' self-efficacy and those possibly affecting performance include gender, age, robot experience and computer experience. Participants' final scores are compiled from training time, final performance time, task accuracy, questions asked during training and written scores. These factors were examined for their impact on the study before further analysis of training and learning styles data was attempted. Results from this examination follow and are summarized in Tables 3.4 and 3.5.

All participants had normal or corrected to near-normal vision with updated optical prescriptions. Every participant claimed they would wear their updated prescriptions with the exception of two male subjects from the original study who

Table 3.4 Gender versus final performance subcomponent scores - revised study

	Maximum Difference Between Means	Komogorov-Smirnov Chi Square	z score	Probability
Questions asked during training	.100	.253	.251	.8016
Time spent in training environment	.267	1.796	.670	.5028
Identification of robot parts	.300	2.274	.754	.4509
Task accuracy	.317	2.533	.796	.4261
Pick and place task time	.333	2.807	.838	.4022

Degrees of freedom = 2

Male cases = 30

Female cases = 8

claimed that glasses were not needed. It was assumed that participants would take necessary measures to function within their designated training environments and no data analysis was conducted on the vision variables.

In the merged sample, eight of the study participants were female (21%) and 30 of the revised study participants (79%) were male. It was assumed that gender was not a significant factor (at an alpha level of .90) for the number of questions asked during training, training time, written test scores, robot accuracy or for final performance times. The Kolmogorov-Smirnov test (Abacus, 1991, pp. 153 & 154) was applied to these variables and the results shown in table 3.4. It can be seen that gender did not play a statistically significant role at the .90 significance level in any of the final performance subcomponent scores. It should be noted that the z score for pick and place task time dropped (and p increased) as the number of females increased from the original study to the revised study. This helped reinforce the assumption that gender was not a significant factor in the pick and place task time component of participants' final performance scores.

Correlations between age and final performance subcomponent scores, robot experience and final performance subcomponent scores and computer experience and final performance subcomponent scores were completed for participants in the revised study. Table 3.5 shows the results of these correlations while the demographics of the revised study participants are listed below.

Ages of the thirty-eight participants in the merged sample varied from 19 to forty-seven years with a mean age of 23.47 years. Thirty-two participants had no robot experience while six participants had robot experience ranging from 2 hours to 1 year. The average time of experience among participants was 10.5 days. Computer experience was indicated for IBM/DOS or compatible machines, Macintosh and SGI/Sun/UNIX machines. Participants had from 0 to 10 years experience using IBM/DOS machines with a mean of 4.11 years. Macintosh use ranged from 0 to 10 years with a mean of 2.85 years. SGI/Sun/UNIX experience ranged from 0 to 12 years with a mean of 1 year. Total computer experience, the

Table 3.5 Final performance score subcomponent correlations - revised study

	Age		Robot Experience		Computer Experience	
	Correlation	R^2	Correlation	R^2	Correlation	R^2
Questions asked during training	.263	.069	.134	.018	-.140	.020
Time spent in training environment	.200	.040	.037	.001	.115	.013
Identification of robot parts	-.184	.034	-.130	.017	-.066	.004
Task accuracy	.193	.037	-.024	.001	-.318	.101
Pick and place task time	.052	.003	.026	.001	-.288	.083

N = 38

Correlation = .00 to .30 (.00 to -.30) Little if any correlation (Hinkle et. al, 1994, p. 119)

.30 to .50 (-.30 to -.50) Low positive (negative) correlation (Hinkle et. al, 1994, p. 119)

R^2 = amount of "variance in one variable that is associated with the other variable" (Hinkle et.al, 1994, p. 119) sum of DOS, Macintosh, UNIX, etc. machines ranged from 1 hour to 22.5 years of experience with average of 7.96 years. Correlation coefficients indicated that there was little correlation between a participant's age and final performance score (.0445, $R^2 = .002$) subcomponents, robot experience and the final performance score subcomponents or computer experience and the final performance score subcomponents. The decision was made to keep all thirty-eight participants in place for analysis.

The final group of participants in the revised study included 25 Mechanical Engineering students (66%), 6 Industrial Technology students (16%) and 7 individuals categorized as "other" (18%). The "other" category included one Environmental Engineering student, one Speech Communication major, one Agricultural Engineering major, two Civil Engineering students, one Physics major and one Aerospace Engineering student.

After accounting for the participants who did not complete the study, fourteen participants were exposed to traditional training methods; ten participants were exposed to simulated training methods; fourteen participants were exposed to virtual reality training methods. These individuals spent between eleven and forty minutes in training and from nine to forty five minutes completing the final performance portion of the study. These variables are examined in detail as outlined in the *Revised Research Design* section of this paper.

Revised Research Design

Recruitment, training and testing phases of this revised study utilized the same assessment instruments and performance indicators that were used in the original study. Subtle changes were made in the recruitment phase of the study to accommodate the schedules of trainees, trainers and the principal investigator. It is assumed that the changes described did not significantly impact the revised study.

Phase IV - Recruitment in Revised Study

Instructors of undergraduate Industrial Technology and Mechanical Engineering courses recruited students to participate in the study and allowed the principal investigator to recruit students for the revised study. Twenty-one student volunteers, recruited from five classes, attended one of five, day-time introductory meetings. The groups attending these session contained between two and seven individuals which was smaller than the groups of eight to twenty which attended the introductory sessions in the original study. All recruiting sessions were conducted in the late morning and early afternoon instead of paralleling the evening recruiting sessions used in the original study. This accommodated the scheduling needs of the new study participants, the trainers and the principal investigator. The same room of Black Engineering, used for recruiting sessions in the original study, was also used for the introductory sessions in the revised study. Scheduling difficulties prevented the principal investigator from assuring familiar surroundings for both Industrial Technology and Mechanical Engineering students.

Except for group size, time of the introductory sessions and the use of one location, each of these introductory sessions was the same length and contained the same content as that used in the original study. Students were introduced to the principal investigator, given contact and pay information, asked to sign a consent form, and completed two assessments. This introductory material is included in Appendix A and is described on pages 58 and 59 of this paper.

Training, testing and data analysis of these new participants followed the same procedures as those used in the original study. It was assumed that the variances in recruiting techniques between the original study and the revised study were minimal and did not affect the study.

Revision of the original study, initially seen as a detrimental factor, may have provided an additional opportunity for the principal investigator. Bishop (1993) implies that external effects attributable to good training and external affects attributable to bad training can be measured at the individual as well as the corporate level. Effects attributed to poor training, such as withholding training objectives from trainees, can be compared to effects attributable to good training, such as providing trainees with training objectives, within the virtual reality training environments used in this study.

RESULTS AND DISCUSSION

Comparing how training using traditional lecture methods, training using computer simulations and training using virtual reality impacts an individual's skill acquisition was the main purpose of this study. Participants' cognitive and kinesthetic gains were measured during the training phase and during the final assessment phase of the study and analyzed using ANOVAs and correlation coefficients. Comparing individuals' final performance scores with individuals' learning styles or major of study to determine if there were indicators of success for a particular training method was a secondary purpose of the study. This data was also subjected to statistical analysis as outlined in Table 3.3.

Participants trained using virtual reality in the original study did not receive adequate information about training objectives. This affected how long trainees stayed in the training environment, what they looked for when they were immersed in the training environment and potentially affected the participants' final performance data. The results from the original study are noted below. A second group of virtual reality training participants was recruited and more data was collected. The second set of virtual reality data that was collected was combined with data from the traditional and simulation environments from the first set of data. The statistical results from the revised study are reported in the Revised Demographic Description section and the Revised Research section found later in this chapter.

Original Demographic Description

Demographics of the sample, as outlined in the *Population and Sample - Original Study* section, changed after data regarding participants' performance were examined. The principal investigator became concerned when one participant's accuracy scores, a subcomponent of the final performance score, of 341 millimeters was found to be 4.92 standard deviations above the sample mean. All five subcomponent scores (including training time, task accuracy, robot pick-and-place task time, questions asked during training, and identification of robot parts) were examined for further outliers. Figure 4.1 is a bar chart showing the

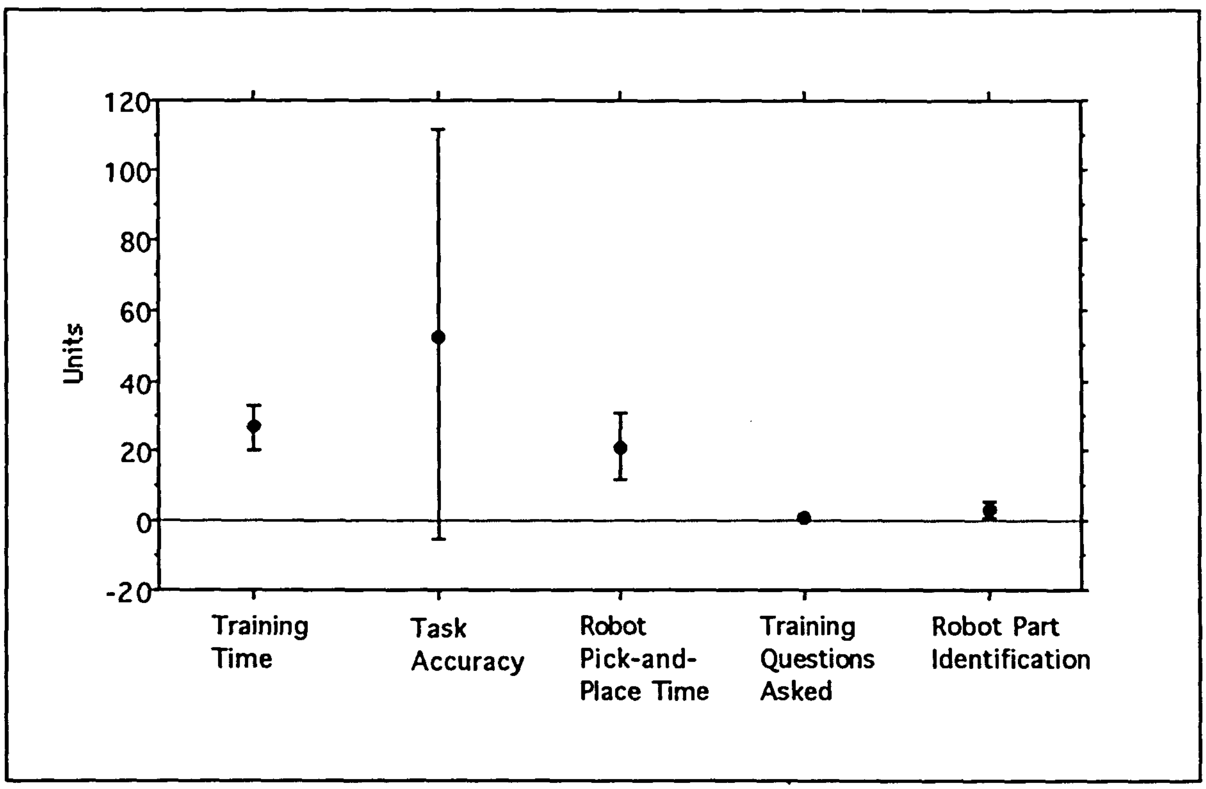


Figure 4.1 Mean and variation of final performance subcomponent scores

mean and standard deviations for five of the "final performance" subcomponent scores from this study. Standard deviations are low for training time (6.723), robot pick-and-place time (9.481), questions asked during training (.588) and robot part identification scores (2.149) when compared against a relatively high standard deviation (58.51) for accuracy scores. These varying standard deviations were expected since measurements of the final performance subcomponents scores, such as questions asked, distance in millimeters and time in minutes, were radically different from one another. A need to normalize the training subcomponent scores for final data analysis was indicated. Converting raw scores to an equal-interval scale allows for statistical comparison. According to Hinkle et al (1994, p. 75) standard score, or *z* score, is calculated by "subtracting the mean from the raw score and dividing the result by the standard deviation [standard score = (raw score-mean)/standard deviation]." Hinkle et al further state that:

> Attractive as z scores are for purposes of comparison, they have some disadvantages. They can be misleading and difficult to manage and to report. . . . Laypeople might interpret a *z* score of 0 as a score of zero correct, rather than the mean value and might overreact to a negative *z* score. A second concern is the number of decimal places to retain. . . . For these reasons, *z* scores are commonly transformed into a different distribution of scores, a distribution that has a predetermined mean and a standard deviation. This new scale of measurement may be chosen arbitrarily. . . . The transformation requires two steps: (1) transform the original distribution of raw scores into a distribution of *z* scores and (2) multiply each *z* score by 10 (the standard deviation) and add 50 (the mean). Transformed score = (10)(z) + 50. (Hinkle et al, 1994, p. 79)

The range of final performance subcomponent scores was compared with the associated standard deviations in order to eliminate outliers from the study. Results from this comparison is shown in Table 4.1. Deciding to eliminate

Table 4.1 Final performance subcomponent score results

	Mean	Standard Deviation	Minimum Score	Maximum Score	Action Taken
Training Time (minutes)	26.432	6.723	10	45	None
Task Accuracy (millimeters)	52.946	58.510	9	341	Eliminate 341 data as outlier
Robot Pick-and-Place Time (minutes)	20.676	9.481	9	45	None
Training Questions Asked (integer 0 and up)	.351	.588	0	2	None
Robot Part Identification (integer 0-6)	3.135	2.149	0	6	None

N = 36

participants due to outlying variables had to be weighed against eliminating too much data from the study. Accuracy scores varied the most and were examined closely. The highest accuracy score of 341 millimeters was 4.92 standard deviations above the sample mean. Agresti and Finlay state that:

> If a particular residual for a set of data occurs several $\hat{\sigma}$ below or above 0, the corresponding observation should be checked to make sure it has not been recorded improperly. Such extreme observations are called **outliers**. If an outlier represents an error in measurement, it could cause a major bias

> in the least squares equation. Even if it is not an error, it should be investigated because it represents an observation that is not typical of the sample data. (Agresti and Finlay, 1986, p. 383)

The accuracy score of 341 millimeters was considered an outlier and this participant's data was removed from the study. The next highest accuracy score was 168 millimeters which was 1.97 standard deviations away from the sample mean. This participant's data was characteristic of other participants' scores and was kept for further analysis. Remaining data fell between 1.46 standard deviations (robot part identification score) and 2.80 standard deviations (questions asked during training) of their respective means. These numbers were reasonable for data analysis but removing outliers changed the demographics of the sample population. A revised demographic description of study participants follows.

Revised Demographic Description - Original Study

Thirty-six participants, recruited from undergraduate courses at Iowa State University, provided the data used for this study. All participants had normal or corrected to normal eye sight. Two male participants, one assigned to the simulation training method and one assigned to the VR training method, indicated they would not wear their glasses during the study. The principal investigator assumed that these individuals were able to function within their training environments.

Thirty-six participants completed training and the final performance measures within the parameters of the study. These individuals spent between ten and forty five minutes (mean = 26.444 minutes) in their respective training environment. Final assessments, where trainees demonstrated cognitive and kinesthetic gains, were scheduled between five and thirteen days (mean =7.583 days) after the participant's training session. Correlation coefficients between three subcomponent scores, used in determining final performance, and the lag time between training and performance dates, measured in days, were run to insure that lag times didn't affect final performance scores. Table 4.2 summarizes these results showing little if any effect between lag time and the subcomponents of the final performance score while the demographic description of the final thirty-six participants is shown in Tables 4.3 through 4.7 on the following pages.

Table 4.2 Lag time and final performance subcomponent score correlations

	Training to Final Performance Lag Time (days)	
	Correlation	R^2
Identification of robot parts	.171	.029
Task accuracy	-.034	.001
Pick and place task time	-.323	.104

N =36

Correlation = .00 to .30 Little if any correlation (Hinkle et. al, 1994, p. 119)

R^2 = amount of "variance in one variable that is associated with the other variable" (Hinkle et. al, 1994, p. 119)

The age of the thirty-six final participants varied from 19 to 36 years of age with a mean age of 22.028 years. Thirty six (94.44 percent) of the participants ranged from the ages of 19 to 26. Table 4.3 shows the frequency distribution of participants by age.

Table 4.3 Participants in study by age

Age	Number	Percent
19-22	17	47.22
22-26	17	47.22
26-30	1	2.78
30-34	0	0.0
34-38	1	2.78

N = 36

Table 4.4 Participants in study by gender

Gender	Number	Percent
male	30	83.33
female	6	16.67

N = 36

Table 4.4 shows that six of the participants were female (16.67 percent) while the remaining 31 participants (83.33 percent) were male. Males outnumbered females by a ratio of 5 to 1 reflecting the fact that Engineering and Industrial Technology are male dominated fields of study.

The final group of participants included twenty-seven Mechanical Engineering students, four Industrial Technology students and five individuals categorized as "other". The "other" category includes students recruited from the aforementioned Mechanical Engineering and Industrial Technology courses but who are enrolled in Electronic, Environmental, Civil and Agricultural Engineering or Speech Communications majors. See Table 4.5.

Ten participants had robot experience ranging from 2 hours to 31 days with the average time of robot experience being 2 days. Study participants indicated that much of this experience involved programming the robot with computers and

Table 4.5 Participants in study by major of study

Major of Study	Number	Percent
Mechanical Engineering	27	73
Industrial Technology	4	10.8
Other	6	16.2

N = 36

not manipulating the teach pendant to complete robot tasks. Correlations between robot experience and task accuracy scores and robot experience and pick-and-place task time were run to insure that the impact of robot experience on the study was minimal. The correlation between robot experience and task accuracy scores was -.027 with R-squared = .001. The correlation between robot experience and pick-and-place task time was -.229 with R-squared = .052. The scores indicate that pick-and-place task accuracy increases and time to complete tasks decreases with robot experience. After referring to Hinkle et al. (p. 119), which indicated that the correlation was weak to non-existent, the decision was made to keep these participants in place for analysis. Table 4.6 indicates the robot experience for participants in this study.

Computer experience, summarized in Table 4.7, was indicated for IBM/DOS or compatible machines, Macintosh, SGI/Sun/UNIX machines and for all of thesecombined. Participants had from 0 to 10 years experience using IBM/DOS

Table 4.6 Robot experience of participants in study

Days of Experience	Number	Percent
0-10	34	94.44
10-20	0	0.0
20-30	2	5.56

N=36

machines with a mean of 4.2 years. Macintosh use ranged from 0 to 10 years with a mean of 2.4 years. SGI/Sun/UNIX experience ranged from 0 to 5 years with a mean of 0.6 years. Participant's total computer experience ranged from 0 to 18 years with a mean of 6.8 years. None of the participants indicated any experience with other computer systems.

Table 4.7 Computer experience of participants in study

Years	Number	Percent
	IBM/DOS	
Under 1	2	5.9
1-3	7	20.6
3-5	9	26.5
5-7	13	38.2
7-9	2	5.9
9 or more	1	2.9
	Macintosh	
Under 1	19	55.9
1-3	3	8.8
3-5	4	11.8
5-7	3	8.8
7-9	3	8.8
9 or more	2	5.9

N=36

Table 4.7 (continued)

Years	Number	Percent
	SGI/SUN/UNIX	
Under 1	29	80.6
1-3	3	8.3
3-5	3	8.3
5-7	1	2.8
	Sum of Computer Experience	
Under 1	4	11.1
1-3	4	11.1
3-5	6	16.7
5-7	5	13.9
7-9	4	11.1
9-11	6	16.7
11-13	3	8.3
13-15	1	2.8
Over 15	3	8.3

No further action was taken with the computer experience data since correlations between computer experience and the subcomponents of the final performance score had already been analyzed (see Table 3.2 on page 55). It can be seen from examining Table 3.2 that there is little or no correlation between the final performance score subcomponents and the sum of computer experience.

The principal investigator felt confident continuing with the study as planned after finding little correlation between participants' self-efficacy factors and final performance indicators as well as little correlation between participants' physical characteristics and final performance indicators. Since training subcomponent scores varied, as shown in Figure 4.1, they were converted to transformed standard scores (Hinkle et. al pp. 79 - 80) using a mean of 50 and a standard deviation of 10. All other scores were converted to transformed standard scores before further data analysis was conducted. A mean of 50 and a standard deviation of 10 was used throughout the study when converting raw data to transformed standard scores to provide uniformity throughout the study.

Comparative statistics, such as correlation coefficients and ANOVAs, were conducted using the computational considerations and formulas as described by Abacus Concepts (1991, pp. 167-171). Comparisons between treatment means were made within each ANOVA and the difference between means, the Fisher PLSD test and Scheffé F-test were provided for each treatment comparison (Abacus Concepts, 1991, p. 140). The results of these statistical comparisons are shown in Table 4.8 and a discussion of the results follow.

Table 4.8 Results of statistical analysis - original study

Hypothesis	Results
Hypothesis 1.1 There is no statistically significant difference in written post test scores after eliminating original differences in pretest scores between individuals trained in traditional, simulated and virtual environments.	The null hypothesis is rejected when participants in traditional and simulated environments demonstrate a higher level of cognitive gain, at a statistically significant level ($p < .01$), than did participants exposed to the virtual reality training method.
Hypothesis 1.2 There is no statistically significant difference in the number of training questions asked by individuals exposed to traditional, simulated and virtual reality training environments.	The null hypothesis was supported when the F distribution showed that there was a .8921 probability for participants exposed to three different training environments to ask the same number of training related questions. There was a .9772 probability that participants exposed to different training environments would ask the same number of content/robot questions. There was a .4369 probability that participants exposed to different training environments would ask the same number of "other" questions and a probability of .9329 that participants in different training environments would ask the same number of total relevant questions.

Table 4.8 (continued)

Hypothesis	Results
Hypothesis 1.3 The amount of time needed to learn a specific task does not differ with significance for individuals trained in traditional, simulated and virtual environments.	The null hypothesis was supported when the F distribution shows that there was a .1805 probability that training time was not different for participants exposed to three different training environments.
Hypothesis 1.4 There is no statistically significant difference in final performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots.	The null hypothesis was supported when the F distribution showed a .609 probability that the final performance time would be similar for participants exposed to different training methods.
Hypothesis 1.5 There is not a statistically significant difference in the "total time" scores of individuals trained using traditional methods, simulations and virtual reality.	A correlation coefficient with R^2 =.009 shows little linear relationship between training time and final task time. The null hypothesis was supported when the F distribution showed a .282 probability that the "total training time" of participants would not vary for trainees exposed to three different training methods.

Table 4.8 (continued)

Hypothesis	Results
Hypothesis 1.6 There is not a statistically significant difference between task accuracy scores of individuals trained using traditional methods, simulation methods and virtual reality methods.	The null hypothesis was supported when the F distribution showed a probability of .3316 that task accuracy would not vary for individuals exposed to three different training methods.
Hypothesis 1.7 There is not a statistically significant difference in the final performance scores of individuals trained using traditional methods, simulations and virtual reality.	The null hypothesis was supported. The F distribution showed a .5307 probability that final performance scores are not affected by the training method participants were exposed to.
Hypothesis 1.8 There is not a significant correlation between an individual's internal immersion score and their final performance score.	The null hypothesis was supported. The correlation coefficient (.0862) with R^2 of .0074 showed that only .7% of the variance in final performance scores could have been attributed to the internal immersion score.

Table 4.8 (continued)

Hypothesis	Results
Hypothesis 1.9 There is not a significant correlation between an individual's external immersion score and their final performance score. scores.	The null hypothesis was supported. A correlation coefficient of -.1724 and R^2 of .0297 showed that only 2.9% of the variance in final performance scores could be explained by the external immersion
Hypothesis 1.10 There is not a statistically significant correlation between an individual's total immersion score and their final performance score.	The null hypothesis was supported. A correlation coefficient of -.0331 with R^2= .0011 shows that there is little linear relationship between the total amount of immersion a person indicates and their final performance scores. Only 3.31 percent of the variance in final performance scores can be attributed to the total amount of immersion a person feels.

Table 4.8 (continued)

Hypothesis	Results
Hypothesis 2.1 There is not a statistically significant difference between the final performance scores of individuals enrolled in Engineering and individuals enrolled in Industrial Technology courses at Iowa State University.	The null hypothesis was supported when the F test showed a .2645 probability that there was not a difference in final performance scores for individuals enrolled in different majors of study at Iowa State University.
Hypothesis 2.2 Individual learning style will have no statistically significant affect on final performance scores among trainees participating in this study.	The null hypothesis was supported when R^2 values showed that the 25 subcomponents of "learning style" accounted for .11% to 15.97% of the variability in final performance scores. The low correlation coefficients were too low to be statistically significant according to Hinkle et. al (1994, p. 119)
Hypothesis 2.3 There is not a statistically significant difference in "Learning Styles Inventory" scores for individuals enrolled in different majors of study at Iowa State University	The null hypothesis was rejected when an ANOVA showed a .054 probability that there was no difference in "kinesthetic" learning styles for different majors of study and a .0901 probability that there was no difference in "oral" learning styles for different majors of study at Iowa State University.

Research Results

Data collected from the participants were used to address the research hypotheses outlined in Chapter 3. Statistical tests were run using an alpha level of .10. This was inconsistent with alpha levels of .05 reported in literature reviews and government sources. Since this study explores areas where data are lacking and since this study lays the foundation for further research into simulation and VR training environments, a less conservative alpha level of .10 (rejecting the null hypothesis when it is true) may help find trends related to VR and simulation training that won't be evident at a significance level of .05. As Hinkle et. al write:

> The selection of the level of significance in behavioral science research does not often receive the attention it merits. The .05 and .01 levels are commonly used, but sometimes there seems to be no rationale for their use other than the fact that R.A. Fisher used them in his agricultural experiemnts several decades ago. (Hinkle et. al, 1994, p. 189)

If significant trends are found within this data, further analysis can be run at higher alpha levels or more research can be completed to refine research hypotheses. The thirteen null hypotheses, stated in the *Literature Review* section of this paper, were analyzed at the stated alpha level of .10 for the reasons stated above and the results of the statistical analyses follow.

Null hypothesis 1.1 states that *There is no statistically significant difference in written post test scores after eliminating original differences in pretest scores between individuals trained in traditional, simulated and virtual environments.* This hypothesis is designed to indicate and compare what effect traditional, simulated and virtual reality training methods have on an individual's cognitive gain during training. An ANCOVA was used to measure cognitive gains demonstrated by participants on an exit survey after correcting for participants' cognitive knowledge demonstrated on an introductory survey. After raw scores were converted to transformed standard scores, "training method" was used as the independent variable, exit survey scores were used as the dependent variable and pre-assessment scores were used as the covariant. The data was compared using an ANCOVA (Elzey, 1985) and the results reported in Table 4.9. Participants in both traditional and simulated environments demonstrated a significantly higher level, significant at $p < .01$, of cognitive gain than did participants in the virtual reality training group. The null hypothesis was rejected but further testing is needed to clarify if the results are due to the training environment or due to the lack of information given to trainees exposed to virtual reality training environments.

Null hypothesis 1.2 states that *there is no statistically significant difference in the number of training questions asked by individuals exposed to traditional, simulated and virtual reality training environments.* Individuals exposed to simulation and virtual reality training environments needed to learn how to function within the training environment as well as learn the intended content and robot manipulation. The principal investigator was interested in knowing if certain types of questions were more frequent in a particular training environment. To analyze this possibility, the original null hypothesis was broken into four subcomponents which include: a) *there is no statistically significant difference in the number of training environment questions asked by individuals exposed to traditional, simulation or virtual reality training environments;* b) *there is no statistically*

Table 4.9 ANCOVA training method and cognitive gain

Source:	Degrees of Freedom:	Sum of Squares:	Mean Square:	F-test:
Between groups	2	1161.396	580.698	8.563
Error	32	2169.982	67.812	p < .01
Total	34	3331.379		

Group:	Count:	Mean of Introductory Survey	Mean of Exit Survey	Adjusted Mean of Exit Survey
Traditional	13	52.747	54.133	53.919
Simulation	10	49.351	54.547	54.598
Virtual Reality	13	47.752	42.063	42.238

N = 36

significant difference in the number of training content/robot related questions asked by individuals exposed to traditional, simulation or virtual reality training environments; c) *there is no statistically significant difference in the number of training environment questions in the number of other training questions asked by individuals exposed to traditional, simulation or virtual reality training environments;* d) *there is no statistically significant difference in the total number of questions relative to training asked by individuals exposed to traditional, simulation and virtual reality training environments.* These hypotheses are designed to measure the cognitive gains made by trainees in system operations that aren't measured by the written exit survey.

Evidence of learning was indicated as study participants asked questions about the training environment, training content, or other questions. Training environment questions included how to change views in simulations, if one could sit down or had to remain standing in the virtual environment or how to focus the head mounted display. Training content and robot questions were asked about what to do with the simulated ball after it was picked up or wondering why robots would not move when they had reached their range of motion limits. "Other" questions could have included relevant items such as what the final assessment was like or irrelevant items like those regarding training time slots for friends. All questions participants asked were relevant to the training so the "training environment", "training content", and "other" categories were added for an indication of "total learning". Questions asked were tallied and raw scores were converted to transformed standard scores with a mean of 50 and a standard deviation of 10. ANOVAs were run using "training method" as the independent variable while "training environment questions" were used as the dependent variable. This process was repeated with "training method" as the independent variable and each of the "content/robot" data, the "other questions" data and the "total relevant" data used as the dependent variable in respective ANOVAs. The data is summarized in Table 4.10.

Variances between and within the groups were measured and compared using the F distribution as the sampling distribution. The probability (p value) that

Table 4.10 ANOVA for X_1: training method and Y_1: questions asked

#	Questions Asked	Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	48.999	9.365	Trad vs. Sim	-1.151
10	Simulation	50.150	10.515	Trad vs. VR	-1.918
13	Virtual Reality	50.917	10.936	Sim vs. VR	- .767
		F-test: .115	p = .8921		
#	Content/Robot			Mean Difference	
13	Traditional	49.783	9.905	Trad vs. Sim	- .824
10	Simulation	50.607	11.294	Trad vs. VR	0.000
13	Virtual Reality	49.783	9.905	Sim vs. VR	.824
		F-test: .023	p = .9772		
#	Other Questions			Mean Difference	
13	Traditional	52.530	13.412	Trad vs. Sim	5.495
10	Simulation	47.036	°	Trad vs. VR	2.747
13	Virtual Reality	49.783	9.905	Sim vs. VR	-2.747
		F-test: .849	p = .4369		
#	Total Relevant Questions			Mean Difference	
13	Traditional	50.398	10.969	Trad vs. Sim	1.427
10	Simulation	48.971	8.146	Trad vs VR	0.000
13	Virtual Reality	50.398	10.969	Sim vs. VR	-1.427
		F-test: .07	p = .9329		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

questions asked during training by participants exposed to traditional, simulated and virtual reality environments was high in all areas and the null hypothesis was accepted. There is not a statistically significant difference in the number of questions asked by participants exposed to traditional, simulated and virtual reality training methods.

Null hypothesis 1.3 states that *the amount of time needed to learn a specific task does not differ with significance for individuals trained in traditional, simulated and virtual environments.* This hypothesis is designed to measure kinesthetic gains in various training environments. Does the training method affect how quickly skills are acquired? It was assumed that participants will be self-directed enough to train until they feel competent to perform tasks using a real robot. Differences in training time will reflect how quickly participants become confident in their abilities. The exception to this is the individuals involved in "traditional" training. Training time in this environment was dictated by the trainer and competency had no bearing on training time. Raw scores were converted to transformed standard scores with a mean of 50 and a standard deviation of 10. "Training method" was used as the independent variable while "training time" was used as the dependent variable and the results from the ANOVA are shown in Table 4.11. Variances were compared using the F distribution and the p value did not exceed the critical level. The null hypothesis was accepted. The amount of time it takes individuals to learn a specific task does not differ with statistical significance for individuals trained in traditional, simulated or virtual reality training environments.

Table 4.11 ANOVA X_1: training method and Y_1: training time

Training Time	Transformed Standard Mean	Standard Deviation	Comparison	
Training Environment			Mean Difference	
Traditional	48.859	0.000	Trad vs. Sim	-6.294
Simulation	55.152	9.740	Trad vs. VR	-1.336
Virtual Reality	47.493	14.355	Sim vs. VR	7.666
	F-test: 1.804	p = .1805		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

Null hypothesis 1.4 states that *there is no statistically significant difference in final performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots.* This hypothesis is designed to measure both kinesthetic gains and application of cognitive knowledge in a real application. In other words, does the training method affect final task time? Participants were told to take as much time as the accuracy of the robot and their patience would allow. It was assumed that trainees with more skill would take less time to complete the final task. Raw scores were converted to transformed standard scores with a mean of 50 and a standard deviation of 10. "Training method" was used as the independent variable and "final task time" was

Table 4.12 ANOVA X_1: training method Y_1: final task time

Final Task Time		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	47.846	10.800	Trad vs. Sim	-2.654
10	Simulation	50.500	7.246	Trad vs. VR	-3.923
13	Virtual Reality	51.769	11.256	Sim vs. VR	-1.269
		F-test: .503	p = .609		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

the dependent variable. Data was compared using ANOVA and is summarized in Table 4.12. The F distribution was used as the sampling distribution and the p value was calculated. The null hypothesis was accepted since the critical .90 level was not exceeded. There is not a statistically significant difference in final pick-and-place task time using a robot for individuals exposed to traditional, simulation and virtual reality training methods.

Null hypothesis 1.5 explores the assumption that the total amount of training time may be impacted by the training method. Thus, an increase in training time may result in a decrease in performance time or vice versa. While the individual training or performance times might not differ significantly, perhaps the cumulative time would show a difference. A correlation coefficient comparing training time to final task time was -.092 with $R^2 = .009$ showed little linear relationship between training time and performance time. The null hypothesis, *there is not a statistically significant difference in the "total time" scores of individuals trained using traditional methods, simulations and virtual reality*, was formulated to determine if "training method" influenced "total time". "Training method" was used as the independent variable while the sum of the "training time" and "final performance time" were added together as the dependent variable in a one-way ANOVA. These scores were normalized (after being summed) with a mean of 50 and standard deviation of 10 to conform to statistical analyses used throughout this study. The results, shown in Table 4.13, show that the p value does not exceed the critical level. The null hypothesis, that there is not a statistically significant difference in the "total time" scores of individuals exposed to traditional, simulation and virtual reality training methods, was accepted.

Null hypothesis 1.6 states that *there is not a statistically significant difference between task accuracy scores of individuals trained using traditional methods, simulation methods and virtual reality methods.* Does the method of training affect kinesthetic gains in trainees? This hypothesis is designed to address this question. Analysis of the thirty eight original data scores showed that three of the accuracy measurements were questionable as outliers. One score of 141, one score of 168 and one score of 341 were examined. Accuracy scores had a mean of 52.946 with a standard deviation of 58.51. The score of 141 was 1.505

Table 4.13 ANOVA X_1: training method Y_1: total time

Total Time		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	47.455	7.896	Trad vs. Sim	-6.659
10	Simulation	54.111	9.507	Trad vs. VR	-1.926
13	Virtual Reality	49.380	11.832	Sim vs. VR	4.733
		F-test: 1.315	p = .282		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

standard deviations from the mean while the score of 168 was 1.966 standard deviations from the mean. The pick-and-place accuracy scores of 141 and 168 were retained while the score of 341 was considered an outlier and the results from this individual were not analyzed as part of this study. Final results are shown in Table 4.14. P scores were derived using the F distribution as the sampling distribution. Since the p score did not exceed the critical .90 level, the null hypothesis was accepted. There was not a statistically significant difference in task accuracy scores for individuals exposed to traditional, simulated or virtual reality training methods.

Null hypothesis 1.7 states that *there is not a statistically significant difference in the final performance scores of individuals trained using traditional*

Table 4.14 ANOVA X_1: training method Y_1: task accuracy

Task Accuracy		Transformed Standard Mean	Standard Deviation	Comparison	
	Training Environment			Mean Difference	
13	Traditional	52.000	12.356	Trad vs. Sim	.300
10	Simulation	51.700	10.467	Trad vs. VR	5.308
13	Virtual Reality	46.692	5.822	Sim vs. VR	5.008
		F-test: 1.142	p = .3316		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

methods, simulations and virtual reality. This hypothesis measures whether the training method has an impact on an individual's overall performance. "Training method" was used as the independent variable while the sum of training time, performance time, accuracy scores and knowledge gained is used as the dependent variable in a one way ANOVA. Since larger training times, larger performance scores and larger accuracy scores indicate worse rather than better performance, these numbers were inverted. These scores were already transformed to standard scores with a mean of 50 and a standard deviation of 10, so inverting them was a matter of subtracting the transformed standard score from 100 to get the inverted standard score. These inverted standard scores were

Table 4.15 ANOVA X_1: training method Y_1: final performance scores

Final Performance Scores		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	52.527	9.628	Trad vs. Sim	3.629
10	Simulation	48.899	12.500	Trad vs. VR	4.207
13	Virtual Reality	48.320	8.414	Sim vs. VR	.578
		F-test: .646	p = .5307		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

added to transformed "cognitive knowledge" scores for an overall performance score and the results shown in Table 4.15. Once again the variances were compared using the F distribution and a p value, not exceeding the critical .90 level, was calculated. The null hypothesis, there is not a statistically significant difference in overall performance scores for individuals exposed to traditional, simulation and VR training environments was supported.

Null hypothesis 1.8 states that *there is not a significant correlation between an individual's internal immersion score and their final performance score.* Does the amount of immersion in a training environment affect an individual's final performance? This hypothesis was formulated to address this question. Since final performance scores were standardized, the internal immersion scores were also standardized with a mean of 50 and a standard deviation of 10. The null hypothesis, there is not a statistically significant correlation between an individual's internal immersion score and their final performance score, was upheld when a correlation coefficient of .0862 with R-squared of .0074 was determined. This low correlation coefficient with only .7% of variance explained by the internal immersion score did not warrant further investigation.

Null hypothesis 1.9 states that *there is not a significant correlation between a individual's external immersion score and their final performance score.* Does the amount of "presence" in a training environment affect an individual's final performance? This hypothesis was formulated to address this question. Presence scores were standardized, with a mean of 50 and a standard deviation of 10, and a correlation coefficient was obtained. The null hypothesis was upheld when a correlation coefficient of -.1724 with R-squared of .0297 was determined. This low correlation coefficient, with only 2.9% of the variance in final performance scores explained by the amount of external immersion, did not warrant further investigation. There was no correlation between an individual's final performance score and the amount of external immersion (or presence) they experienced during training.

Null hypothesis 1.10 states that *there is not a statistically significant correlation between an individual's total immersion score and their final performance score.* Does the total amount of realism in a training environment, as indicated by immersion and presence, affect an individual's final performance?

This hypothesis was formulated to address this question. Since final performance scores were normalized, the presence and immersion scores were also normalized after they were added together. The null hypothesis was upheld when a correlation coefficient of -.0331 with R-squared of .0011 was determined. The null hypothesis, there is not correlation between a person's final performance score and a person's total immersion score, was supported. The low correlation coefficients between variables did not warrant further investigation within this study.

The second part of this study examined how learning styles or differences in individuals, as opposed to differences in training environments, affected performance.

Null hypothesis 2.1 states that *there is not a statistically significant difference between the final performance scores of individuals enrolled in Engineering and individuals enrolled in Industrial Technology or other majors of study at Iowa State University.* Does a person's major of study reflect a certain learning style which may or may not affect learning in virtual, simulated or traditional training environments? A one way ANOVA was run using "major of study" as the independent variable and the standardized "final performance scores" as the dependent variable. Results, shown in Table 4.16, show that the p score derived from the F-test did not exceed the critical level. The null hypothesis was supported. There was not a statistically significant difference in final performance scores for individuals exposed to traditional, simulated and virtual reality training environments.

Table 4.16 ANOVA X_1: major of study Y_1: final performance scores

#	Major of Study	Transformed Standard Mean	Standard Deviation	Comparison Mean Difference	
27	ME	51.582	8.613	ME vs IT	5.966
4	IT	45.616	7.626	ME vs OTH	6.613
5	OTH	44.968	16.775	IT vs OTH	.647
		F-test: 1.385	p = .2645		

N = 36

DF:	Between groups	2	ME = Mechanical Engineering
	Within groups	33	IT = Industrial Technology
	Total	35	OTH = Other

Null hypothesis 2.2 states that *individual learning styles have no statistical correlation with final performance scores among trainees participating in this study.* There was not one score for the "Learning Style Inventory" administered to study participants. Scores given for five major domains with subscales under each domain. Correlation coefficients were run for each of the subscales. The results are shown in Table 4.17.

Examination of the table shows that there was a slight positive correlation between the "Data" category and final performance scores. This indicates that people who like working with facts and figures may have better "final performance"

Table 4.17 Final performance score and learning style subcomponent correlation

Physical Domain	Correlation	R-squared
Kinesthetic	.0331	.0011
Visual	.1908	.0364
Tactile	-.1308	.0171
Auditory	.1962	.0385
Social Domain		
Group	.1020	.0104
Individual	-.1227	.0151
Environmental Domain	Correlation	R-squared
Design/Formal	.3234	.1046
Design/Informal	-.3340	.1115
Well Lit	.0842	.0071
Dimly Lit	-.0340	.0012
Cool Temperature	-.2150	.0462
Warm Temperature	-.0299	.0009
Without Sound	.1675	.0281
Noisy	-.1558	.0243

N = 36

R^2 = amount of "variance in one variable that is associated with the other variable" (Hinkle et. al, 1994, p. 119)

Table 4.17 (continued)

Mode of Expression		
Oral	-.0682	.0046
Written	.0469	.0022
Work Characteristics		
Outdoors	-.0904	.0082
Indoors	-.0694	.0048
Sedentary	.1029	.0106
Non-sedentary	.1014	.0103
Lifting	.0967	.0094
Non-lifting	.0469	.0022
Data	.3997	.1597
People	-.1154	.0133
Things	.2035	.0414

scores. There is also a slight negative correlation between the "Informal Design" category which corresponds to a slight positive correlation between the "Formal Design" category and final performance scores. The individuals who like a formal learning setting such as straight chairs, tables and desks may be the same individuals who dislike the informal learning environments with soft chairs, couches and pillows. Common sense suggests that students enrolled in a university are accustomed to the formal learning setting and are comfortable within this environment.

Overall there was minimal correlation between learning styles and final performance scores and thus the null hypothesis is supported. The lack of significant correlations may be the result of a homogenous group with similar learning styles which may be an accurate reflection of the university environment.

Null hypothesis 2.3 states that *there is not a statistically significant difference between an individual's major of study and any of the"Learning Style Inventory" scores among trainees participating in this study.* The "Learning Style Inventory" groups 25 different elements under five domains which describe an individual's preference for learning environments. A one-way ANOVA was run for all of the 25 elements of the *Learning Style Inventory* and the results are shown in Table 4.18.

There was a significant difference ($p = .054$) in kinesthetic learning styles between the Mechanical Engineering group and the Industrial Technology group. There was also a significant difference between the Mechanical Engineering group and the "Other" group for "Oral Expression". The null hypothesis was rejected because a difference in learning styles is demonstrated at a significant level by students enrolled in different majors of study at Iowa State University.

Discussion

Ten hypotheses were formulated and tested to find significant differences among learners who were exposed to three different training methods on the trainee-trainer-technology continuum (Figure 2.1). Three more hypotheses were formulated to determine if internal or external factors affected an individual's skill

Table 4.18 ANOVA X_1: major of study Y_1: learning style indicators

#	Major of Study	Transformed Standard Mean	Standard Deviation	Comparison	
			Physical Domain		
#	Kinesthetic			Mean Difference	
27	ME	51.984	9.367	ME vs IT	3.469
4	IT	48.515	11.516	ME vs OTH	11.498*
5	OTH	40.486	7.979	IT vs OTH	8.029
		F-test: 3.193	p = .054		
		*Significant at 90% Fisher PLSD and Scheffe F-test			
#	Visual			Mean Difference	
27	ME	50.354	11.155	ME vs IT	1.060
4	IT	49.294	6.359	ME vs OTH	1.696
5	OTH	48.658	5.688	IT vs OTH	.636
		F-test: .0681	p = .934		
#	Tactile			Mean Difference	
27	ME	50.740	9.513	ME vs IT	5.169
4	IT	45.571	12.648	ME vs OTH	1.182
5	OTH	49.558	11.959	IT vs OTH	-3.988
		F-test: .4566	p = .637		

N = 36

Source:

Between groups	2
Within groups	33
Total	35

ME = Mechanical Engineering
IT = Industrial Technology
OTH = Other

Table 4.18 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Auditory			Mean Difference	
27	ME	48.639	9.087	ME vs IT	-2.505
4	IT	51.244	7.383	ME vs OTH	-7.720
5	OTH	56.359	15.265	ME vs OTH	-5.115
		F-test: 1.3148	p = .282		
		Social Domain			
#	Group			Mean Difference	
27	ME	49.677	9.073	ME vs IT	5.910
4	IT	43.767	14.679	ME vs OTH	-7.055
5	OTH	56.732	9.058	IT vs OTH	-12.964
		F-test: 2.0383	p = .146		
#	Individual			Mean Difference	
27	ME	50.153	9.367	ME vs IT	1.834
4	IT	48.319	11.516	ME vs OTH	-3.668
5	OTH	50.520	7.979	IT vs OTH	-2.201
		F-test: .0629	p = .939		
		Environmental Domain			
#	Formal Design			Mean Difference	
27	ME	50.900	10.037	ME vs IT	5.878
4	IT	45.022	3.734	ME vs OTH	1.770
5	OTH	49.130	13.360	IT vs OTH	-4.108
		F-test: .6100	p = .549		

Table 4.18 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Informal Design			Mean Difference	
27	ME	48.930	10.377	ME vs IT	-3.742
4	IT	52.672	6.143	ME vs OTH	-4.705
5	OTH	53.635	10.737	IT vs OTH	- .962
		F-test: .6141	p = .5472		
#	Bright Lights			Mean Difference	
27	ME	49.857	9.522	ME vs IT	1.432
4	IT	48.425	10.733	ME vs OTH	- 2.177
5	OTH	52.034	13.835	IT vs OTH	- 3.609
		F-test: .1483	p = .863		
#	Dim Lights			Mean Difference	
27	ME	50.545	9.894	ME vs IT	2.476
4	IT	48.069	6.906	ME vs OTH	1.942
5	OTH	48.604	13.949	IT vs OTH	- .535
		F-test: .1556	p = .857		
#	Warm Temperature			Mean Difference	
27	ME	50.920	9.763	ME vs IT	- 2.241
4	IT	53.161	6.214	ME vs OTH	8.377
5	OTH	42.543	11.893	IT vs OTH	10.617
		F-test: 1.7796	p = .185		

Table 4.18 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Cool Temperature			Mean Difference	
27	ME	48.540	9.371	ME vs IT	- 1.603
4	IT	50.143	8.819	ME vs OTH	- 9.240
5	OTH	57.780	12.472	IT vs OTH	- 7.637
		F-test: 1.894	p = .167		
#	With Sound			Mean Difference	
27	ME	50.466	8.496	ME vs IT	3.379
4	IT	47.087	15.075	ME vs OTH	.653
5	OTH	49.813	15.007	IT vs OTH	-2.727
		F-test: .1907	p = .827		
#	Without Sound			Mean Difference	
27	ME	48.889	9.132	ME vs IT	-6.993
4	IT	55.882	10.509	ME vs OTH	-2.398
5	OTH	51.287	14.297	IT vs OTH	4.595
		F-test: .8944	p = .4185		
		Mode of Expression			
#	Oral			Mean Difference	
27	ME	47.904	10.208	ME vs IT	-8.206
4	IT	56.110	8.138	ME vs OTH	-8.523*
5	OTH	56.434	5.410	IT vs OTH	- .324
		F-test: 2.5907	p = .0901		

*Significant at 90% Fisher PLSD

Table 4.18 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Written			Mean Difference	
27	ME	51.662	9.346	ME vs IT	8.938
4	IT	42.724	8.284	ME vs OTH	4.815
5	OTH	46.847	13.106	IT vs OTH	-4.123
		F-test: 1.7524	p = .1891		
		Work Characteristics			
#	Outdoors			Mean Difference	
27	ME	49.372	9.281	ME vs IT	3.443
4	IT	45.947	16.679	ME vs OTH	- 7.255
5	OTH	56.627	5.707	IT vs OTH	-10.680
		F-test: 1.5238	p = .234		
#	Indoors			Mean Difference	
27	ME	50.683	10.336	ME vs IT	3.668
4	IT	47.016	10.071	ME vs OTH	1.989
5	OTH	48.694	9.4946	IT vs OTH	-1.678
		F-test: .272	p = .764		
#	Sedentary			Mean Difference	
27	ME	50.060	9.367	ME vs IT	1.334
4	IT	48.727	11.516	ME vs OTH	- .630
5	OTH	50.691	7.979	IT vs OTH	- 1.964
		F-test: .0424	p = .959		

Table 4.18 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Non-sedentary			Mean Difference	
27	ME	49.506	9.942	ME vs IT	.826
4	IT	48.680	12.260	ME vs OTH	- 4.229
5	OTH	53.734	9.9514	IT vs OTH	- 5.055
		F-test: .4023	p = .672		
#	Lifting			Mean Difference	
27	ME	50.107	10.315	ME vs IT	- .864
4	IT	50.971	9.519	ME vs OTH	1.468
5	OTH	48.639	10.589	IT vs OTH	2.332
		F-test: .0631	p = .939		
#	Non-lifting			Mean Difference	
27	ME	51.211	9.829	ME vs IT	.757
4	IT	50.455	12.077	ME vs OTH	8.109
5	OTH	43.102	8.260	IT vs OTH	7.353
		F-test: 1.4254	p = .255		
#	Data			Mean Difference	
27	ME	50.883	9.367	ME vs IT	8.592
4	IT	48.340	11.516	ME vs OTH	11.432
5	OTH	46.549	7.979	IT vs OTH	16.567
		F-test: .4434	p = .646		

Table 4.18 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	People			Mean Difference	
27	ME	48.956	9.488	ME vs IT	- 4.037
4	IT	52.993	11.374	ME vs OTH	- 4.294
5	OTH	53.250	12.772	IT vs OTH	- .257
		F-test: .5761	p = .568		
#	Things			Mean Difference	
27	ME	50.499	9.747	ME vs IT	- 1.820
4	IT	52.319	5.674	ME vs OTH	5.060
5	OTH	45.440	14.157	IT vs OTH	6.880
		F-test: .6477	p = .5298		

N = 36

acquisition. The resulting data was subjected to statistical analysis and the null hypotheses either accepted or rejected.

Accepting or rejecting null hypotheses was a relatively simple task based on the mathematical p scores which resulted from statistical analysis. Explaining why these results occurred is more difficult. Many of the null hypotheses formulated were rejected. There are several reasons that this may have happened. First, the sample population used in this study was small; a larger population may be needed to demonstrate the effectiveness of different training methods. Second, the sample population had little variance in learning styles and in the stated major of study. A more varied population may be needed to demonstrate the effectiveness of the three different methods of training. Third, the indicators used to demonstrate skill acquisition may not be as effective as the principal investigator assumed they would be. Refinement of both assessment and analysis instruments may be needed. It may also be true that this study accurately reflects the current state of traditional, simulation and virtual reality training methods and the training results indicative of each approach.

Study results showed that individuals trained using traditional and simulation training methods made significantly greater cognitive gains than the individuals trained using virtual reality. When factual information needs to be conveyed, virtual reality would not be the indicated training choice. These results may also reflect the fact that participants exposed to the virtual reality training environment did not receive the training objectives. Part two of this study will help determine if virtual reality is ineffective for developing cognitive skills or if statistical differences really exist.

The number of questions asked during training did not prove to be a good indicator of learning among this group of participants. Either the sample was to small to detect a significant difference or trainees with radically different computer backgrounds would need to be compared. Training environment questions, training content questions, other training related questions and the total relevant questions did not reach a level of significance and will be eliminated as a learning indicator in further studies.

While the amount of time needed to learn a specific task did not reach statistical significance the results have implications for training applications. The average training time was the lowest in virtual reality environments (mean 47.493) and highest for simulations (mean 55.152). Traditional method training time fell in between these two (mean 48.859) and could have varied with depth of content, trainer-trainee interaction, or decisions made by training institutions had they been involved. This demonstrates that participants exposed to virtual reality training methods can learn content and operate within a virtual reality training environment without having any prior VR experience. Participants exposed to traditional methods had 0 variance in their training time since training time was dictated by the trainer. Zero variance in training time assumes that all trainees learn the intended content within the specified training time and may not be the best training practice. Participants exposed to virtual reality training methods had greater training time variance but overall demonstrated the ability to complete their training within a time frame that is competitive with traditional training techniques.

Participants exposed to simulation training methods had a higher mean training time than did the participants exposed to traditional and virtual reality methods. While this did not reach the predetermined .90 significance level, it would have been statistically significant at a .80 level. The probability that 80% of a company's workforce would take longer to complete training using simulations instead of traditional or virtual reality training methods would impact the way training was delivered within the company. This higher mean among participants exposed to simulation training methods may also reflect a trainee's ability, or lack of ability, to get help within a training environment. Participants exposed to traditional training methods can get feedback from the trainer. Participants exposed to virtual reality training methods enter an intuitive environment where cause-and-effect is evident. Participants exposed to this simulation environment had to contend with a human-computer interface without an intelligent tutoring system built in and without a trainer available to answer training questions. Developing an intelligent tutoring system for use within both simulation and virtual environments may be useful for reducing training time and is an area for further study.

The difference between training times may also be the result of inadequate training practices. Participants assigned to the VR training method did not receive the training objectives. This may have increased VR training time scores as participants tried to analyze the purpose of the training; the low "training time" suggests that participants left the VR training environment because there was no apparent purpose for their being there. The revised study will help identify the variances in training time.

Null hypothesis 1.4, *there is no statistically significant difference in performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots*, was accepted. Neither the means nor the standard deviations were statistically different from one another to indicate statistical significance or have a large impact on training decisions. The principal investigator assumed that training competence and skill, developed during training, would cross over to final performance times. This did not happen. Participants were allowed to take as much time as they needed to complete the pick-and-place robot task. Extraneous variables, such as an individual's desire to complete the tasks with an accuracy that exceeded the robot's capabilities, or an individual's schedule that required them to quit the pick-and-place task early, affected the measurement of final performance time. "Final performance time", as structured, was not a satisfactory measure of performance. Future studies should include task accuracy within a given amount of time which is set at a predetermined level. This would more accurately reflect how well trainees reach competency levels within different training environments. The principal investigator would be reluctant to drop this as an assessment criterion because it is relevant to industrial productivity and it as a part of the "total time" scores which do have some relevance to training. Further investigation, and an examination of data from the revised study, is needed before including or deleting this variable as a measure of performance in other studies.

"Total time", training time plus final performance time, did not reach a statistically significant level but it does have implications for training. The lowest mean total time (47.455) was indicated for participants exposed to traditional training environments. Participants exposed to virtual reality training methods had a mean "total time" of 49.380 while participants exposed to simulation had a mean "total time" of 54.111. The null hypothesis was accepted because a significance level of .90 was not reached. If one assumes that "total time" represents the time it takes to complete training and reach competent task performance, then business and industry would take note of the "total time" score. A 70% chance that employees would spend longer in simulation training environments and developing task competence would lead employers to choose traditional techniques for delivering training. This seems like an easy training decision to make until two other factors are considered.

Two variables may have influenced the outcome of null hypothesis 1.5 which examines the effect of training method on final performance time. Training objectives were not supplied to participants exposed to the VR training method resulting in trainees spending less time in the VR training environment than in other training environments. If this trend holds true in the revised portion of the study then low "total time" scores will be acknowledged as a benefit of traditional training for this study. The sample in this study was a group of university students the majority of whom are enrolled in Engineering courses. They are being trained to visualize complex interactions within their mind and design or analyze mechanisms that work within given parameters. These visualization skills may be the same ones needed to succeed in traditional training environments. A more diverse population will need to be examined to determine if engineering skills cross over to traditional training techniques and impact final performance scores.

Task accuracy scores were of particular interest to the principal investigator because many VR applications address this type of training. Astronauts were trained to replace lenses on the Hubble telescope using a VR application. Airplane pilots are taught to fly in simulators. Industry usage seems to indicate that this is where VR and simulation strengths lie. Yet the null hypothesis in this study was accepted because the probability of increasing task accuracy using simulation or virtual reality was only 66%. These are similar to results found in other studies. There is a trend within the task accuracy scores that warrants further attention from a training perspective.

The mean score for task accuracy for participants exposed to traditional training methods was 52.000. Simulation task accuracy scores had a mean of 51.700 while virtual reality task accuracy scores had a mean of 46.692. All of these scores hover around the transformed standard mean and look unremarkable. The benefits of utilizing simulation and virtual reality training methods are better understood when looking at the respective standard deviations of the different training methods. Variance in traditional environments is twice as high as variance in virtual reality training environments. As trainees are exposed to training technologies that involve less trainer input, that require more trainee input and utilize more technology, variances among trainees decrease around the mean. This concept is presented in Figure 4.2. This author contends that no study will show a significant difference in task accuracy scores as they relate to training method because variances narrow around the same hypothetical mean with traditional training methods encompassing all others with the largest variance. It is this trend that makes simulation and virtual reality training environments useful for business and industry training applications. This theory will have to be tested in future studies.

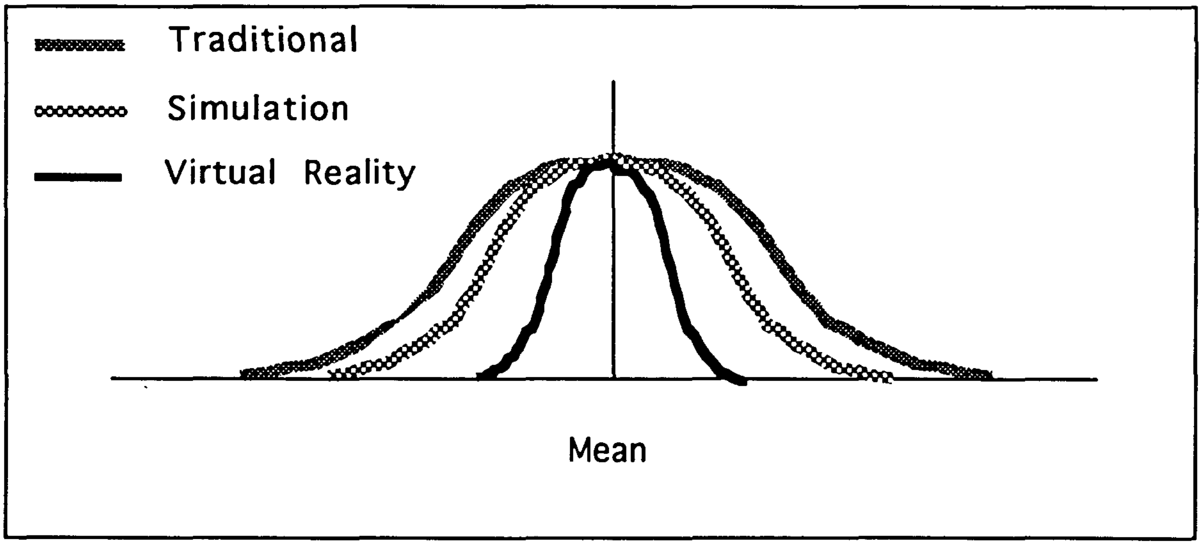


Figure 4.2 Standard deviations for task accuracy and different training methods

There was not a statistically significant difference in final performance scores for individuals exposed to traditional, simulation and virtual reality training methods. The homogeneous nature of the sample population and small sample size may be one explanation for this result. Indicators of performance should also be examined for their merit and either used or discarded in future studies. These results may also reflect the fact that virtual reality environments, and perhaps simulation environments, help overcome the results of poor training. Virtual reality trainees had no idea what the training objectives were yet they still performed well enough to compete statistically with trainees from simulated and traditional environments. These results may also reflect the self-directedness of this particular group of participants and may not apply to sample populations who are less self-motivated.

Internal immersion scores, the amount individuals become immersed in a task, had little correlation with final performance scores. The Virtual Environment Performance Assessment Battery (VEPAB) was designed to measure immersion as it related to individuals moving through a virtual environment while this study measured performance of individuals as they acted upon an environment. The immersion questionnaire portion of the VEPAB was also administered to trainees exposed to simulated and traditional training environments. The VEPAB was not designed for traditional and simulated environments and the immersion assessment is still being refined which means that the VEPAB may not be an accurate assessment of internal immersion in this training environment. It is also possible that the sample population is too small for any correlation to be evident. The internal immersion score was not considered significant enough to warrant further investigation within this study.

Researchers are worried about the realism their simulations and virtual environments entail. Some researchers design computer applications as realistic as possible while other researchers contend that a simulated or virtual environment need only be detailed enough to convey information needed for training. The level of "detail needed" could vary greatly from application to application and was not addressed within the parameters of this study. Presence scores may help determine this level of need but within this study participants scores were unaffected by the external environment used to deliver training. There was very little correlation (R-squared = .0297) between the amount of realism, measured by the "total presence" score, and final performance scores. Results from this study indicate that neither the internal immersion scores nor the external presence variables, alone or in combination, had any association with the final performance scores. The Virtual Environment Performance Assessment Battery (VEPAB) was designed to measure presence as it related to individuals moving within a virtual environment while this study measured performance of individuals as they acted upon an object.

The VEPAB was also administered to trainees exposed to simulated and traditional training environments which the VEPAB was not designed for. Using the VEPAB out of context and the fact that the VEPAB is still being refined are admittedly limitations of this study. It is also possible that the sample population is too small or too uniform for any correlation to be evident. While the VEPAB assessments may be kept in place in future studies the test instrument may need to be refined or its subcomponent scores examined for better indicators of affect.

Individual differences may have some impact on training effectiveness. Participants enrolled in "Industrial Technology" and "Other" majors showed little mean difference (.647) in the "major of study" versus "final performance " score correlation. There was a greater mean difference between the "Industrial Technology" group and the "Mechanical Engineering" group (5.966) as well as a greater mean difference between the "Mechanical Engineering" group and "Other" group (6.613). These scores did not reach the .90 significance level but the probability of a trainee's major of study correlating with final performance scores 74% of the time may be of interest to training professionals. It may be possible that

"Major of Study" is indicative of an internal factor that effects performance. More studies are needed to determine if there is a relationship between these two variables.

The lack of any statistically significant correlation between "Learning Style" scores and "final performance scores" can be attributed to similarities in learning styles among the participants used in this study. The "Learning Styles Inventory" (LSI) indicated if individuals had a predominant or "major" learning style as well as indicated "minor" learning styles. Two thirds of the participants utilized several, minor learning styles instead of having one, strong learning style. Correlations between learning styles and final performance scores will be weak since there is not much variation in learning styles. A more diverse group with more diverse learning styles or a second group from outside the university needs to be examined for the effect of learning styles on final performance scores.

The fact that there is a statistically significant difference between the "Industrial Technology" group and the "Other" group for a kinesthetic learning style is of interest to the principal investigator. There is also a significant difference in the "Oral" mode of expression between these two groups. Is it possible that these learning style differences, significant at the .90 level, are related to the changes in task accuracy scores exhibited in the study? People with higher kinesthetic scores, learning through active involvement, may be able to complete pick-and-place tasks easier than others. Perhaps simulation and virtual reality training environments are interacting with learning styles to reduce variance as shown within this study.

It is necessary to collect more data, over a broader range of trainees, with more varied backgrounds to find interactive patterns between learning styles and training method variables.

Population and Sample - Revised Study

Demographics of the revised study were a combination of volunteers from the first study, who completed the traditional and simulation training portions of the study within specified parameters, and new volunteers recruited for the virtual reality portion of the study. Twenty-one new participants were recruited from undergraduate Mechanical Engineering and Industrial Technology courses at Iowa State University in Ames, Iowa. These students were targeted because they had little or no robot experience, because they had the potential of demonstrating differing learning styles and because this maintained consistency with the first part of the study. The student volunteers spent two to three hours participating in this study and were reimbursed at a rate of six dollars per hour for their time.

Thirty-seven of the fifty original participants completed the study within the specified parameters as noted in the *Population and Sample - Original Study* section of this paper. These were added to the twenty-one new recruits to make up the revised study sample which now included fifty-eight individuals. The process of eliminating individuals who did not complete the study within the specified study parameters or eliminating data with outliers was begun. A parallel process like that described in the *Population and Sample - Original Study* section, the *Original*

Demographic Description and the *Population and Sample -Revised Study* section of this paper was applied to the new sample.

Data from the thirteen participants assigned to the virtual reality training method in the original study were removed from the data in the revised study. This left twenty-four of the original participants, assigned to "traditional" or "simulation" training environments in place. Of the twenty-one new recruits, two were trained in an updated version of the VR training environment which violated study parameters and they were removed from the study. One new recruit failed to give enough data for comparison while four new recruits failed to participate in the final evaluation session. Fourteen new recruits were added to the twenty four original recruits to make a total of thirty-eight participants that completed the study within the specified parameters of the revised study.

Verifying that the assumptions made regarding the participants in this study were accurate (see pages 40 and 41) was important. Gist, Schwoerer and Rosen (1989) found that people with high computer self-efficacy performed better in computer software training than people with low computer self-efficacy. Robinson-Staveley and Cooper (1990) described how gender and the presence of other people affected an individual's performance in human-computer interactions. The *Population and Sample - Revised Study* section of this paper describes the methods used to determine that the assumptions made on pages 40 and 41 of this paper applied to the revised study participants.

Revised Study - Demographic Description

Demographics of the revised sample changed after data regarding participants' performance was examined. The principal investigator became concerned when one participant's accuracy scores, a subcomponent of the final performance score, of 341 millimeters was found to be 3.98 standard deviations above the sample mean. All five subcomponent scores (including training time, task accuracy, robot pick-and-place task time, questions asked during training, and identification of robot parts) were examined for further outliers. Figure 4.3 is a bar

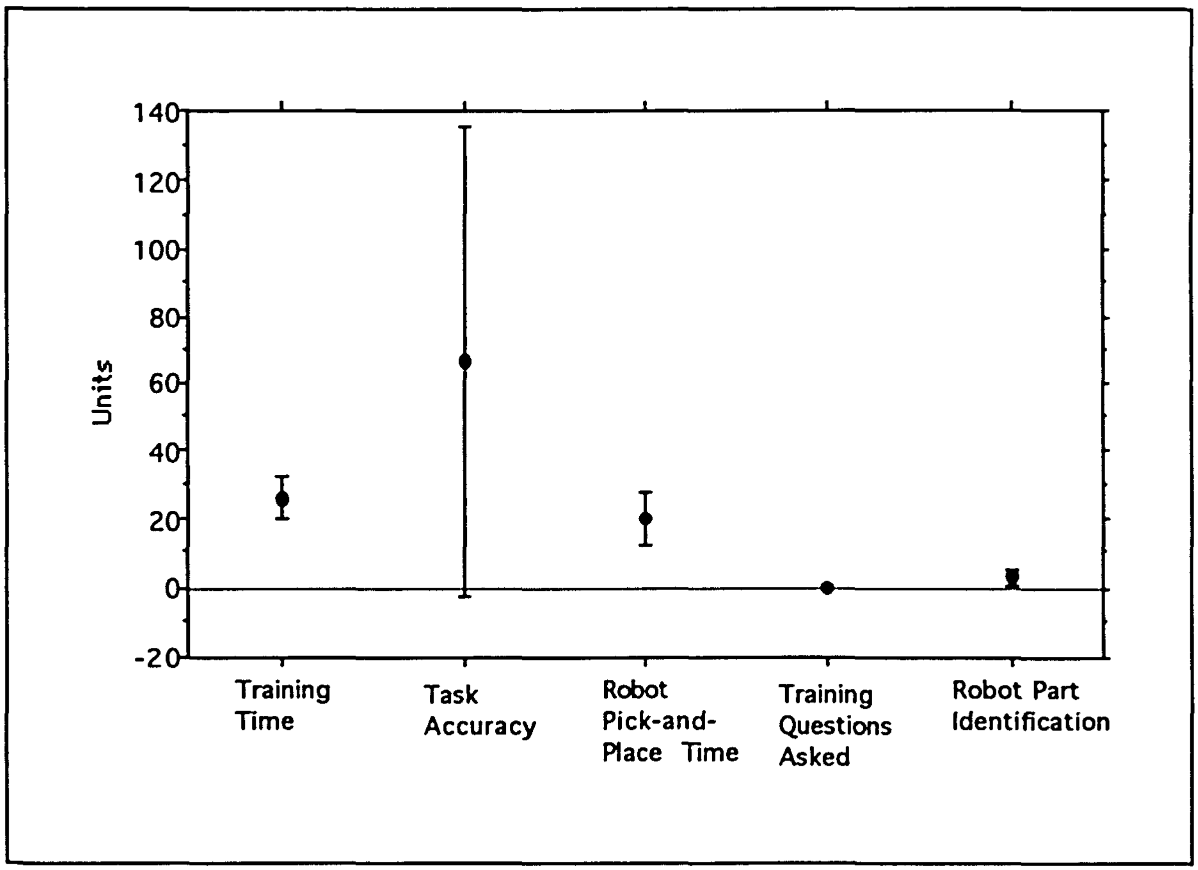


Figure 4.3 Mean and variance for final performance subcomponents

chart showing the mean and variance of "final performance" subcomponent scores for participants in the revised study. Standard deviations are low for training time (6.268), robot pick-and-place time (7.674), questions asked during training (.604) and robot part identification scores (2.085) when compared against a relatively high standard deviation (68.9243) for accuracy scores. These varying standard deviations were expected since measurements of the final performance subcomponents scores, such as questions asked, distance in millimeters and time in minutes, were radically different from one another. A need to normalize the training subcomponent scores for final data analysis was indicated.

The range of final performance subcomponent scores was compared with the associated standard deviations in order to eliminate outliers from the study. Results from this comparison is shown in Table 4.19. Deciding to eliminate participants due to outlying variables had to be weighed against eliminating too much data from the study. Accuracy scores varied the most and were examined closely.

The highest accuracy score of 341 millimeters was considered an outlier and this participant's data was removed from the study. The next highest accuracy score of 286 millimeters, 3.18 standard deviations away from the sample mean, was also considered an outlier and was removed from the study. The third highest score of 168 was 1.47 standard deviations from the mean and was also the highest accuracy score used during the original study. This participant's data was characteristic of other participants' scores and was kept for further analysis. Remaining data fell between 1.615 standard deviations (robot part identification

Table 4.19 Final performance subcomponent score results in revised study

	Mean	Standard Deviation	Minimum Score	Maximum Score	Action Taken
Training Time (minutes)	26.553	6.268	11	40	None
Task Accuracy (millimeters)	66.658	68.924	16	341	Eliminate 286 & 341 data as outliers
Robot Pick-and-Place Time (minutes)	20.026	7.674	9	45	None
Training Questions Asked (integer 0 and up)	.474	.604	0	2	None
Robot Part Identification (integer 0-6)	3.368	2.085	0	6	None

N = 38

score) and 3.25 standard deviations (final robot time) of their respective means. All scores fell within the same range as the scores used within the original study. Final robot time scores exceeded the limit the principal investigator set in the first study. These scores were left in place because too many scores would have been eliminated from the data to make statistical analysis meaningful, because scores fell within the same range as the original study and because the reliability of time scores, as collected, was questioned during the first part of the study. These numbers were reasonable for data analysis but removing outliers changed the demographics of the sample population. A revised demographic description of study participants follows.

Revised Demographic Description - Revised Study

Thirty-six participants, recruited from undergraduate courses at Iowa State University, provided the data used for this study. All participants had normal or corrected to normal eye sight. Two male participants, one assigned to the simulation training method and one assigned to the VR training method, indicated they would not wear glasses during the study. The principal investigator assumed that these individuals were able to function within their training environments.

Thirty-six participants completed training and the final performance measures within the parameters of the study. These individuals spent between eleven and forty minutes (mean = 26.553 minutes) in their respective training environment. Final assessments, where trainees demonstrated cognitive and kinesthetic gains, were scheduled between five and twenty-three days (mean = 11.444 days) after the participant's training session. Correlation coefficients between three subcomponent scores, determining final performance, and the lag time between training and performance dates, measured in days, were run to insure that lag times didn't affect final performance scores. Table 4.20 summarizes these results showing little effect between lag time and the subcomponents of the

Table 4.20 Lag time and final performance subcomponent score correlations

	Training to Final Performance Lag Time (days) Correlation	R^2
Identification of robot parts	-.500	.250
Task accuracy	.095	.009
Pick and place task time	-.095	.009

N =36

Correlation = .00 to .30 Little if any correlation (Hinkle et. al, 1994, p. 119)

R^2 = amount of "variance in one variable that is associated with the other variable" (Hinkle et. al, 1994, p. 119)

final performance score while the demographic description of the final thirty-six participants is shown in Tables 4.21 through 4.25 on the following pages.

The age of the thirty-six final participants varied from 19 to 47 years of age with a mean age of 23.25 years. Thirty-two (88.89 percent) of the participants ranged from the ages of 19 to 26. Table 4.21 shows the frequency distribution of participants by age. Table 4.22 shows that seven of the participants were female (19.44 percent) while the remaining 29 participants (80.57 percent) were male. Males outnumbered females by a ratio of 4 to 1 reflecting the fact that Engineering and Industrial Technology are male dominated fields of study.

Table 4.21 Participants in revised study by age

Age	Number	Percent
19-22	15	41.67
22-26	17	47.22
26-30	1	2.78
30-34	0	0.0
34-38	1	2.78
. . .	0	0.00
46-50	1	2.78

N = 36

Table 4.22 Participants in revised study by gender

Gender	Number	Percent
male	29	80.57
female	7	19.44

N =36

The final group of participants included twenty-four Mechanical Engineering students, five Industrial Technology students and seven individuals categorized as "other". The "other" category includes students recruited from the Mechanical Engineering and Industrial Technology courses but who are enrolled in Electronic,

Table 4.23 Participants in revised study by major of study

Major of Study	Number	Percent
Mechanical Engineering	27	73
Industrial Technology	4	10.8
Other	6	16.2

N=36

Environmental, Civil and Agricultural Engineering or Speech Communications majors. See Table 4.23.

Six participants had robot experience ranging from 3 hours to one year with the average time of robot experience being 11 days. Study participants indicated that much of this experience involved programming the robot with computers and not manipulating the teach pendant to complete robot tasks. Correlations between robot experience and task accuracy scores and robot experience and pick-and-place task time were run to insure that the impact of robot experience on the study was minimal. The correlation between robot experience and task accuracy scores was -.024 with R-squared = .001. The correlation between robot experience and pick-and-place task time was .026 with R-squared = .001. The scores indicate that there was little, if any, correlation between task accuracy and time to complete tasks. The decision was made to keep these participants in place for analysis. Table 4.24 indicates the robot experience for participants in this study.

Table 4.24 Robot experience of participants in revised study

Days of Experience	Number	Percent
0-10	34	94.44
10-20	0	0.0
20-30	0	0.0
30-40	1	2.78
. . .	0	0.0
360-370	1	2.78

N =36

Computer experience, summarized in Table 4.25, was indicated for IBM/DOS or compatible machines, Macintosh, SGI/Sun/UNIX machines and for all of these combined. Participants had from 1 hour to 10 years experience using IBM/DOS machines with a mean of 4.2 years. Macintosh use ranged from 0 to 10 years with a mean of 3.01 years. SGI/Sun/UNIX experience ranged from 0 to 12 years with a mean of 1.05 years. Participant's total computer experience ranged from 0 to 22.5 years with a mean of 8.28 years. None of the participants indicated any experience with other computer systems.

Table 3.5 on page 79 indicates that there is not a significant correlation between computer experience and the final performance score subcomponent scores. These results were consistent with those found in the original study and no further action was taken with the computer experience data.

Table 4.25 Computer experience of participants in revised study

Years	Number	Percent
	IBM/DOS	
Under 1	1	2.8
1-3	8	22.2
3-5	12	33.3
5-7	11	30.6
7-9	1	2.8
9 or more	3	8.3
	Macintosh	
Under 1	17	47.2
1-3	4	11.1
3-5	5	13.9
5-7	2	5.6
7-9	4	11.1
9 or more	4	11.1
	SGI/SUN/UNIX	
Under 1	27	75.0
1-3	3	8.3
3-5	4	11.1
5-7	1	2.8
9 or more	1	2.8

N=36

Table 4.25 (continued)

Years	Number	Percent
Sum of Computer Experience		
Under 1	1	2.8
1-3	4	11.1
3-5	6	16.7
5-7	4	11.1
7-9	5	13.9
9-11	6	16.7
11-13	3	8.3
13-15	3	8.3
Over 15	4	11.1

The revised study was completed using transformed standard scores with a mean of 50 and a standard deviation of 10. The same comparative correlation coefficients and ANOVAs used in the original study were applied to the data in the revised study. The results of the statistical comparisons are shown in Table 4.26 and a discussion of the results follows.

Table 4.26 Results of statistical analysis - revised study

Hypothesis	Results
Hypothesis 1.1 There is no statistically significant difference in written post test scores after eliminating original differences in pretest scores between individuals trained in traditional, simulated and virtual environments.	The null hypothesis is rejected when participants in traditional and simulated environments demonstrate a higher level of cognitive gain, at a statistically significant level ($p < .016$), than did participants exposed to the virtual reality training method.
Hypothesis 1.2 There is no statistically significant difference in the number of training questions asked by individuals exposed to traditional, simulated and virtual reality training environments.	The null hypothesis was supported when the F distribution showed that there was a .186 probability for participants exposed to three different training environments to ask the same number of training related questions. There was a .505 probability that participants exposed to different training environments would ask the same number of content/robot questions. There was a .163 probability that participants exposed to different training environments would ask the same number of "other" questions and a probability of .257 that participants in different training environments would ask the same number of total relevant questions.

Table 4.26 (continued)

Hypothesis	Results
Hypothesis 1.3 The amount of time needed to learn a specific task does not differ with significance for individuals trained in traditional, simulated and virtual environments.	The null hypothesis was supported when the F distribution shows that there was a .1941 probability that training time was not different for participants exposed to three different training environments.
Hypothesis 1.4 There is no statistically significant difference in final performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots.	The null hypothesis was supported when the F distribution showed a .689 probability that the final performance time would be similar for participants exposed to different training methods.
Hypothesis 1.5 There is not a statistically significant difference in the "total time" scores of individuals trained using traditional methods, simulations and virtual reality.	A correlation coefficient with R^2 =.005 shows little linear relationship between training time and final task time. The null hypothesis was supported when the F distribution showed a .204 probability that the "total training time" of participants would not vary for trainees exposed to three different training methods.

Table 4.26 (continued)

Hypothesis	Results
Hypothesis 1.6 There is not a statistically significant difference between task accuracy scores of individuals trained using traditional methods, simulation methods and virtual reality methods.	The null hypothesis was supported when the F distribution showed a probability of .923 that task accuracy would not vary for individuals exposed to three different training methods.
Hypothesis 1.7 There is not a statistically significant difference in the final performance scores of individuals trained using traditional methods, simulations and virtual reality.	The null hypothesis was supported. The F distribution showed a .6571 probability that final performance scores are not affected by the training method participants were exposed to.
Hypothesis 1.8 There is not a significant correlation between an individual's internal immersion score and their final performance score.	The null hypothesis was supported. The correlation coefficient (.2375) with R^2 of .0564 showed that only 5.6% of the variance in final performance scores could have been attributed to the internal immersion score.

Table 4.26 (continued)

Hypothesis	Results
Hypothesis 1.9 There is not a significant correlation between an individual's external immersion score and their final performance score.	The null hypothesis was supported. A correlation coefficient of -.239 and R^2 of .0571 showed that only 5.7% of the variance in final performance scores could be explained by the external immersion scores.
Hypothesis 1.10 There is not a statistically significant correlation between an individual's total immersion score and their final performance score.	The null hypothesis was supported. A correlation coefficient of -.0011 with $R^2 = 1.217^{-6}$ shows that there is little linear relationship between the total amount of immersion a person indicates and their final performance scores. A minute amount of the variance in final performance scores can be attributed to the total amount of immersion a person feels.

Table 4.26 (continued)

Hypothesis	Results
Hypothesis 2.1 There is not a statistically significant difference between the final performance scores of individuals enrolled in Engineering and individuals enrolled in Industrial Technology courses at Iowa State University.	The null hypothesis was supported when the F test showed a .7825 probability that there was not a difference in final performance scores for individuals enrolled in different majors of study at Iowa State University.
Hypothesis 2.2 Individual learning style will have no statistically significant affect on final performance scores among trainees participating in this study.	The null hypothesis was supported when R^2 values showed that the 25 subcomponents of "learning style" accounted for .0% to 25.72% of the variability in final performance scores.
Hypothesis 2.3 There is not a statistically significant difference in "Learning Styles Inventory" scores for individuals enrolled in different majors of study at Iowa State University	The null hypothesis was rejected when an ANOVA showed a .1087 probability that there was no difference in "kinesthetic" learning styles for different majors of study, a .0949 probability that there was no difference in "auditory" learning styles for different majors of study and a .0095 that there was no difference in "formal design" learning for different majors of study at Iowa StateUniversity.

Research Results - Revised Study

Data collected from the participants were used to answer the research hypotheses outlined in Chapter 3. Statistical tests were run using an alpha level of .10 and results from the revised study were then compared to the results from the original study.

Null hypothesis 1.1 states that *There is no statistically significant difference in written post test scores after eliminating original differences in pretest scores between individuals trained in traditional, simulated and virtual environments.* This question is designed to indicate and compare what effect traditional, simulated and virtual reality training methods have on an individual's cognitive gain during training. An ANCOVA was used to measure cognitive gains demonstrated by participants on an exit survey after correcting for participants' cognitive knowledge demonstrated on an introductory survey. The data was compared using an ANCOVA (Elzey, 1985) and the results reported in Table 4.27. Participants in both traditional and simulated environments demonstrated a significantly higher level, significant at $p < .016$, of cognitive gain than did participants in the virtual reality training group. The null hypothesis was rejected as it was in the original study. Cognitive gains in traditional and simulated environments were greater than those made in virtual reality training environments.

Null hypothesis 1.2 states that *there is no statistically significant difference in the number of training questions asked by individuals exposed to traditional, simulated and virtual reality training environments.* Individuals exposed to simulation and virtual reality training environments needed to learn how to function within the training environment as well as learn the intended content and robot manipulation. The principal investigator was interested in knowing if certain types of questions were more frequent in a particular training environment. To analyze this possibility, the original null hypothesis was broken into four subcomponents which include: a) *there is no statistically significant difference in the number of training environment questions asked by individuals exposed to traditional, simulation or virtual reality training environments;* b) *there is no statistically*

Table 4.27 ANCOVA training method and cognitive gain

Source:	Degrees of Freedom:	Sum of Squares:	Mean Square:	F-test:
Between groups	2	763.322	381.661	4.672
Error	32	2614.339	81.698	p < .016
Total	34	3377.661		

Group:	Count:	Mean of Introductory Survey	Mean of Exit Survey	Adjusted Mean of Exit Survey
Traditional	13	53.149	53.634	53.375
Simulation	10	49.708	53.743	53.767
Virtual Reality	13	47.077	43.486	43.727

N=36

significant difference in the number of training content/robot related questions asked by individuals exposed to traditional, simulation or virtual reality training environments; c) *there is no statistically significant difference in the number of training environment questions in the number of other training questions asked by individuals exposed to traditional, simulation or virtual reality training environments;* d) *there is no statistically significant difference in the total number of questions relative to training asked by individuals exposed to traditional, simulation and virtual reality training environments.* These hypotheses are designed to measure the cognitive gains made by trainees in system operations that aren't measured by the written exit survey.

Evidence of learning was indicated as study participants asked questions about the training environment, training content, or other questions. All questions participants asked were relevant to the training so the "training environment", "training content", and "other" categories were added for an indication of "total learning". Questions asked were tallied and raw scores were converted to transformed standard scores with a mean of 50 and a standard deviation of 10. ANOVAs were run using "training method" as the independent variable while "training environment questions" were used as the dependent variable. This process was repeated with "training method" as the independent variable and each of the "content/robot" data, the "other questions" data and the "total relevant" data used as the dependent variable in respective ANOVAs. The data are summarized in Table 4.28.

Table 4.28 ANOVA for X_1: training method and Y_1: questions asked

Questions Asked		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	47.272	8.266	Trad vs. Sim	-1.016
10	Simulation	48.288	9.281	Trad vs. VR	-6.773
13	Virtual Reality	54.044	11.421	Sim vs. VR	-5.757
		F-test: 1.7685	p = .186		
#	Content/Robot			Mean Difference	
13	Traditional	48.233	7.909	Trad vs. Sim	- .658
10	Simulation	48.891	9.017	Trad vs. VR	- 4.387
13	Virtual Reality	52.620	12.504	Sim vs. VR	- 3.729
		F-test: .6982	p = .505		
#	Other Questions			Mean Difference	
13	Traditional	54.229	16.166	Trad vs. Sim	6.623
10	Simulation	47.607	°	Trad vs. VR	6.223
13	Virtual Reality	47.607	0.000	Sim vs. VR	3.47^{-18}
		F-test: 1.9167	p = .163		
#	Total Relevant Questions			Mean Difference	
13	Traditional	48.561	10.684	Trad vs. Sim	1.390
10	Simulation	47.172	7.934	Trad vs VR	-5.054
13	Virtual Reality	53.615	10.355	Sim vs. VR	-6.444
		F-test: 1.417	p = .257		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

Variances between and within the groups was measured and compared using the F distribution as the sampling distribution. The probability (p value) that questions asked during training were similar within different training environments was high in all areas and the null hypothesis was accepted. There is not a statistically significant difference in the number of questions asked by participants exposed to traditional, simulated and virtual reality training methods. There was a difference between the "other" and "total relevant" questions asked between participants in the original study and the participants in the revised study. The probability of "other" questions asked for participants exposed to different training methods in the original study was $p = .437$ but it dropped to $p = .163$ in the revised study. Similar results were found in the "total relevant questions" asked with $p = .933$ in the original study but dropping to $p = .257$ in the revised study.

Null hypothesis 1.3, *the amount of time needed to learn a specific task does not differ with significance for individuals trained in traditional, simulated and virtual environments,* is designed to measure kinesthetic gains in training environments. Differences in training time reflect how quickly participants become confident in their abilities. The exception to this is the individuals involved in "traditional" training. Training time in this environment was dictated by the trainer and competency had no bearing on training time. "Training method" was used as the independent variable while "training time" was used as the dependent variable and the results from the ANOVA are shown in Table 4.29. Variances were compared using the F distribution and the p value did not exceed the critical level. The null hypothesis was accepted. Comparison of the revised data with the original data

Table 4.29 ANOVA X_1: training method and Y_1: training time

Training Time	Transformed Standard Mean	Standard Deviation	Comparison	
Training Environment			Mean Difference	
Traditional	48.961	0.000	Trad vs. Sim	-7.016
Simulation	55.976	10.857	Trad vs. VR	.480
Virtual Reality	48.481	14.699	Sim vs. VR	7.495
	F-test: 1.724	p = .1941		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

showed that the statistical results were uniform from the original study to the revised study. While this is not statistically significant it has implications for training that will be discussed later.

Null hypothesis 1.4 is designed to measure both kinesthetic gains and application of cognitive knowledge in a real application. In other words, does the training method affect final task time? Participants were told to take as much time as the accuracy of the robot and their patience would allow. It was assumed that trainees with more skill would take less time to complete the final task. "Training method" was used as the independent variable and "final task time" was the independent variable. Data were compared using ANOVA as is summarized

Table 4.30 ANOVA X_1: training method Y_1: pick-and-place task time

Final Task Time		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	48.223	14.152	Trad vs. Sim	-3.671
10	Simulation	51.894	9.615	Trad vs. VR	-2.098
13	Virtual Reality	50.321	3.942	Sim vs. VR	1.573
		F-test: .3774	p = .689		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

in Table 4.30. There is not a statistically significant difference in final pick-and-place task time using a robot for individuals exposed to traditional, simulation and virtual reality training methods. The null hypothesis was accepted since the critical .90 level was not exceeded but data showed a trend that was not apparent during the first study. The final pick-and-place task time centered around a similar mean but the standard deviations narrowed considerably as the training environment went from least immersive to most immersive. This was a pattern similar to that of task accuracy scores noted in the original study.

The assumption that an increase in training time may result in a decrease in performance time or vice versa was addressed using null hypothesis 1.5. While the individual training or performance times might not differ significantly, perhaps the cumulative time would show a difference. A correlation coefficient comparing training time to final robot time was .068 with $R^2 = .005$ showed little, if any, linear relationship between training time and performance time. The null hypothesis, *there is not a statistically significant difference in the "total time" scores of individuals trained using traditional methods, simulations and virtual reality,* was formulated to determine if "training method" influenced "total time". The results of the one-way ANOVA, see Table 4.31, show that the p value does not exceed the critical level. The null hypothesis, that there is not a statistically significant difference in the "total time" scores of individuals exposed to traditional, simulation

Table 4.31 ANOVA X_1: training method Y_1: total time

Total Time		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	48.066	9.820	Trad vs. Sim	-6.753
10	Simulation	54.819	10.111	Trad vs. VR	-1.617
13	Virtual Reality	49.228	9.580	Sim vs. VR	6.591
		F-test: 1.670	p = .204		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

and virtual reality training methods, was accepted. "Total time" data acquired from the revised study was very similar to that acquired during the original study. The training implications of this result are discussed later.

Null hypothesis 1.6 states that *there is not a statistically significant difference between task accuracy scores of individuals trained using traditional methods, simulation methods and virtual reality methods.* Analysis of the thirty eight original data scores showed that three of the accuracy measurements were questionable as outliers. One score of 168, one score of 286 and one score of 341 were examined. Accuracy scores had a mean of 66.658 with a standard deviation of 68.924. The score of 341and 286 were considered an outlier and the results

Table 4.32 ANOVA X_1: training method Y_1: task accuracy

Task Accuracy		Transformed Standard Mean	Standard Deviation	Comparison	
	Training Environment			Mean Difference	
13	Traditional	49.547	11.406	Trad vs. Sim	.141
10	Simulation	49.406	9.621	Trad vs. VR	-1.364
13	Virtual Reality	50.910	9.526	Sim vs. VR	-1.504
		F-test: .0804	p = .923		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

from these individual were not analyzed as part of this study. Final results, shown in Table 4.32, shows a narrowing of variance in task accuracy around a mean but it is not as extensive as was demonstrated in the original study. Since the p score did not exceed the critical .90 level, the null hypothesis was accepted. There is not a statistically significant difference in task accuracy scores for individuals exposed to traditional, simulated or virtual reality training methods.

Null hypothesis 1.7 states that *there is not a statistically significant difference in the final performance scores of individuals trained using traditional methods, simulations and virtual reality.* An individual's overall performance is the sum of training time, performance time, accuracy scores and questions asked

Table 4.33 ANOVA X_1: training method Y_1: final performance scores

Final Performance Scores		Transformed Standard Mean	Standard Deviation	Comparison	
#	Training Environment			Mean Difference	
13	Traditional	52.057	8.120	Trad vs. Sim	3.543
10	Simulation	48.514	13.559	Trad vs. VR	2.971
13	Virtual Reality	49.086	8.974	Sim vs. VR	- .571
		F-test: .4252	p = .6571		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

during training and the final score on a written assessment. Since larger training times, larger performance scores and larger accuracy scores indicate worse rather than better performance, these numbers were inverted. "Training method" was used as the independent variable and overall performance scores used as the dependent variable in an one-way ANOVA and the results shown in Table 4.33. Results from the revised study were similar to those of the original study. The null hypothesis was accepted.

Does the amount of immersion in a training environment affect an individual's final performance? Null hypothesis 1.8, *There is not a significant correlation between an individual's internal immersion score and their final performance score,* was formulated to address this question. The null hypothesis, was upheld, as it was in the original study, when a correlation coefficient of .2375 with R-squared of .0564 was determined. This low correlation coefficient, with only 5% of variance explained by the internal immersion score, did not warrant further investigation in this study.

Null hypothesis 1.9, *there is not a significant correlation between a individual's external immersion score and their final performance score,* addresses whether the amount of "presence" in a training environment affects an individual's final performance. The null hypothesis was upheld, as it was in the original study, when a correlation coefficient of -.239 with R-squared of .0571 was determined. This low correlation coefficient with only 5.7% of variance explained by the amount of external immersion did not warrant further investigation.

Does the total amount of realism in a training environment, as indicated by immersion and presence, affect an individual's final performance? Null hypothesis 1.10 addresses this question. A correlation coefficient of -.0011 with R-squared of 1.217^{-6} indicated that there is not a significant correlation between a person's final performance score and a person's total immersion score. The immersion and presence variables did not warrant further investigation within this study.

The second part of this study examined how learning styles or differences in individuals, *as opposed to differences in training environments, affected* performance.

Does a person's major of study reflect a certain learning style which may or may not affect learning in virtual, simulated or traditional training environments? A one way ANOVA was run using "major of study" as the independent variable and the standardized "final performance scores" as the dependent variable. Results, shown in Table 4.34, show that the p score derived from the F-test did not exceed the critical level. The probability that there was not a difference in final performance scores increased as the diversity of the study participants' declared major of study increased. These results were similar to those in the original study and the null hypothesis was accepted. There was not a statistically significant difference in final performance scores for individuals exposed to traditional, simulated and virtual reality training environments.

Null hypothesis 2.2 states that *individual learning styles have no statistical correlation with final performance scores among trainees participating in this study.*

Table 4.34 ANOVA X_1: major of study Y_1: final performance scores

#	Major of Study	Transformed Standard Mean	Standard Deviation	Comparison Mean Difference	
24	ME	50.679	7.743	ME vs IT	1.581
5	IT	47.175	12.500	ME vs OTH	5.590
7	OTH	49.689	15.516	IT vs OTH	5.865
		F-test: .247	p = .7825		

N = 36

DF:	Between groups	2
	Within groups	33
	Total	35

ME = Mechanical Engineering
IT = Industrial Technology
OTH = Other

There is not one score for the "Learning Style Inventory" administered to study participants. Scores given for five major domains with subscales under each domain. Correlation coefficients were run for each of the subscales. The results appear in Table 4.35.

Examination of the table shows that there are no significant correlations between any of the learning style components and final performance scores. The lack of significant correlations may be the result of a homogenous group with similar learning styles which may be an accurate reflection of the university environment.

Table 4.35 Final performance score and learning style subcomponent correlation

Physical Domain	Correlation	R-squared
Kinesthetic	.2625	.0689
Visual	.1252	.0157
Tactile	-.1893	.0358
Auditory	.3465	.1200
Social Domain		
Group	.2095	.0439
Individual	-.2792	.0779
Environmental Domain	Correlation	R-squared
Design/Formal	.5071	.2572
Design/Informal	-.4008	.1606
Well Lit	.1312	.0172
Dimly Lit	-.0306	.0009
Cool Temperature	-.0167	.0003
Warm Temperature	-.1026	.0105
Without Sound	.2152	.0463
Noisy	-.1311	.0172

N = 36

R^2 = amount of "variance in one variable that is associated with the other variable" (Hinkle et. al, 1994, p. 119)

Table 4.35 (continued)

Mode of Expression		
Oral	-.0099	.0001
Written	.0609	.0037
Work Characteristics		
Outdoors	.0104	.0001
Indoors	-.0739	.0055
Sedentary	.1042	.0109
Non-sedentary	.1604	.0257
Lifting	.1351	.0182
Non-lifting	-.0004	1.667^{-7}
Data	.1883	.0354
People	.1432	.0205
Things	.1422	.0202

Null hypothesis 2.3 states that *there is not a statistically significant difference between an individual's major of study and any of the"Learning Style Inventory" scores among trainees participating in this study.* The "Learning Style Inventory" groups 25 different elements under five domains which describe an individual's preference for learning environments. A one-way ANOVA was run for all of the 25 elements of the *Learning Style Inventory* and the results are shown in Table 4.36. The null hypothesis was rejected, as it was in the first study, when significant differences in learning styles were demonstrated by students enrolled in Mechanical Engineering, Industrial Technology and "Other" majors of study. Mechanical Engineering majors and Industrial Education majors differed greatly in the kinesthetic component. Significant differences in learning styles were also noted in the "Auditory" and "Formal Design" categories. It should be noted that a small change in the "Major of Study" demographics resulted in a statistically significant difference in "learning styles".

Table 4.36 ANOVA X_1: major of study Y_1: learning style indicators

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
		Physical Domain			
#	Kinesthetic			Mean Difference	
24	ME	52.343	8.433	ME vs IT	9.327*
5	IT	43.016	12.597	ME vs OTH	5.385
7	OTH	46.958	11.469	IT vs OTH	-3.943

F-test: 2.375 p = .1087
*Almost reaches significance at 90% Fisher PLSD

N = 36

Source:
- Between groups 2
- Within groups 33
- Total 35

ME = Mechanical Engineering
IT = Industrial Technology
OTH = Other

Table 4.36 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Visual			Mean Difference	
24	ME	48.249	9.425	ME vs IT	-4.355
5	IT	52.604	6.849	ME vs OTH	-5.900
7	OTH	54.149	13.174	IT vs OTH	-1.545
		F-test: 1.1496	p = .3291		
#	Tactile			Mean Difference	
24	ME	51.292	8.222	ME vs IT	4.422
5	IT	46.870	15.759	ME vs OTH	3.484
7	OTH	47.808	11.756	IT vs OTH	- .938
		F-test: .5993	p = .555		
#	Auditory			Mean Difference	
24	ME	48.376	8.477	ME vs IT	- .797
5	IT	47.579	8.894	ME vs OTH	-8.922*
7	OTH	57.298	13.326	ME vs OTH	-9.719*
		F-test: 2.5307	p = .0949		
		*Significant at 90% Fisher PLSD			
		Social Domain			
#	Group			Mean Difference	
24	ME	49.131	10.189	ME vs IT	1.130
5	IT	48.001	11.304	ME vs OTH	-5.276
7	OTH	54.407	8.438	IT vs OTH	-6.4056
		F-test: .8634	p = .431		

Table 4.36 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Individual			Mean Difference	
24	ME	49.254	10.408	ME vs IT	-3.538
5	IT	52.792	10.119	ME vs OTH	-1.307
7	OTH	50.562	9.525	IT vs OTH	2.231
		F-test: .2612	p = .7717		
		Environmental Domain			
#	Formal Design			Mean Difference	
24	ME	52.185	8.304	ME vs IT	1.695*
5	IT	37.868	9.940	ME vs OTH	4.445
7	OTH	51.176	10.478	IT vs OTH	3.960*
		F-test: 5.3767	p = .0095		
		* Significant at 90% Fisher PLSD & Scheffe F-test			
#	Informal Design			Mean Difference	
24	ME	49.080	9.716	ME vs IT	-8.459
5	IT	57.540	8.183	ME vs OTH	1.314
7	OTH	47.770	10.968	IT vs OTH	9.773
		F-test: 1.772	p = .1858		
#	Bright Lights			Mean Difference	
24	ME	50.825	9.098	ME vs IT	5.019
5	IT	45.806	13.278	ME vs OTH	.656
7	OTH	50.163	11.449	IT vs OTH	- 4.363
		F-test: .508	p = .6065		

Table 4.36 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Dim Lights			Mean Difference	
24	ME	48.933	8.344	ME vs IT	-3.914
5	IT	52.846	15.095	ME vs OTH	-2.694
7	OTH	51.627	12.255	IT vs OTH	- 1.220
		F-test: .4175	p = .6621		
#	Warm Temperature			Mean Difference	
24	ME	49.634	10.114	ME vs IT	- 3.823
5	IT	53.457	7.997	ME vs OTH	.847
7	OTH	48.786	11.677	IT vs OTH	4.670
		F-test: .3528	p = .7053		
#	Cool Temperature			Mean Difference	
24	ME	49.666	8.380	ME vs IT	- .120
5	IT	49.786	15.828	ME vs OTH	- 1.634
7	OTH	51.230	12.029	IT vs OTH	- 1.514
		F-test: .0698	p = .9328		
#	With Sound			Mean Difference	
24	ME	51.013	8.177	ME vs IT	3.324
5	IT	47.689	14.094	ME vs OTH	2.834
7	OTH	48.179	13.497	IT vs OTH	- .490
		F-test: .359	p = .7011		

Table 4.36 (continued)

#	Major of Study	Transformed Standard Mean	Standard Deviation	Comparison	
#	Without Sound			Mean Difference	
24	ME	49.473	9.532	ME vs IT	-3.477
5	IT	52.951	9.138	ME vs OTH	- .226
7	OTH	49.699	13.073	IT vs OTH	3.252
		F-test: .2431	p = .7856		
		Mode of Expression			
#	Oral			Mean Difference	
24	ME	49.509	10.233	ME vs IT	2.554
5	IT	46.955	12.222	ME vs OTH	-4.350
7	OTH	53.859	7.500	IT vs OTH	-6.904
		F-test: .7719	p = .4703		
#	Written			Mean Difference	
24	ME	49.823	9.227	ME vs IT	1.025
5	IT	48.799	12.859	ME vs OTH	-1.640
7	OTH	51.464	11.955	IT vs OTH	-2.665
		F-test: .1089	p = .8971		

Table 4.36 (continued)

#	Major of Study	Transformed Standard Mean	Standard Deviation	Comparison	
		Work Characteristics			
#	Outdoors			Mean Difference	
24	ME	50.377	10.095	ME vs IT	5.561
5	IT	44.815	10.577	ME vs OTH	- 2.035
7	OTH	52.412	9.398	IT vs OTH	- 7.596
		F-test: .8868	p = .4216		
#	Indoors			Mean Difference	
24	ME	49.368	9.371	ME vs IT	-4.832
5	IT	54.201	10.327	ME vs OTH	.203
7	OTH	49.165	12.590	IT vs OTH	5.035
		F-test: .4986	p = .6119		
#	Sedentary			Mean Difference	
24	ME	49.336	9.570	ME vs IT	.399
5	IT	48.937	5.820	ME vs OTH	- 3.700
7	OTH	53.036	14.009	IT vs OTH	- 4.098
		F-test: .3896	p = .6804		
#	Non-sedentary			Mean Difference	
24	ME	50.156	9.687	ME vs IT	.842
5	IT	49.314	6.400	ME vs OTH	.201
7	OTH	49.956	14.020	IT vs OTH	- .642
		F-test: .0139	p = .9862		

Table 4.36 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Lifting			Mean Difference	
24	ME	51.646	9.559	ME vs IT	1.679
5	IT	49.967	13.515	ME vs OTH	7.267
7	OTH	44.379	7.973	IT vs OTH	5.588
		F-test: 1.695	p = .2447		
#	Non-lifting			Mean Difference	
24	ME	49.724	8.767	ME vs IT	.332
5	IT	49.392	12.982	ME vs OTH	- 1.660
7	OTH	51.383	13.172	IT vs OTH	- 1.991
		F-test: .0809	p = .9225		
#	Data			Mean Difference	
24	ME	50.143	8.976	ME vs IT	- .601
5	IT	50.744	12.827	ME vs OTH	1.165
7	OTH	48.978	12.768	IT vs OTH	1.766
		F-test: .0500	p = .9513		
#	People			Mean Difference	
24	ME	48.879	10.506	ME vs IT	- 2.101
5	IT	50.981	9.434	ME vs OTH	- 4.262
7	OTH	53.142	9.141	IT vs OTH	- 2.161
		F-test: .5055	p = .6078		

Table 4.36 (continued)

Major of Study		Transformed Standard Mean	Standard Deviation	Comparison	
#	Things			Mean Difference	
24	ME	50.890	10.435	ME vs IT	- .623
5	IT	50.267	8.774	ME vs OTH	4.132
7	OTH	46.758	9.956	IT vs OTH	3.509
		F-test: .4501	p = .6414		

Discussion

Ten hypotheses, formulated and tested in the original study, were reexamined in the revised study. A statistically significant difference in cognitive gains made among learners who were exposed to three different training methods was found in both studies. Other variables examined did not show any statistically significant differences but did indicate trends which warrant further study.

Accepting or rejecting null hypotheses was a relatively simple task based on the mathematical p scores which resulted from statistical analysis. Explaining why these results occurred is more difficult. It is furthered complicated when one references the results from the original study with the results from the second study.

The reasons for the null hypotheses being rejected in the revised study are similar to the reasons stated in the original study. First, the sample population used in this study was small; a larger sample may be needed to demonstrate the effectiveness of different training methods. Second, the sample population had little variance in learning styles and in the stated major of study. A more varied sample may be needed to demonstrate the effectiveness of the three different methods of training. Comparing the results from Table 4.18 and 4.36 shows that as the sample population's "Major of Study" demographics change the number and type of "Learning Style" indicators change as well. It may be possible that "learning styles" and internal variable unique to each individual is more important than a "sense of presence" or "degree of immersion" when dealing with simulated and virtual environments. Third, the indicators used to demonstrate skill acquisition may not be as effective as the principal investigator assumed they would be. Refinement of both assessment and analysis instruments may be needed. It may also be true that this study accurately reflects the current state of traditional, simulation and virtual reality training methods and the training results indicative of each approach.

Study results showed that individuals trained using traditional and simulation training methods made significantly greater cognitive gains than the individuals trained using virtual reality. When factual information needs to be conveyed, virtual reality would not be the indicated training choice. These results are consistent with the original study. Future investigations comparing training environments will therefore focus on the kinesthetic and endurance aspects of skill acquisition.

The number of questions trainees asked during training did not prove to be a good indicator of learning for different training methods. The limited number of questions asked by trainees (0 to 3) was not enough to provide good statistical analysis of "learning". The revised study did show that trainees immersed in virtual environments asked more questions about the training environment, about "other" training related items and in general asked more relevant questions than they had in the original study. This indicates that study participants were learning the technology along with the content. This may have had an effect on final performance scores. Future studies should center around setting a competency level and repeatedly exposing participants to the training environment until they reach predetermined competency levels. Training time and retention, better indicators of learning, could then be examined as evidence of skill acquisition.

While the amount of time needed to learn a specific task did not reach statistical significance the results have implications for training applications. The average training time was the lowest in virtual reality environments (mean 48.481) and highest for simulations (mean 55.976). Traditional method training time fell in between these two (mean 48.961) which demonstrates that participants exposed to virtual reality training methods can learn content and operate within a virtual reality training environment without having any prior VR experience. The VR trainees can complete training within a time frame comparable to that demonstrated by participants exposed to traditional training techniques. Participants exposed to traditional methods had 0 variance in their training time since training time was dictated by the trainer. Zero variance in training time assumes that all trainees learn the intended content within the specified training time which may not be the best training practice.

Participants exposed to simulation training methods had a higher mean training time than did the participants exposed to traditional and virtual reality methods. While the ANOVA comparing "training method" to "training time" did not reach the predetermined .90 significance level, it would have been statistically significant at a .80 level and it duplicates the results found in the original study. The need for an intelligent tutoring system, developing trainee competency before using a particular training delivery systems, or developing other methods to get help within simulation training environments, is indicated. Employing an intelligent tutoring system within both simulation and virtual training environments may reduce training time and is an area for further study.

Null hypothesis 1.4, *there is no statistically significant difference in performance time between individuals trained using traditional methods, simulations and virtual reality when they perform a task using real robots*, was accepted. Participants were allowed to take as much time as they needed to complete the pick-and-place robot task. The revised study indicated that there was a trend in pick-and-place task time which may be of interest to trainers. The pick-and-place task times in the revised study displayed the same trend that accuracy scores displayed in the original study (see Figure 4.4). The task times centered around a similar mean but the variation of completion time dropped from a standard deviation of 14.152 in traditional environments to 3.92 in virtual

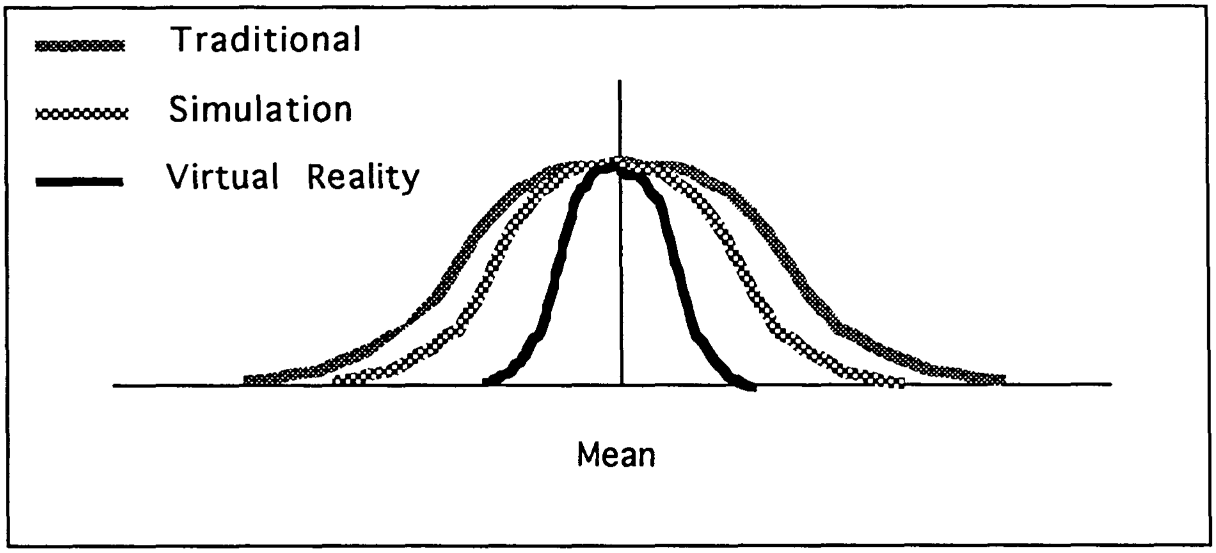


Figure 4.4 Standard deviations for pick-and-place task time

environments (p = .689). This would be a significant savings of money if trainees could complete tasks faster after being exposed to more immersive environments. The results were different than those indicated in the original study and may indicate a strength of virtual environments. This theory should be explored in future studies. When examining task completion times, extraneous variables, such as an individual's desire to complete the tasks with an accuracy that exceeded the robot's capabilities, or an individual's schedule that required them to quit the pick-and-place task early must be minimized.

"Final performance time", as structured, was a questionable measure of performance. Variances in training time scores and final performance time were presumably affected by too many extraneous variables. The accumulated error present in "final performance time" was too great to be useful for statistical analysis. Future studies should measure task accuracy within a predetermined amount of time. This would more accurately reflect how well trainees reach competency levels within different training environments.

"Total time", training time plus final performance time, did not reach a statistically significant level but it does have implications for training. The lowest mean total time (48.066) was indicated for participants exposed to traditional training environments. Participants exposed to virtual reality training methods had a mean "total time" of 49.228 while participants exposed to simulation had a mean "total time" of 54.819. The null hypothesis was rejected, as it was in the original study, because a significance level of .90 was not reached. If one assumes that "total time" represents the time it takes to complete training and reach competent task performance, then business and industry would take note of the "total time" score. An 80% chance that employees would take longer to develop task competency within simulation training environments would lead employers to choose traditional or virtual reality techniques for delivering training. Two factors need to be considered before choosing traditional or virtual environments for training.

Lack of an intelligent tutoring system within the simulated training environment may have affected training time and thus impacted final performance times. University students enrolled in Engineering courses are being trained to visualize complex interactions within their mind and design or analyze mechanisms that work within given parameters. These visualization skills may be the same ones needed to succeed in traditional training environments. A more diverse population will need to be examined to determine if engineering skills cross over to traditional training techniques and impact final performance scores.

Task accuracy scores followed the same pattern as they did in the original study. They narrowed around a similar mean and variation around that mean narrowed as the training environment went from less immersive to more immersive. The trend was not as significant as it was in the first study but it reinforces the author's argument made in the original study. Studies will not show a significant difference in task accuracy scores because variances narrow around the same hypothetical mean with traditional training methods encompassing all others with the largest variance.

There was not a statistically significant difference in final performance scores for individuals exposed to traditional, simulation and virtual reality training methods. The homogeneous nature of the sample population and small sample size may be one explanation for this result. Indicators of performance should also be examined for their merit and either used or discarded in future studies. These results may also reflect the self-directness of this particular group of participants and may not apply to sample populations who are less self-motivated.

Internal immersion scores, the amount individuals become immersed in a task, had little correlation with final performance scores. The Virtual Environment Performance Assessment Battery (VEPAB) was designed to measure immersion as it related to individuals moving through a virtual environment while this study measured performance of individuals as they acted upon an environment. The immersion questionnaire portion of the VEPAB was also administered to trainees exposed to simulated and traditional training environments. The VEPAB was not designed for traditional and simulated environments and the immersion assessment is still being refined which means that the VEPAB may not be an accurate assessment of internal immersion in this training environment. It is also possible that the sample was too small for any correlation to be evident. The internal immersion score was not considered significant enough to warrant further investigation in this study. This was consistent with the original study.

There was very little correlation (R-squared = .0571) between the amount of realism, measured by the "total presence" score, and final performance scores. Results from this study indicate that neither the internal immersion scores nor the external presence variables, alone or in combination, had any association with the final performance scores. The Virtual Environment Performance Assessment Battery (VEPAB) was designed to measure presence as it related to individuals moving within a virtual environment while this study measured performance of individuals as they acted upon an object. The VEPAB was also administered to trainees exposed to simulated and traditional training environments which the VEPAB was not designed for. Using the VEPAB out of context and the fact that the VEPAB is still being refined, may make it limited for use within this context. It is also possible that the sample population is too small or too uniform for any correlation to be evident. While these assessments may be kept in place in future studies the test instrument may need to be refined or its subcomponent scores examined for better indicators of affect.

Individual differences may have been responsible for the variations noted in the study. "Learning styles" and "major of study" variables were examined since immersion and presence scores showed little statistical significance as it related to overall performance scores. Results in the original and revised study showed that there was no statistical relationship between a person's "major of study" and their "final performance scores". The same was true for correlations between "individual learning styles" and "final performance scores" in both studies. Both studies did show a significant difference in learning styles for students enrolled in different majors of study at Iowa State University. "Learning style" differences appeared in the "kinesthetic" and "oral" categories in the original study. "Task accuracy" variations in the original study were highest for participants trained in traditional environments and decreased for participants trained in simulation and virtual environments. In the revised study the "kinesthetic" category was less significant but the "auditory" and "formal design" categories became more significant. As "kinesthetic" scores became less significant, the "task accuracy" scores varied less. As the "auditory" and "formal design" categories became more significant the variances in task time, which was high for participants trained using traditional techniques, decreased for trainees exposed to simulation and virtual training environments. Kinesthetic learners prefer to learn through involvement and action so higher task accuracy scores would make sense for individuals who prefer this learning style. People who prefer formal learning environments like more structure and organization. Perhaps they are able to structure their environment quickly, or complete a pick-and-place task quickly, as a result of this learning style. Evidence of this did not show up during any of the statistical analysis because levels of significance were not reached in either the "task accuracy" or the" task completion times". Simulation and virtual environments appear to interact with individual learning styles to impact some components of final performance. These trends must be examined in further studies.

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study, to compare how training methods affect trainee performance, was reached. The study also collected data about individual learning styles and performance within traditional, simulation and virtual reality training environments. A pilot study would have been beneficial in refining training environments and assessment techniques. This was not possible because of personnel, funding and time constraints. Nevertheless, this study laid the necessary groundwork for the principal investigator to refine the original study and identify areas for future exploration.

It should be clear that this study was conducted in two parts. One-third of the study was rerun two months after the original study concluded. The principal investigator believes that the integrity of the study was preserved despite the revision in the original study. Conclusions were drawn after the appropriate statistical analyses were performed.

Small sample sizes may have affected the number of statistically significant relationships that were found in this study. The level of significance was set at .10 for all of the statistical analyses used in this study. There is a 10% chance of having a Type I error (the probability of rejecting the null hypothesis when it is true) in this study. Hinkle et. al make a good point when they ask:

> What if the null hypothesis is actually false? If the researcher rejects it, a proper decision is made, if not, a Type II error is made. . . . Because rejecting the false null hypothesis is precisely what the researcher wants to accomplish, the quantity 1-ß is defined as the power of the statistical test.

> . . . Type I errors are generally more serious than Type II errors, and (researchers) have suggested a 4:1 ratio of β to α. That is, if the level of significance (α) is established, a priori, at .05, then the corresponding power is 1 - 4(.05) = .80. (Hinkle et. al, 1994, p. 282 and 299)

Using this formula we see that with the significance level of .10, established a priori in this study, the power of the statistical tests used becomes 1 - 4(.10) = .60. There is a .60 probability that statistically significant differences will be found in this study. The power of the statistical tests would have increased with a larger number of participants. As Cohen states:

> . . . Most important, whatever else sample reliability may be dependent upon, it *always* depends upon the size of the sample. . . . The larger the sample size, other things being equal, the smaller the error and the greater the reliability or precision of the results. The further relationship with power is also intuitively evident: the greater the precision of the sample results, other things being equal, the greater the probability of detecting a nonnull state of affairs. (Cohen, 1969, p. 7)

A lack of statistically significant findings may be the results of small sample sizes which in turn made it difficult to detect nonnull relationships. The principal investigator acknowledges this as a limiting factor in the study and examined trends within the data that may have been significant if a larger sample had been utilized.

Trends noted within this study never reach a level of statistical significance but are mentioned when they approach a 70% probability level. These trends may be of interest to training professionals. This specifically applies to larger companies, with many employees, where a 10% increase in productivity might mean saving millions of dollars. Reviewing literature will demonstrate that most of the companies reporting benefits from simulation and virtual reality training fit this profile.

Conclusions

Traditional and simulated training environments are significantly better than virtual training environments for developing cognitive skills among trainees. This was demonstrated in both the original and revised studies. If content is the only training factor to be considered, then virtual environments would not be as cost effective as traditional or simulation methods for content delivery.

This study demonstrated that simulation and virtual reality training environments can overcome the effects of inadequate training. Participants exposed to the simulation and virtual reality training methods had final performance scores which did not differ with statistical significance from participants exposed to traditional training mentors. This was true in the original study where virtual reality trainees were not given the training objectives. The mean final performance score of trainees exposed to virtual training environments was 48.320 in the original study and 49.086 in the revised study. This consistency in final performance scores demonstrates that training objectives are met in virtual environments even when inadequate training was provided. The rise in the final performance score for trainees exposed to virtual reality training methods (from 48.320 to 49.086) reflects the rise in the number of questions asked by trainees exposed to virtual training environments. The number of questions asked by trainees exposed to virtual environment training methods increased as more information was provided about the purpose of the training. The probability that there was a difference between the number of "training environment" questions asked by participants exposed to different training methods dropped from p = .8921 in the original study to .186 in the revised study. The probability that there was a difference between the number of "content/robot" questions asked by participants exposed to different training methods dropped from .9772 in the original study to .505 in the revised study. The probability that there was a difference in the number of "other relevant" questions asked by participants exposed to different training methods dropped from .4369 in the original study to .163 in the revised study. The probability that there was a difference in the number of "total relevant" questions asked by trainees exposed to different training methods dropped from .9329 in the original study to .257 in the revised study. This demonstrates that learning, as indicated by the number of questions asked, will increase as more information about training objectives is given to the trainees exposed to virtual training environments.

Studies have tried to show that virtual reality is a better training tool than either simulations or traditional training methods. This study does not have any statistical evidence indicating that this is true. Yet, companies and military institutions continue to develop virtual training environments and proclaim their benefits. The author believes that there are trends present within this study that explain why this is happening and identifies areas that warrant further investigation.

Past studies have looked for a statistically significant difference in mean performance scores. That is the mean performance score of group A will be significantly different than the mean performance score of group B. This is not how simulation and virtual reality environments affected training performance in this study. Instead, variation of performance scores decreased as the training environments became more immersive. Figures 4.2 and 4.4 display this idea. Statistical significance will not be found unless the trainee population is a very diverse group with significant differences in learning styles. This is why large companies and military institutions see benefits from simulation and VR training. Reducing trainee variance becomes significant at an approximate p level of .70. Studies with small sample sizes or companies with two or three employees will not see this benefit of using simulation and virtual reality training methods because the variability is too high to be evident.

Many VR studies use a homogenous group of people with little variation in technical experience, age, computer experience or learning styles. Past studies that did find differences between virtual reality and traditional training methods, used populations with a diverse background. A psychologist doing a study on the fear of the outdoors using acrophobiacs will probably have a more diverse sample than this study did when it used students enrolled at Iowa State University. Thus the principal investigator exploring training methods for acrophobiacs will be more likely to find training differences than were evident in this study.

When the study sample is recruited from a homogenous population (such as Mechanical Engineers and Industrial Technologists), few training differences are likely to be found. When the same study is administered to radically different populations (such as university students and community college students), radically different results will be obtained. This is because the effectiveness of traditional, simulation and virtual training methods may be related to individual learning styles. Control does not lie with the trainer or within the training environment. Control lies within the individual trainee as a result of an interaction between individual learning styles and training environments.

Researchers are assuming that success or failure in virtual environments is the result of the technology used for presentation. The degree of presence or the amount of immersion affects performance. This study failed to find any significant correlation between immersion and final performance scores or between presence and final performance scores. This was similar to the results found by Witmer and Singer who state:

> (When measuring presence in virtual environments) the total (Presence Questionnaire) score was correlated with the task performance measures (and) few significant correlations were found. There were negative, but non-significant, correlations between the totals for both administrations of the (Presence Questionnaire) and performance measures on almost all of the tasks. (Witmer and Singer, 1994, p. 22)

Witmer and Singer (1994) suggest that the lack of significant correlations was the result of trainees having difficulty with the type of control devices (joysticks or spaceballs) used during training. They used partial correlations to reduce the variance of the performance measure associated with the control devices and then found significant correlations in some tasks which they outlined in their study.

This principal investigator suggests that other factors, besides presence and immersion, may affect the immersion-task performance correlations and the presence-task performance correlations.

First, the sample sizes used in this study may have been to small to reflect any significant correlations. Yet, the immersion and presence correlations found in this study are similar to the results found by Witmer and Singer (1994).

Second, the simulation and virtual reality training environments may have been real enough to accomplish the training objectives but may not have been realistic enough to create a sense of presence. The lack of realism is present in current VR training systems. Olaf Westgaard, a consultant helping develop Motorola's *Virtual Assembly Line*, states that:

> Motorola wanted 100% fidelity, and got 100% of what was instructionally important. However, Westgaard is the first to admit that 100% fidelity was not achieved. He explained 'past a certain point, realism detracts from the experience. In VR we focus only on the important things.' The look and feel of the line was instantly recognizable to the trainees, including one who had never seen the lab ... (Immersive VR tests best, 1994, p. 2)

While training professional develop virtual reality training environments to meet training objectives, other groups are developing virtual reality environments to create the greatest sense of presence or immersion. It is possible that these differing objectives are not compatible.

Third, the degree of immersion or presence may be related to task complexity. A significant degree of immersion may be present in jet fighter simulations where trainees are operating within a complex environment and training for automaticity (Schneider, 1994). Trainees are aware that inadequate training may result in loss of life or the destruction of expensive equipment. Trainee's in this study utilized simulations and virtual environments to operate robots. Automatic processing was not a goal and loss of life or the loss of expensive equipment was not a concern.

Fourth, the degree of immersion or presence a trainee experiences may be associated with the type of training task. Immersion and presence variables were previously studied as participants moved within a virtual environment. Trainees had to move through a building and complete a set of tasks. This study examines immersion and presence variables as participants act upon objects within a virtual environment. Virtual robots were used to pick up objects and place them in different locations. Moving within a virtual environment instead of acting upon a virtual environment may impact immersion and presence scores.

Finally, this study suggests that it may not have been the training technology but rather the trainee and her/his learning style that affected success or failure within a particular training scenario. In the original portion of the study there was a significant difference in "kinesthetic" learning styles for trainees. Pick-and-place variances were less for trainees exposed to simulation and virtual training environments than they were for participants exposed to traditional training environments when the "kinesthetic" learning style reached significance. In the revised portion of this study there was a significant difference in the "formal design" learning style for trainees. Accuracy variances were less for trainees exposed to simulation and virtual training environments than they were for participants exposed to traditional training environments when the "formal design" learning style reached significance. It is possible that internal variables such as "learning style" will impact a trainees final performance score.

There is not enough research in place to state with confidence that these are the mechanisms that make simulation and virtual reality training more effective than traditional training. It should also be noted that the statistical tests used within the study describe the association between variables but causality cannot be assumed. Scores for one variable are not necessarily caused by the second variable. More research must be conducted to verify the results found in this study or find new trends that may explain why simulations and virtual environments are effective training methods in some situations. The conclusions the principal investigator made leads to suggestions for further study as noted below.

Recommendations

Several recommendations can be made to improve this study in case it should be reimplemented and other recommendations can be made for further investigation.

Improvements to this study can be made by altering the way "skill acquisition" is measured. It has been determined that cognitive knowledge is best gained in traditional environments. This applies to short term retention but does not address long-term retention. Removing the "cognitive gain" component so emphasis can be placed on the kinesthetic and the endurance components of skill acquisition is the first improvement to be made.

"Training time" and "performance time" measures should be changed to reflect industrial training environments. Establishing competency levels and recording the training time it takes for participants to achieve these predetermined levels may be a better measure of "training time". Pick-and-place tasks need to be administered so trainees know that time is a factor in performance. Instead of taking the time they need to place blocks into position, trainees should be instructed to place the blocks into position as quickly as possible. Measures would be changed to reflect what a trainee "can do" instead of what a trainee "will do". This is described by DuBois, Sackett, Zedeck and Fogli (1993, p. 205) when they write that 'maximum performance measures are designed to reflect what an individual "can do," whereas typical performance measures are designed to reflect what an individual "will do." DuBois et. al (1993, p. 207) further state that "the variance in maximum performance criteria is primarily ability related, whereas the variance in typical performance criteria contains substantial components that are not related to ability." Changing measures from those that measure typical performance to those that measure maximum performance will help determine if there are differences in training and performance times for traditional, simulated and virtual reality training methods.

Finally, the VEPAB's immersion and presence questionnaires need to be revised for participants exposed to traditional and simulation training techniques. The VEPAB components were designed for virtual environments. Participants in traditional and simulation environments were unable to answer the VEPAB questions consistently. For example, one VEPAB question asks trainees to identify how much control they feel they have within their training environment. At least one person in the traditional environment expressed a great deal of control because he volunteered for the study and was able to walk out at any time. While this accurately reflected his feelings, the individual had little control over the training environment as viewed from a trainer's perspective. The principal investigator believes these types of misinterpretations affected "immersion" and "presence" scores. Revising these instruments for use in traditional and simulation training environments would alleviate this problem.

This study also identified trends or showed statistically significant differences which warrant further investigation. Suggestions for further research are indicated on the following pages. They include:

1. Run a similar study using a more diverse population and gather a larger sample. This may include individuals from an actual company, a vocational school versus a college or people who have been raised in America with individuals raised in some other country. Populations studied have been too homogenous to date.
2. When investigating virtual reality, individual learning styles must also be investigated. This will help determine whether variances in training are the result of the training method or the result of the training methodology and technology.
3. Conduct a similar study which measures the amount of time it takes to reach a predetermined competency level. Final performance time should be

measured with participants knowing that they have either a predetermined time limit or must complete the task as quickly as possible.

4. Revise the "immersion" and "presence" questionnaires found in the VEPAB and use in other comparative studies to find out if "immersion" and "presence" affect training effectiveness.
5. Collect "learning style" data for participants exposed to traditional, simulation and virtual training methods to find which, if any, learning style indicators correspond to improved performance in training environments.
6. Compare the retention rate, both long and short term, for trainees exposed to traditional, simulation and virtual environments. Is one training method more effective for developing short and long term retention?
7. Study the effects of adding intelligent tutoring systems to both simulation and virtual environments.
8. Compare a virtual training environment with a head mounted display to an equivalent panel mounted display as suggested by Ellis (Stephen Ellis, 1994, p. 20-21).
9. Study the effects of realism in VR to training effectiveness (McCormick, 1981). How realistic does the training model have to be to be an effective training tool?
10. Explore the effect of lag time between training to application in different environments. Is there a higher retention rate in one method of training than than another as this lag time increases?

11. Distinguish between types of training tasks, i.e. trainees acting within an environment (moving through a house) and acting upon an environment (manipulating a robot), and determine if presence and immersion scores for the two groups differ.
12. Compare how the immersion and presence affect a trainee's ability to handle tasks varying in complexity.
13. Study the effects of training method on an individual's stamina/task endurance during training and in task performance.

This study served as a starting point for research into the effectiveness of simulation and virtual reality as a training tool. There may be some benefits to using simulations or VR for training but more studies must be completed to establish if the patterns found in this study are indicative of results found in real-world scenarios. Studying the thirteen suggested topics will help establish where the strengths and weaknesses of VR and simulation training lie. These research projects may help VR and simulation training become accepted and more widely used as a training tool in American business and industry.

APPENDIX A

RECRUITMENT AND INTRODUCTORY MATERIALS

January 2, 1997

To all interested test participants:

I am a graduate student at Iowa State University, who is conducting research titled "Comparison of Traditional Training to Virtual Environments." This investigation compares traditional reading and lecture methods of learning to achievement in simulated and virtual environments. As the principal investigator of this project, I will collect data to be used in my thesis.

The test is going to be conducted in the ICEMT computer laboratories in Black Engineering and at the Industrial Education II building on the Iowa State University campus. About 40 participants will be involved in performing simple tasks in a traditional, simulated or virtual environment as well as on an actual robot. Confidentiality is ensured and no participant names will be used during the test or the statistical analysis.

A pretest questionnaire and a learning styles inventory will be given at an announced date. This will take about two hours to complete. Another one to three hours of time will be needed to receive training, work on a robot and complete exit questionnaires. This is not a longitudinal study, so you will not be contacted in the future for further research.

Some people experience physical discomfort, such as nauseousness, when in a virtual environment. If you are in a virtual environment and you do have this experience, you may immediately remove yourself from the virtual environment. You do not need to reenter the environment which caused discomfort.

Robots used in this study are table top, educational robots with little chance of causing physical injury to an individual. Safety areas will be marked around robots when they are used in the final evaluation. The principal investigator will be present when the robot is operating to answer your questions and oversee safe handling procedures.

Participants in this study is voluntary. If you choose to take part in this research project please return this form with your signature below acknowledging your consent to participate.

Please contact me at work 515-433-0890, ext 275 or at home 515-432-2803 if you have any questions.

Sincerely,

Sylvia Tiala
Principal Investigator

Yes, I consent to participate in this study:

______________________________ ____________________
Name Date

March 31, 1997

Dear Engineering Students:

I am a graduate student at Iowa State University who is conducting research during the Spring, 1997 term. This research will be used to complete my thesis for a MS degree. I need interested participants who have little or no robotic experience to complete this study.

The purpose of this study is to compare traditional teaching techniques to simulated training techniques and virtual reality training techniques. Study participants will be assigned to either the "traditional", "simulated" or "virtual reality" group. During training you will learn how to operate a small robot. You then will be asked to move object(s) from one point to another using this real robot.

The whole study is estimated to take between three and six hours to complete. You will be instructed how to keep track of your time so you can get reimbursed at a rate of $6/hour. This is a short-term study and you will not be asked for further help or input beyond this semester.

If you are interested in participating in this study you need to sign up on the registration sheet provided. You also need to attend the introductory meeting where you will complete a "Learning Styles" inventory, provide a contact address, and sign a consent form. The whole process should take about 1 hour.

Two meetings are set up for interested participants. You may come to either one. These will be at:

Black Engineering room 3004/3006
Wednesday, April 2 at 5:00 PM
OR
Monday, April 7 at 5:00 PM

Please contact me if you have questions or concerns.

Sylvia Tiala
801 Carroll Street
Boone, IA 50036
515-432-2803

Comparison of Traditional, Simulated and Virtual Training Methods
Sign Up Sheet

April 1, 1997
Participant Contact Information:

I would like to make your participation in this study as convenient as possible. I also need to randomly assign you to one of three training groups. I will need the following information from you in order to contact you and still insure confidentiality.

Name: ____________________

Student ID Number: ____________________

email address: ____________________

Contact Address: ____________________

____

____

Phone Number(s) ____________________

Best time to call: ____________________

Please specify the times you ARE available on the following week days:

Monday (from 5PM or later) ____________________

Tuesday (from 5PM or later) ____________________

Wednesday (from 5PM or later) ____________________

Thursday (from 5PM or later) ____________________

Friday (from 5PM or later) ____________________

Saturday ____________________

Sunday ____________________

TO: Dr. and Dr.
FROM: Sylvia Tiala
DATE: June 10, 1997
REGARDING: Virtual Reality Study

Thank you for agreeing to recruit students for my study in virtual reality training. The goal is to measure the transfer of training from a virtual environment to a real setting. I am trying to recruit about 15 students to participate in this phase of the study. This includes having students enter a virtual environment where they learn to operate a robot and then try to do similar activities using a real robot.

I have enclosed this letter, a sign up sheet and recruitment letters as per your direction. I would like to run my introductory session this Thursday and Friday. Can you please hand out the recruitment letters to your students, collect signatures on the "Sign Up Sheet" and return the "Sign Up Sheet" to the Mechanical Engineering Office by Thursday morning? Your time and help is greatly appreciated.

Thank you for your efforts. Please call me if you have any questions or concerns.

Sylvia Tiala
515-432-2803
sylvia.tiala@boone.k12.ia.us

June 10, 1997

To all Undergraduate Engineering Students:

I am a graduate student at Iowa State University, who is conducting research titled "Comparison of Traditional Training to Virtual Environments." This investigation compares traditional reading and lecture methods of learning to achievement in simulated and virtual environments. As the principal investigator of this project, I will collect data to be used in my thesis.

The test is going to be conducted in the ICEMT computer laboratories in Black Engineering. Participants will be involved in performing simple tasks in a virtual environment as well as on an actual robot. Confidentiality is ensured and no participant names will be used during the test or the statistical analysis

The study will take about three hours of your time. An introductory session, lasting about an hour, will introduce you to the study, and preliminary data will be collected. A second session will be scheduled for you in the virtual reality lab in Black Engineering. The final session, also lasting about an hour will have you working with a small robot. You will be paid for your time during this study at the rate of $6 per hour. This is not a longitudinal study, so you will not be contacted in the future for further research.

Some people experience physical discomfort, such as nauseousness, when in a virtual environment. If you are in a virtual environment and you do have this experience, you may immediately remove yourself from the virtual environment. You do not need to reenter the environment which caused discomfort.

Robots used in this study are table top, educational robots with little chance of causing physical injury to an individual. Safety areas will be marked around robots when they are used in the final evaluation. The principal investigator will be present when the robot is operating to answer your questions and oversee safe handling procedures.

Participants in this study is voluntary. If you choose to take part in this research project please sign up on the sheet your instructor has for participation and come to one of two introductory sessions. The sessions are as follows:

Thursday:	June 12, 1997	Black Engineering room 3004	3:00 PM
Friday:	June 13, 1997	Black Engineering room 3004	1:00 PM

Please contact me at home 515-432-2803 or at: sylvia. tiala@boone.k12.ia.us if you have any questions.

Sincerely,

Sylvia Tiala
Principal Investigator

Virtual Reality Training Sign Up Sheet

Name	Phone	email address	Convenient time for Wednesday, Thursday or Friday Session Specify DAY & TIME

June 11, 1997
Participant Contact Information:

I would like to make your participation in this study as convenient as possible. I also need to schedule you into a virtual environment and schedule you for time on a robot. I will need the following information from you in order to contact you and still insure confidentiality.

Name: ____________________

Student ID Number: ____________________

Student email address: ____________________

Contact Address: ____________________

____

____

Phone Number(s) ____________________

Best time to call: ____________________

Please specify the times you ARE available on the following week days:

Monday (8AM-6PM) ____________________

Tuesday (8AM-6PM) ____________________

Wednesday (8AM-6PM) ____________________

Thursday (8AM-6PM) ____________________

Friday (8AM-6PM) ____________________

Piney Mountain Press, Inc. (1994)

VOCATIONAL LEARNING STYLES INVENTORY   RESPONSE SHEET 1

NAME:____________________ DATE:____________

Study each statement carefully and choose one of the 4 answers that best describes how you feel about what is said. Fill in the space containing the number of your choice.

[4] = MOST LIKE ME [3] = SOMEWHAT LIKE ME [2] = NOT MUCH LIKE ME [1] = LEAST LIKE ME

---

1. When I am trying hard to learn or study something, I pace the floor ---- [4][3][2][1] 1.
2. I remember what I learn by closing my eyes to recall it ---- [4][3][2][1] 2.
3. Taking notes in a notebook helps me learn best ---- [4][3][2][1] 3.
4. When learning information for the first time I read it aloud ---- [4][3][2][1] 4.
5. I like studying with one or more friends ---- [4][3][2][1] 5.
6. Studying alone is enjoyable to me ---- [4][3][2][1] 6.
7. I study better when sitting at a desk or table ---- [4][3][2][1] 7.
8. When I study, I like to sit in a soft chair, on pillows or on a couch ---- [4][3][2][1] 8.
9. A well lit room helps me study better ---- [4][3][2][1] 9.
10. I learn best in a room that is dimly lit ---- [4][3][2][1] 10.
11. Studying in a warm, cozy room makes it easier for me to learn ---- [4][3][2][1] 11.
12. I feel more comfortable in cool weather ---- [4][3][2][1] 12.
13. Studying is best for me when it is quiet ---- [4][3][2][1] 13.
14. Noise helps me to study or concentrate ---- [4][3][2][1] 14.
15. Speaking helps me express my ideas better than writing ---- [4][3][2][1] 15.
16. It is easier for me to write what is on my mind than to speak it ---- [4][3][2][1] 16.
17. Working in jobs out-of-doors is enjoyable to me ---- [4][3][2][1] 17.
18. I prefer jobs requiring me to work indoors ---- [4][3][2][1] 18.
19. I like working on a job that requires me to work at a desk or table ---- [4][3][2][1] 19.
20. Moving from one area to another to work is something I enjoy ---- [4][3][2][1] 20.
21. I enjoy lifting and moving items on my job ---- [4][3][2][1] 21.
22. Lifting or moving things on my job is not what I like to do ---- [4][3][2][1] 22.
23. Looking up information in a library is enjoyable to me ---- [4][3][2][1] 23.
24. I enjoy working with people more than working with data ---- [4][3][2][1] 24.
25. I prefer working with things rather than with people ---- [4][3][2][1] 25.
26. Tapping my foot or fingers helps me to study or learn ---- [4][3][2][1] 26.
27. When I read materials, important facts are easy to remember ---- [4][3][2][1] 27.
28. Using an outline helps me study ---- [4][3][2][1] 28.
29. I learn best through class discussions and lectures ---- [4][3][2][1] 29.
30. The things I do best I do with my friends ---- [4][3][2][1] 30.
31. The things I do best I do alone, without my friends ---- [4][3][2][1] 31.
32. When I study, I like to sit in a straight chair ---- [4][3][2][1] 32.
33. I learn best when I am sitting on the floor in a relaxed area ---- [4][3][2][1] 33.
34. A well-lit area helps me think more clearly ---- [4][3][2][1] 34.
35. I like to study in a dimly-lit area ---- [4][3][2][1] 35.
36. I can think or concentrate better when I am warm ---- [4][3][2][1] 36.
37. When I am cool, I think more clearly ---- [4][3][2][1] 37.
38. Noise keeps me from thinking or concentrating on my work ---- [4][3][2][1] 38.

Piney Mountain Press, Inc. (1994)

VOCATIONAL LEARNING STYLES INVENTORY — RESPONSE SHEET 2

NAME:______________________ DATE:__________

Study each statement carefully and choose one of the 4 answers that best describes how you feel about what is said. Fill in the space containing the number of your choice.

[4] = MOST LIKE ME [3] = SOMEWHAT LIKE ME [2] = NOT MUCH LIKE ME [1] = LEAST LIKE ME

39. Before studying new information, I turn on the radio or television ---------- [4][3][2][1] 39.
40. I enjoy being called upon to explain answers or situations ---------- [4][3][2][1] 40.
41. I express myself better in writing than in speaking ---------- [4][3][2][1] 41.
42. Working out-of-doors relaxes me ---------- [4][3][2][1] 42.
43. Working indoors relaxes me ---------- [4][3][2][1] 43.
44. I enjoy working in one area ---------- [4][3][2][1] 44.
45. Working in one area for a long period of time bothers me ---------- [4][3][2][1] 45.
46. Lifting and moving things helps me show others how strong I am ---------- [4][3][2][1] 46.
47. I seek jobs that do not require me to lift or move objects ---------- [4][3][2][1] 47.
48. Working with facts or figures is enjoyable to me ---------- [4][3][2][1] 48.
49. I would rather work with people than with things, facts or figures ---------- [4][3][2][1] 49.
50. I would rather work with things than with people, facts or figures ---------- [4][3][2][1] 50.
51. When I can relate to something I have done, I understand it better ---------- [4][3][2][1] 51.
52. I enjoy reading ---------- [4][3][2][1] 52.
53. When I read, I remember best when I underline the important facts ---------- [4][3][2][1] 53.
54. To remember important facts, I need only to listen carefully ---------- [4][3][2][1] 54.
55. I like my friends to assist me in completing my assignments ---------- [4][3][2][1] 55.
56. Studying is something I like to do by myself ---------- [4][3][2][1] 56.
57. I like to have all my materials handy when I study ---------- [4][3][2][1] 57.
58. When sitting on my bed, I study or learn new information better ---------- [4][3][2][1] 58.
59. Bright lights help me think better ---------- [4][3][2][1] 59.
60. Dim lights help me think better ---------- [4][3][2][1] 60.
61. Being in a warm area helps keep me alert ---------- [4][3][2][1] 61.
62. Cool surroundings help me stay alert ---------- [4][3][2][1] 62.
63. Loud or soft noises bother me when I am trying to study ---------- [4][3][2][1] 63.
64. I study best in a noisy area ---------- [4][3][2][1] 64.
65. I would rather call a friend on a telephone than write a letter ---------- [4][3][2][1] 65.
66. When I want to express my ideas, I jot them down first ---------- [4][3][2][1] 66.
67. If I could choose my job setting it would be out-of-doors ---------- [4][3][2][1] 67.
68. If I could choose my job setting it would be indoors ---------- [4][3][2][1] 68.
69. I would rather work in one area than moving to different areas ---------- [4][3][2][1] 69.
70. I would rather have different work areas than just one work area ---------- [4][3][2][1] 70.
71. Moving or arranging things is something I seek in a job ---------- [4][3][2][1] 71.
72. Letting others know how strong I am on a job is not important ---------- [4][3][2][1] 72.
73. I seek jobs that require me to work with facts or figures ---------- [4][3][2][1] 73.
74. Working with people is something I seek in a job ---------- [4][3][2][1] 74.
75. Something I seek in a job is working with things ---------- [4][3][2][1] 75.

HOURLY PARTICIPATION LOG

NAME: ______________________________

DATE:	TIME IN:	TIME OUT:	TOTAL HOURS:
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________
______	__________	__________	_______________

Introductory Survey

Student ID Number: _______________

Date: _______________

Age: _______________

Major of Study: _______________

Gender: (circle one) Male Female

Do you use glasses or lenses?

If yes:

Are you nearsighted? ________

Are you farsighted? ________

Are your corrective lenses up to date? Yes No

Will you be using them during this study Yes No

Do you have any previous experience with robots? Yes ___ No ___

If yes: Estimate the number of hours and list type of robot(s) you have used.

Type of Robot	Time spent using	(circle one)			
_________________	_________	hours	days	months	years
_________________	_________	hours	days	months	years
_________________	_________	hours	days	months	years

Do you have previous computer experience? Yes No

If yes how many hours/days/months experience do you have with:

IBM or compatible:	_______	hours	days	months	years
Apple/Macintosh:	_______	hours	days	months	years
SGI/SUN/UNIX:	_______	hours	days	months	years
Other____________: (list)	_______	hours	days	months	years

Identify as many of the major elements in this Rhino robot system as you can. Write the name of each part in the numbered blanks below.

______________________1.

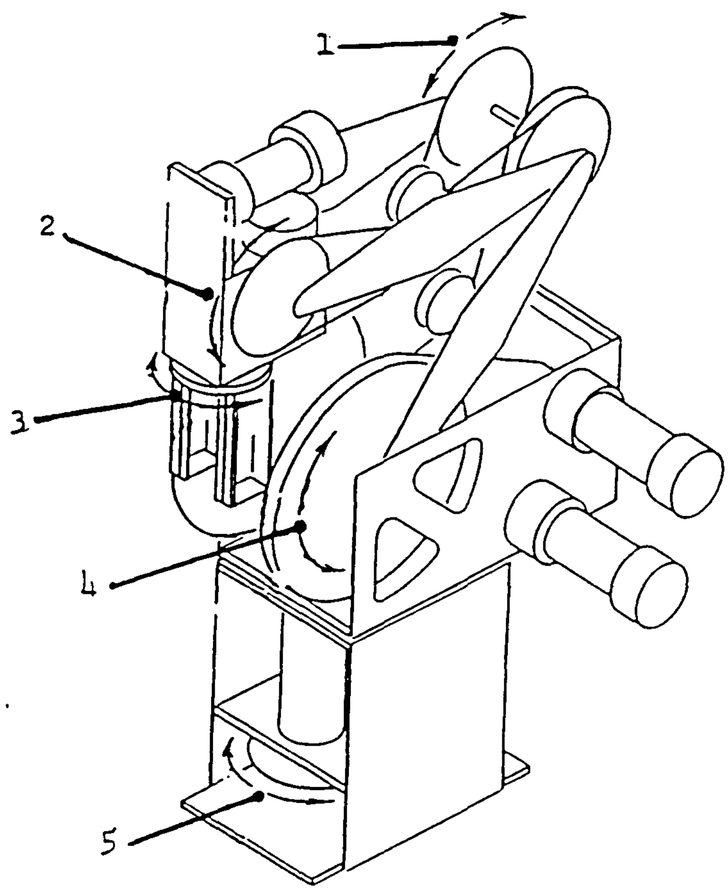
______________________ 2.

______________________ 3.

______________________ 4.

______________________ 5.

______________________ 6.



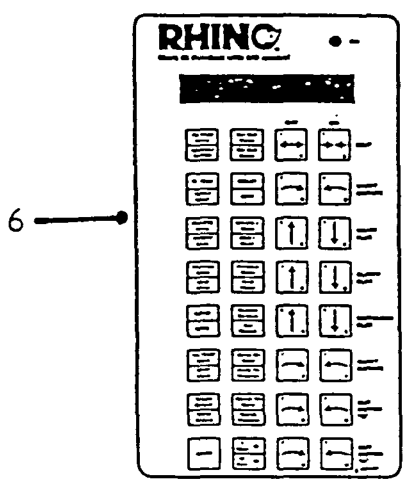


Figure reprinted with permission of Rhino Robots, (1985)

PLEASE COMPLETE AND TURN IN THIS QUESTIONNAIRE AND YOUR LEARNING STYLES INVENTORY BEFORE LEAVING THIS SESSION.

THANK YOU FOR YOUR TIME AND HELP

APPENDIX B

TRAINING MATERIALS

VR Time Schedule for the week of June 16 - 22

Time	Monday 16	Tuesday 17	Wednesday 18	Thursday 19	Friday 20
8-9AM	_____	_____	_____	_____	_____
9-10AM	_____	_____	_____	_____	_____
10-11AM	_____	_____	_____	_____	_____
11-Noon	_____	_____	_____	_____	_____
12-1PM	_____	_____	_____	_____	_____
1-2PM	_____	_____	_____	_____	_____
2-3PM	_____	_____	_____	_____	_____
3-4PM	_____	_____	_____	_____	_____
4-5PM	_____	_____	_____	_____	_____
5-6PM	_____	_____	_____	_____	_____

ID Number ____________________

Date ____________________

IMMERSIVE TENDENCIES QUESTIONNAIRE
(Witmer & Singer, Version 3.01, September 1996)

Indicate your preferred answer by marking an "X" in the appropriate box of the seven point scale. Please consider the entire scale when making your responses, as the intermediate levels may apply. For example, if your response is once or twice, the second box from the left should be marked. If your response is many times but not extremely often, then the sixth (or second box from the right) should be marked.

1. Do you easily become deeply involved in movies or tv dramas?

|_____|_____|_____|_____|_____|_____|_____|
NEVER OCCASIONALLY OFTEN

2. Do you ever become so involved in a television program or book that people have problems getting your attention?

|_____|_____|_____|_____|_____|_____|_____|
NEVER OCCASIONALLY OFTEN

3. How mentally alert do you feel at the present time?

|_____|_____|_____|_____|_____|_____|_____|
NOT ALERT MODERATELY FULLY ALERT

4. Do you ever become so involved in a movie that you are not aware of things happening around you?

|_____|_____|_____|_____|_____|_____|_____|
NEVER OCCASIONALLY OFTEN

5. How frequently do you find yourself closely identifying with the characters in a story line?

|_____|_____|_____|_____|_____|_____|_____|
NEVER OCCASIONALLY OFTEN

6. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?

|_____|_____|_____|_____|_____|_____|_____|
NEVER OCCASIONALLY OFTEN

7. What kind of books do you read most frequently? (CIRCLE ONE ITEM ONLY!)

Spy novels	Fantasies	Science fiction
Adventure novels	Romance novels	Historical novels
Westerns	Mysteries	Other fiction
Biographies	Autobiographies	Other non-fiction

8. How physically fit do you feel today?

|_______|_______|_______|_______|_______|_______|_______|

NOT FIT   MODERATELY FIT   EXTREMELY FIT

9. How good are you at blocking out external distractions when you are involved in something?

|_______|_______|_______|_______|_______|_______|_______|

NOT VERY GOOD   SOMEWHAT GOOD   VERY GOOD

10. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?

|_______|_______|_______|_______|_______|_______|_______|

NEVER   OCCASIONALLY   OFTEN

11. Do you ever become so involved in a daydream that you are not aware of things happening around you?

|_______|_______|_______|_______|_______|_______|_______|

NEVER   OCCASIONALLY   OFTEN

12. Do you ever have dreams that are so real that you feel disoriented when you awake?

|_______|_______|_______|_______|_______|_______|_______|

NEVER   OCCASIONALLY   OFTEN

13. When playing sports, do you become so involved in the game that you lose track of time?

|_______|_______|_______|_______|_______|_______|_______|

NEVER   OCCASIONALLY   OFTEN

14. How well do you concentrate on enjoyable activities?

|______|______|______|______|______|______|______|

NOT AT ALL MODERATELY WELL VERY WELL

15. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)

|______|______|______|______|______|______|______|

NEVER OCCASIONALLY OFTEN

16. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

|______|______|______|______|______|______|______|

NEVER OCCASIONALLY OFTEN

17. Have you ever gotten scared by something happening on a TV show or in a movie?

|______|______|______|______|______|______|______|

NEVER OCCASIONALLY OFTEN

18. Have you ever remained apprehensive or fearful long after watching a scary movie?

|______|______|______|______|______|______|______|

NEVER OCCASIONALLY OFTEN

19. Do you ever become so involved in doing something that you lose all track of time?

|______|______|______|______|______|______|______|

NEVER OCCASIONALLY OFTEN

20. On average, how many books do you read for enjoyment in a month?

|______|______|______|______|______|______|______|

NONE ONE TWO THREE FOUR FIVE MORE

21. Do you ever get involved in projects or tasks, to the exclusion of other activities?

|______|______|______|______|______|______|______|

NEVER OCCASIONALLY OFTEN

22. How easily can you switch attention from the activity in which you are currently involved to a new and completely different activity?

|_____|_____|_____|_____|_____|_____|_____|

NOT SO EASILY — FAIRLY EASILY — QUITE EASILY

23. How often do you try new restaurants or new foods when presented with the opportunity?

|_____|_____|_____|_____|_____|_____|_____|

NEVER — OCCASIONALLY — FREQUENTLY

24. How frequently do you volunteer to serve on committees, planning groups, or other civic or social groups?

|_____|_____|_____|_____|_____|_____|_____|

NEVER — SOMETIMES — FREQUENTLY

25. How often do you try new things or seek out new experiences?

|_____|_____|_____|_____|_____|_____|_____|

NEVER — OCCASIONALLY — OFTEN

26. Given the opportunity, would you travel to a country with a different culture and a different language?

|_____|_____|_____|_____|_____|_____|_____|

NEVER — MAYBE — ABSOLUTELY

27. Do you go on carnival rides or participate in other leisure activities (horse back riding, bungee jumping, snow skiing, water sports) for the excitement of thrills that they provide?

|_____|_____|_____|_____|_____|_____|_____|

NEVER — OCCASIONALLY — OFTEN

28. How well do you concentrate on disagreeable tasks?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — MODERATELY WELL — VERY WELL

29. How often do you play games on computers?

|____|____|____|____|____|____|____|
NOT AT ALL OCCASIONALLY FREQUENTLY

30. How many different video, computer, or arcade games have you become reasonably good at playing?

|____|____|____|____|____|____|____|
NONE ONE TWO THREE FOUR FIVE SIX OR MORE

31. Have you ever felt completely caught up in an experience, aware of everything going on and completely open to all of it?

|____|____|____|____|____|____|____|
NEVER OCCASIONALLY FREQUENTLY

32. Have you ever felt completely focused on something, so wrapped up in that one activity that nothing could distract you?

|____|____|____|____|____|____|____|
NOT AT ALL OCCASIONALLY FREQUENTLY

33. How frequently do you get emotionally involved (angry, sad, or happy) in news stories that you see, read, or hear?

|____|____|____|____|____|____|____|
NEVER OCCASIONALLY OFTEN

34. Are you easily distracted when involved in an activity or working on a task?

|____|____|____|____|____|____|____|
NEVER OCCASIONALLY OFTEN

Student ID #: ______________

PRESENCE QUESTIONNAIRE
(Witmer & Singer, Vs. 3.0, Nov. 1994)

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT

1. How much were you able to control events?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — SOMEWHAT — COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

|_______|_______|_______|_______|_______|_______|_______|

NOT RESPONSIVE — MODERATELY RESPONSIVE — COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

|_______|_______|_______|_______|_______|_______|_______|

EXTREMELY ARTIFICIAL — BORDERLINE — COMPLETELY NATURAL

4. How much did the visual aspects of the environment involve you?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — SOMEWHAT — COMPLETELY

5. How much did the auditory aspects of the environment involve you?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL — SOMEWHAT — COMPLETELY

6. How natural was the mechanism which controlled movement through the environment?

|_______|_______|_______|_______|_______|_______|_______|

EXTREMELY ARTIFICIAL — BORDERLINE — COMPLETELY NATURAL

7. How compelling was your sense of objects moving through space?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — MODERATELY COMPELLING — VERY COMPELLING

8. How much did your experiences in the virtual environment seem consistent with your real world experiences?

|_____|_____|_____|_____|_____|_____|_____|

NOT CONSISTENT — MODERATELY CONSISTENT — VERY CONSISTENT

9. Were you able to anticipate what would happen next in response to the actions that you performed?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — SOMEWHAT — COMPLETELY

10. How completely were you able to actively survey or search the environment using vision?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — SOMEWHAT — COMPLETELY

11. How well could you identify sounds?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — SOMEWHAT — COMPLETELY

12. How well could you localize sounds?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — SOMEWHAT — COMPLETELY

13. How well could you actively survey or search the virtual environment using touch?

|_____|_____|_____|_____|_____|_____|_____|

NOT AT ALL — SOMEWHAT — COMPLETELY

14. How compelling was your sense of moving around inside the virtual environment?

NOT COMPELLING	MODERATELY COMPELLING	VERY COMPELLING

15. How closely were you able to examine objects?

NOT AT ALL	PRETTY CLOSELY	VERY CLOSELY

16. How well could you examine objects from multiple viewpoints?

NOT AT ALL	SOMEWHAT	EXTENSIVELY

17. How well could you move or manipulate objects in the virtual environment?

NOT AT ALL	SOMEWHAT	EXTENSIVELY

18. How involved were you in the virtual environment experience?

NOT INVOLVED	MILDLY INVOLVED	COMPLETELY ENGROSSED

19. How much delay did you experience between your actions and expected outcomes?

NO DELAYS	MODERATE DELAYS	LONG DELAYS

20. How quickly did you adjust to the virtual environment experience?

NOT AT ALL	SLOWLY	LESS THAN ONE MINUTE

21. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

NOT PROFICIENT	REASONABLY PROFICIENT	VERY PROFICIENT

22. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

NOT AT ALL	INTERFERED SOMEWHAT	PREVENTED TASK PERFORMANCE

23. How much did the control devices interfere with the performance of assigned tasks or with other activities?

NOT AT ALL	INTERFERED SOMEWHAT	INTERFERED GREATLY

24. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

NOT AT ALL	SOMEWHAT	COMPLETELY

25. How completely were your senses engaged in this experience?

NOT ENGAGED	MILDLY ENGAGED	COMPLETELY ENGAGED

26. To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?

NOT AT ALL	MODERATELY	VERY MUCH

27. Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?

NOT AT ALL	SOMEWHAT	VERY MUCH

28. Were you involved in the experimental task to the extent that you lost track of time?

|_______|_______|_______|_______|_______|_______|_______|

NOT AT ALL SOMEWHAT COMPLETELY

29. How easy was it to identify objects through physical interaction; like touching an object, walking over a surface, or bumping into a wall or object?

|_______|_______|_______|_______|_______|_______|_______|

IMPOSSIBLE MODERATELY DIFFICULT VERY EASY

30. Were there moments during the virtual environment experience when you felt completely focused on the task or environment?

|_______|_______|_______|_______|_______|_______|_______|

NONE OCCASIONALLY FREQUENTLY

31. How easily did you adjust to the control devices used to interact with the virtual environment?

|_______|_______|_______|_______|_______|_______|_______|

DIFFICULT MODERATE EASILY

32. Was the information provided through different senses in the virtual environment (e.g., vision, hearing, touch) consistent?

|_______|_______|_______|_______|_______|_______|_______|

NOT CONSISTENT SOMEWHAT CONSISTENT VERY CONSISTENT

Pre-Display System Comfort Questionnaire
(Kennedy, Lane, Berbaum, & Lillienthal, 1993)

Display System Comfort Questionnaire # ___________

(pre)

1. Are you in your usual state of fitness: YES NO

   If not, what is the nature of your illness (flu, cold, etc).

2. Please indicate all medication you have used in the past 24 hours:

   (a) NONE

   (b) Sedatives or tranquilizers

   (c) Aspirin, Tylenol, other analgesics

   (d) Anti-histamines

   (e) Decongestants

   (f) other (specify):

3. How many hours sleep did you get last night? ___ (Hours)

   Was this amount sufficient? YES NO

Post-Display System Comfort Questionnaire
(Kennedy, Lane, Berbaum, & Lillienthal, 1993)

Student ID #____________________ Date:_______________

Display System Comfort Questionnaire (post)

1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eye Strain	None	Slight	Moderate	Severe
5.	Difficulty focusing	None	Slight	Moderate	Severe
6.	Salivation increased	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty concentrating	None	Slight	Moderate	Severe
10.	"Fullness of the Head"	No	Yes		
11.	Blurred Vision	No	Yes		
12.	a. Dizziness with eyes open	No	Yes		
	b. Dizziness with eyes closed	No	Yes		
13.	Vertigo	No	Yes		
14.	*Stomach awareness	No	Yes		
15.	Burping	No	Yes	No. of times ____	

16. Other: ____

* Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

ROBOT OPERATION USING THE TEACH PENDANT USING TRADITIONAL TRAINING TECHNIQUES (Instructor Copy)

(Adapted from Rhino Student Workbook, "Introduction to the Robot System" and "Operation of the Robot System" , 1985 edition. Permission for use obtained from Rhino Robotics Ltd., P.O. Box 230, Miamitown, OH 45041)

Teacher's Notes for Lecture in Traditional Training Techniques:

*Record Start Time: ________________

Setting the Learning/Teaching Environment:

*Before starting introduce yourself
*Answer any questions they may have
*Pass out copy of Objective sheet (Student Handout #1)
*Pass out drawing of robot with blanks for critical parts (Figure 2-13 from Rhino Robot Student Workbook, Module 1, Experiment 2, Student Handout #2)
*Pass out operation of the robot system (Figure 2-3, showing teach pendant, from Rhino Robot Student Workbook, Module 1, Experiment 2, student handout #3).
*Start recording questions posed by individuals on "Questions in Traditional Training" sheet.

Goals and Objectives:

You are here today to learn about the parts and operation of an XR-3 Rhino robot. Your objectives are:

Overhead #1= Goals and Objectives

[Put up overhead one and read out loud]
[Give students time to copy if they so choose, DO NOT tell them to take notes. If asked, say "yes" they should]

Robot System:

In order to accomplish this, you must become familiar with robotic systems and their parts.

The Rhino XR-3 robot system has all of the elements of an industrial robot. You will be working with three of these parts which includes:

[Put up overhead of the Rhino robot system]

Overhead #2= System diagram with all system shown but Teach pendant, XR arm and gripper highlighted.

The robotic arm, its gripper and the teach pendant that controls the robot's actions. Let's take a look at these three items.

Robotic Arm

The XR-3 robotic arm has five places where it moves around a centered axis. This is most commonly referred to as five degrees of freedom. These are the points around which the robot moves. The five axes of motion include:

[Instruct students to pull out sheet handed out in beginning of class with blank robot parts on it. Label each of the parts and motion how the robot will move around these axes using your arm and hand.]

Overhead #3=Diagram of robot with blanks in for major parts. Identify these parts on overhead while students write in parts on worksheet.

Waist (rotation), shoulder (flex), elbow (flex), wrist (rotate), wrist (flex) and gripper.

Motion is transferred from the drive motor axis to the joints by chain and lever linkages. The drive motors are controlled using optical encoders that determine joint angles and arm positions. These motors and linkages move when a command is given to the robot using the teach pendant.

Overhead #4= Diagram of Teach Pendant

[With overhead of teach pendant displayed indicate where the 32 keys are, the 7 character digital display, the reset button and the 16 keys for motion control. Indicate that they need not be concerned with the left set of keys used for program development.]

Teach Pendant:

The teach pendant has 32 keys which can be used to control and program the robot. It has a 7 character digital display and a reset button to restart the controller and act as an emergency stop. Fifteen of the keys are used for program development and 16 provide motion control for the robots 5 axis motors and gripper.

The motion keys on the Rhino teach pendant in Figure 2-3 form two similar groups plus a third group called auxiliary motors. The position axes are waist, shoulder, and elbow, while the orientation axes include the two wrist motions flex and rotation. There is motion control for two additional axes on the auxiliary equipment designated AUX. MOTOR "G" and AUX. MOTOR "H". Neither of these auxiliary motors are connected for this study and they can be ignored.

When any of the axis motion keys, A through H, are pressed, the axis motor moves 10 increments on the optical encoder which is about 1.2 degrees for the position axes. Each axis has a key for either the positive or negative direction. The teach pendant display shows the current axis move.

The first digit in the readout will be a "P" to indicate that the robot is in the play mode. The second digit will indicate the motor designation by letter. The third digit will be a + or - to indicate what direction the robot axis is moving from the home position. If a motor hits an object and cannot complete a move, the teach pendant will display PStall.
[Using handout of Figure 2-13 and using handout of teach pendant, go over what buttons on the teach pendant will control what actions on the robot
Have students as a group move an object from an hypothetical point A to point B.]

Record End Time: ____________________

Objectives:

1. Identify by name and location the following parts of a Rhino Robot:

   teach pendant
   gripper
   wrist rotation
   wrist flex
   elbow
   shoulder
   waist.

2. Move an object from point A to point B using a Rhino XR-3 robot and a teach pendant.

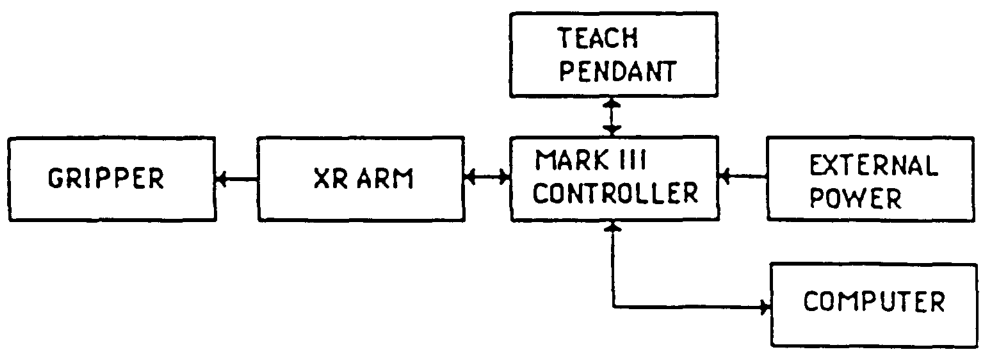


Figure 1-1

Overhead #2

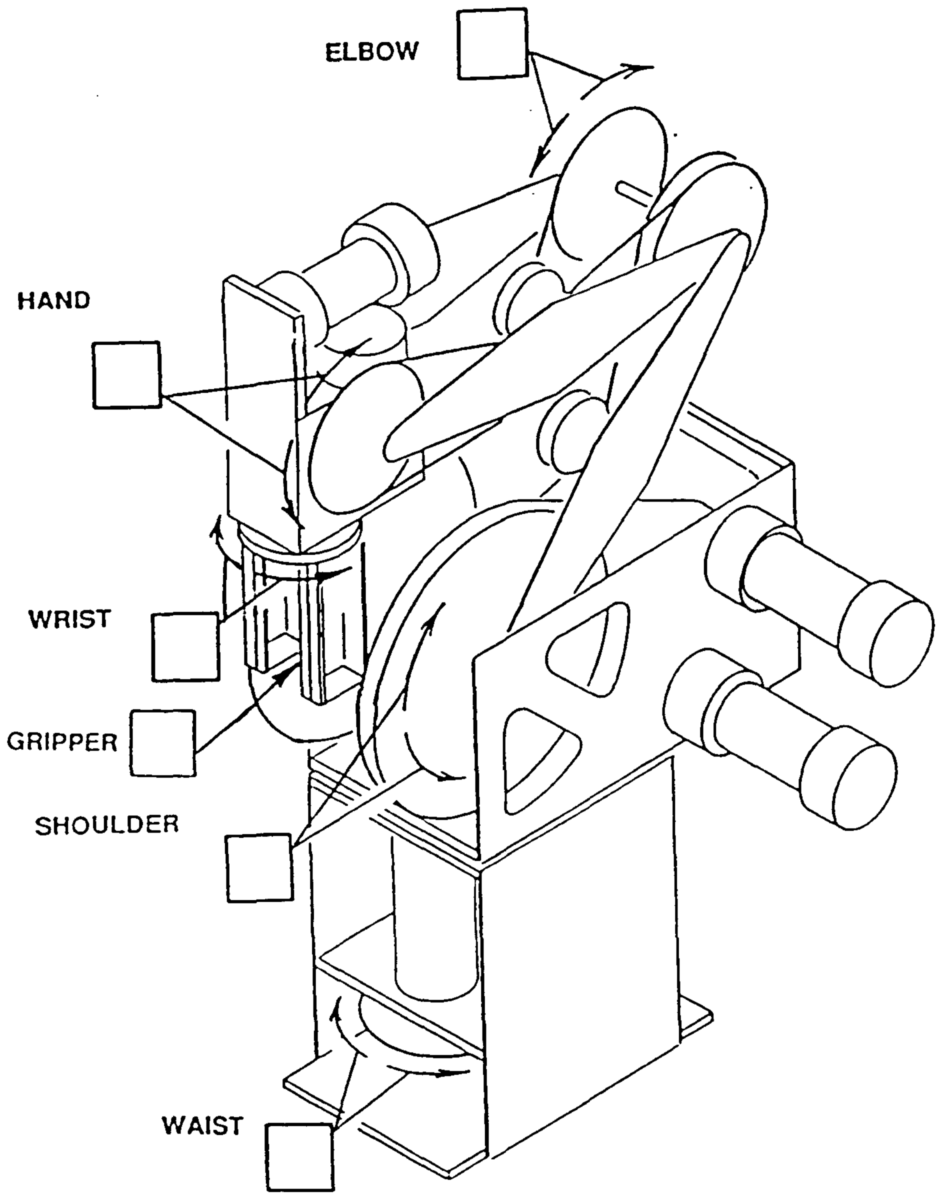


Figure 2-13

Overhead #3

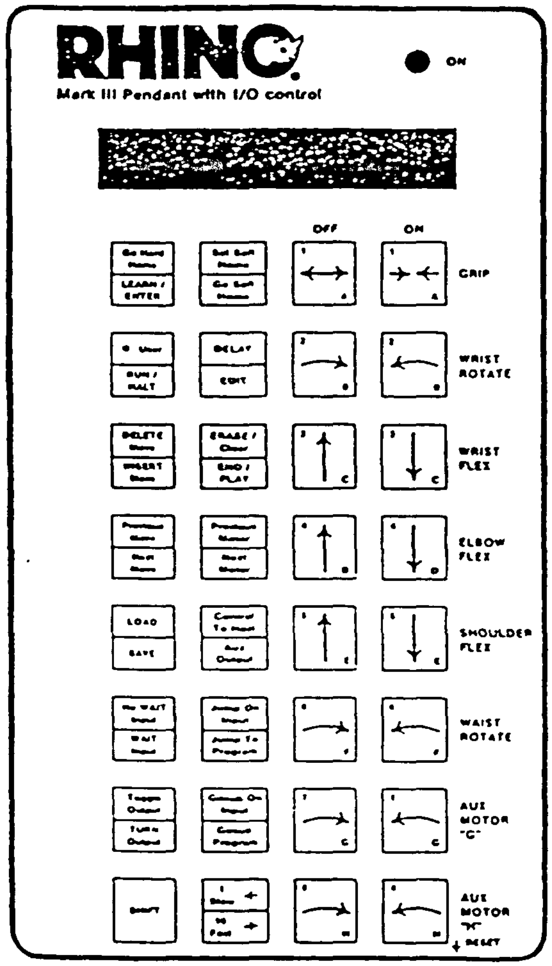


Figure 2-3

Overhead #4

LAB SETUP FOR
COMPUTER SIMULATION AND
VIRTUAL REALITY
(Instructions for uniform training in one hour sessions)

1. Setup lab
   *Make sure simulations/VR running
   *Straighten all peripheral cords
   *Insure all video, audio and tracking devices working correctly
   *Attach "Questions in Simulated Environments" or "Questions in Virtual Environments" sheets where they are accessible for you to access and record questions.

2. When trainees arrive:
   *Introduce yourself
   *Ask if they have any preliminary questions and answer them.

3. Begin training session:
   *Participants fill out "Immersive Tendency Questionnaires". Make sure the participant identification number is written down.
   *Record the starting time on the "Questions in Simulated/VR Environments" sheet.
   *Pass out "Student Handout Sheets" number 1 through 3 showing study objectives, robot parts, and teach pendant.
   *Read objectives aloud to each participant.
   *Show participants "Student Handout Sheets" number 2 and 3.

4. Introduce participant to Simulation/VR:
   *Prepare a short introduction that introduces participant to the training environment and ensures that the equipment is working. This includes but is not limited to pointing and clicking with the mouse, donning and doffing head-mounted-displays and pinch gloves, focusing head-mounted-displays, changing views with a mouse, changing body positioning, etc. MAKE SURE THIS IS THE SAME FOR ALL PARTICIPANTS.

5. Ending Session: Stop 15 minutes before end of scheduled session
   *Record end time on the "Questions in Simulation/VR" sheet
   *Each participant should fill out a "Presence Questionnaire" make sure student identification number is complete.
   *Tell participants to schedule more time with the principal investigator if they need more training time.

ROBOT OPERATION USING THE TEACH PENDANT IN COMPUTER SIMULATION (Instructor Copy)

Objectives:

1. Identify by name and location the following parts of a Rhino Robot: teach pendant, gripper, wrist rotation, wrist flex, elbow, shoulder and waist.

2. Move an object from point A to point B using a Rhino XR-3 robot and a teach pendant.

Setting the Learning/Teaching Environment:

*Boot up simulation on computer.
*Before starting introduce yourself.
*Administer the "Display System Comfort Questionnaire" (make sure their student ID number is on it)
*Administer the "Immersive Tendencies Questionnaire" (make sure their student ID number is on it)
*Ask for their student ID number and record it on the "Questions Asked" sheet taped or located near their workstation.
*Give a brief, scripted overview of the system (must be consistent)
*Pass out student handout #1, "Objectives" and read it to them.
*Pass out drawing of robot with blanks for critical parts (Figure 2-13 from Rhino Robot Student Workbook, Module 1, Experiment 2, student handout #2)
*Pass out operation of the robot system (Figure 2-3 from Rhino Robot Student Workbook, Module 1, Experiment 2, student handout #3).

Instruct:

You will be using the teach pendant to manipulate the robotic arm. The 16 buttons on the left side of the teach pendant will not be used in this exercise. Concentrate on using the 16 buttons on the right side of the teach pendant which opens and closes motors. You need to practice with these control keys on the teach pendant until you can identify which buttons are controlling which motors, what the name of each of the motors are and you can move an object from point A to point B.

*Start recording the type and number of questions they have in:
"Questions in Simulated Environments".

*Start recording the type and time of system failures they encounter during training.

Finish:

*Administer "Post Display System Comfort Questionnaire"
(make sure their student ID number written on it)

*Administer "Presence Questionnaire"
(make sure their student ID number written on it)

ROBOT OPERATION USING THE TEACH PENDANT IN VIRTUAL ENVIRONMENTS (Instructor Copy)

Objectives:

1. Identify by name and location the following parts of a Rhino Robot: teach pendant, gripper, wrist rotation, wrist flex, elbow, shoulder and waist.

2. Move an object from point A to point B using a Rhino XR-3 robot and a teach pendant.

Setting the Learning/Teaching Environment:

*Boot up simulation on computer.
*Before starting introduce yourself.
*Administer the Display System Comfort Questionnaire (make sure their student ID number is on it)
*Administer the "Immersive Tendencies Questionnaire (make sure their student ID number is on it)
*Ask for their student ID number and record it on the "Questions Asked" sheet taped or located near their workstation.
*Give a brief, scripted overview of the system (must be consistent)
*Pass out student handout #1 "Objectives" and read it to them.
*Pass out drawing of robot with blanks for critical parts (Figure 2-13 from Rhino Robot Student Workbook, Module 1, Experiment 2, student handout #2)
*Pass out operation of the robot system (Figure 2-3 from Rhino Robot Student Workbook, Module 1, Experiment 2, student handout #3).
*Fit individuals into VR hardware and let them practice.

Instruct:

You will be using the teach pendant to manipulate the robotic arm. The 16 buttons on the left side of the teach pendant will not be used in this exercise. Concentrate on using the 16 buttons on the right side of the teach pendant which opens and closes motors. You need to practice with these control keys on the teach pendant until you can identify which buttons are controlling which motors, what the name of each of the motors are and you can move an object from point A to point B.

*Start recording the number and types of questions they have in:
"Questions in Virtual Environments".

*Start recording the type and time of system failures they encounter during training.

Finish:

*Administer the "Post Display System Comfort Questionnaire"
(make sure their student ID number is on it)

*Administer the "Presence Questionnaire"
(make sure their student ID number is on it)

Objectives:

1. Identify by name and location the following parts of a Rhino Robot:

   teach pendant
   gripper
   wrist rotation
   wrist flex
   elbow
   shoulder
   waist.

2. Move an object from point A to point B using a Rhino XR-3 robot and a teach pendant.

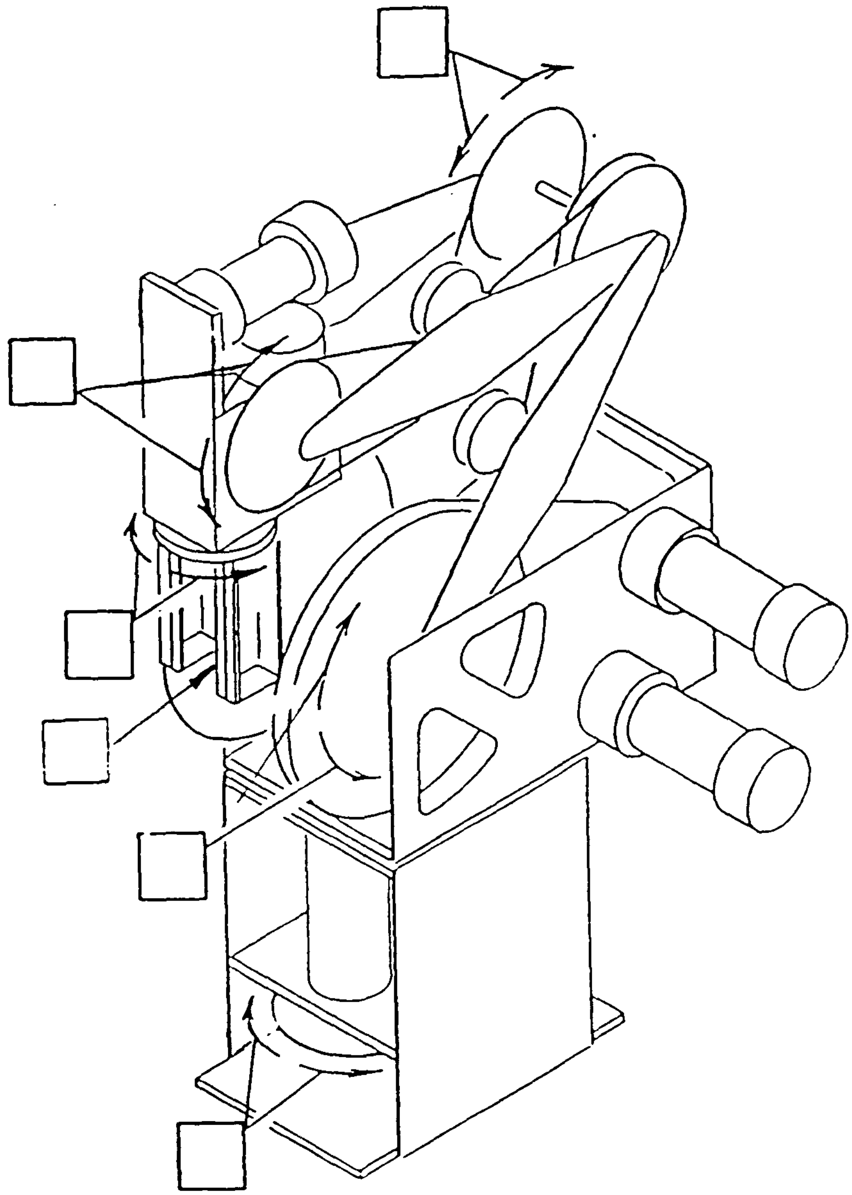


Figure 2-13

Student Handout #2

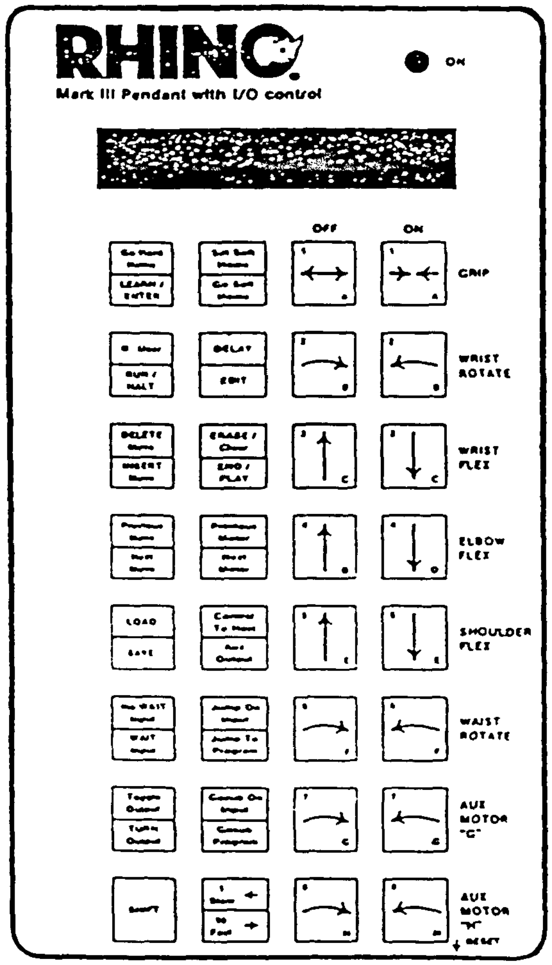


Figure 2-3

Student Handout #3

Questions in Simulated Environments:

Student ID Number: ______________________________

Please record the number of questions which are asked about the following items:

Robot or robot parts:

Computer applications, software, etc.:

Other: (Indicate question and what it was about)

Questions in Virtual Environments:

Student ID Number: ______________________________

Please record the number of questions which are asked about the following items:

Robot or robot parts:

Virtual environment, hardware devices, etc.:

Other: (Indicate question and what it was about)

"Down Time" due to hardware/software problems:

Start: End:

Questions in Traditional Environments:

The instructor will record the number of questions asked by each trainee and indicate what the general topic of concern is.

Student ID Number:	Robot or robot parts:	Computer applic., software, etc.:	Other: (Indicate what about)
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
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____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____
____________	_____	______	_____

APPENDIX C

TESTING MATERIALS

Exit Survey

Student ID Number: ________________

Date: ________________

Age: ________________

Major of Study: ________________

Record your starting time here: ______________

Identify as many of the major elements in this Rhino robot system as you can. Write the name of each part in the numbered blanks below. Use the terminology given to you in your training sessions.

____________________ 1.

____________________ 2.

____________________ 3.

____________________ 4.

____________________ 5.

____________________ 6.

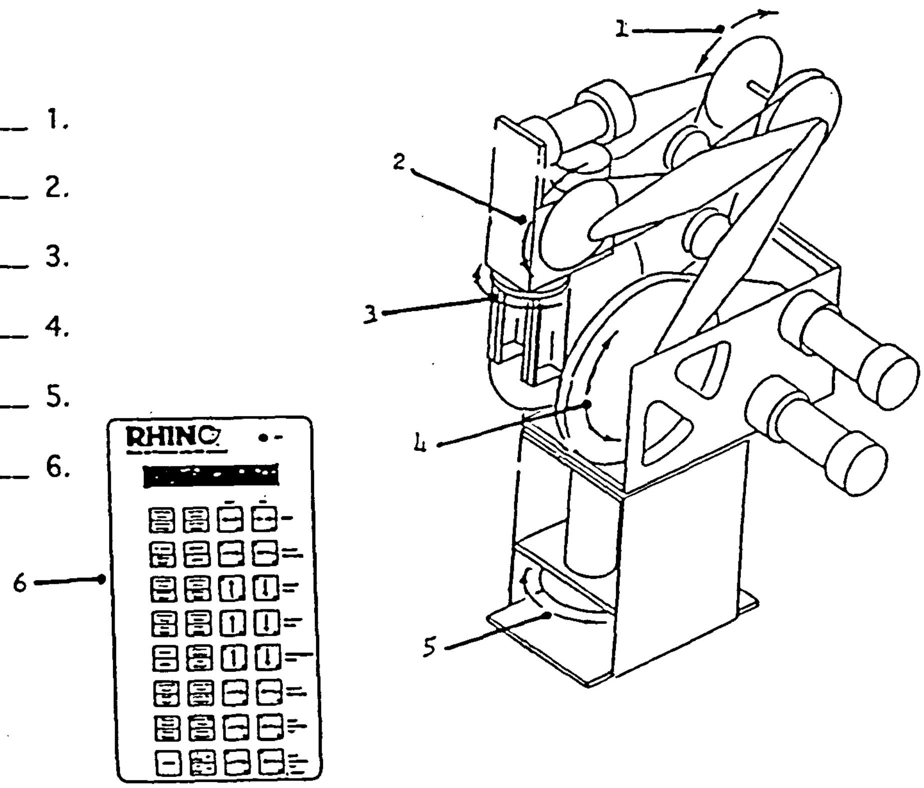


Figure © Rhino Robots Ltd

Record Time Finished Here: __________________

Robot Safety

Safety in the work place is important because workers and expensive production equipment must be protected from accidents. For humanistic and economic reasons people and machines must be protected from harm. The robot arm can move over a large volume called the work envelope. In some work cell applications the operator and robot must occupy adjacent work spaces, and in many programming situations the human and robot must share the same work space.

Please follow the following rules when completing the following exercise:

- The RESET button on the Mark III controller will function as an emergency stop. The RESET button on the teach pendant will function as an emergency stop. Identify them and use them if needed to prevent injury to persons or damage to equipment
- Do not pass the marked safety zone when the arm motor power is "on"
- Keep all books, papers and clothing out of the experiment zone.
- When lab is complete return all equipment to the HOME position
- Have at least one other person on hand when operating this robot
- Do not perform any maintenance tasks on this robot unless instructed to do so
- If there is an procedure or robot behavior you do not understand, stop what you are doing and get help.

DO NOT PROCEED UNLESS YOU UNDERSTAND AND AGREE TO ABIDE BY THE SAFETY RULES LISTED ABOVE!

The following activity illustrates one scenario where robots might be used. Please read all directions carefully. Make sure that all cubes are oriented correctly. Please limit robot operations to the right half of the teach pendant keypad. Use either of the emergency stop buttons if needed.

Robot Activity
(Adapted from Robotic Technology, Utah State Department of Education)

During this activity, imagine you are a member of a "Hazardous Waste Clean-up Crew." There has been a semi tractor and trailer roll over. The trailer was loaded with 55 gallon containers of very poisonous chemicals. The area has been evacuated and your crew has been called upon to clean up the barrels of chemicals before they begin to leak. The chemicals are so poisonous that if they touch your skin, you could become very ill and even die. You understand the danger of the job, so you bring in your XR-3 Rhino Robot and teach pendant to assist you.

Your job is to use the robot and pick up the containers then place them into the crate so they can be transported away on another truck and trailer. As you pick them up, they must be oriented into the crate with the yellow and blue corners oriented to match the truck bed. This will insure that the containers can be secured for safe shipping and handling.

If you have any questions about the task you should consult the facilitator now.

Record your starting time: _________________

Now, using the robot, carefully pick up each of the four containers and place them into the recovery truck. Position the blocks over the indicated rectangles in the truck bed. Make certain the yellow and blue corners of the blocks align with the yellow and blue corners indicated on the truck bed.

When you have completed loading the barrels into the crate press the "Go Soft Home" button on the teach pendant. The robot will run through a routine taking it back to its starting position.
Wait until the robot has finished this routine and record your finishing time.

Finishing time _________________

Please complete the Post Virtual Environment Experience Immersion Questionnaire before you leave.

THANK YOU FOR YOUR TIME AND COOPERATION

ROBOT OPERATION USING A TEACH PENDANT
INSTRUCTIONS FOR GETTING UNIFORM TASK ASSESSMENT

Prepare the robot for the task at hand:

1. Construct the testing environment (shown on pages 253 through 255). Note that some of the details may vary depending on the specific robot used.

1. Mark out the safety zone of the Rhino Robot and instruct participant to keep their body out of this safety zone.

2. Follow power up procedures attached in the following pages from pages 2-10 to 2-14 of the Rhino Robot Student Manual, Module 1, Experiment 2, 1986 version.

3. Park robot at the hard home position in the play mode. All participants will start from this uniform position.

4. Use Utah's adapted robot lab for the final performance assessment. Make sure that robot "hard home" and "container" positions are marked and located in the same starting position for every individual.

Power-up Procedures

The Rhino robot system includes 3 microcomputers. The most obvious is the IBM PC/XT™ or Apple IIe™ connected to the MARK III controller with the serial link. The less visible computers are in the MARK III and in the teach pendant. The presence of multiple computers in a system often requires specific power-up procedures so that the communication between the computers can be established. While it is not always necessary you should develop the habit of using the same power-up and power-down sequence with multiple computer systems like the Rhino.

The power-up procedure for the Rhino system is:

1. With a system disk in drive A (IBM) or drive 1 (Apple) apply power to the external microcomputer and "boot" the system. The system disk used depends on the type of programming that is planned and is selected as follows:

   a) IBM or Apple system disk -- Robot programming in BASIC and teach pendant work on the Rhino robot

   b) RoboTalk™ program disk -- RoboTalk language programming

   SYSTEM RESPONSE: No response from the robot. The external computer screen will indicate that the disk operating system has been loaded and a prompt or menu will be displayed.

2. With the **MODE SELECT** switch set in the **UP** position for **TEACH PENDANT** apply power to the controller using the **MAIN** power switch located on the back of the controller.

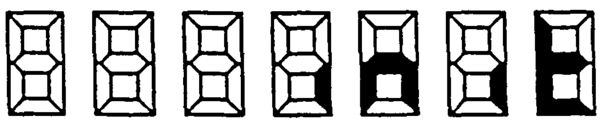
   SYSTEM RESPONSE: The main power light on the right front of the controller will take several seconds before it indicates that main power is applied. The "ON" light on the top right of the teach pendant will indicate that power has been applied to the teach pendant.

3. Turn the **MOTOR POWER** switch on the front panel of the MARK III controller to the **UP** or **ON** position.

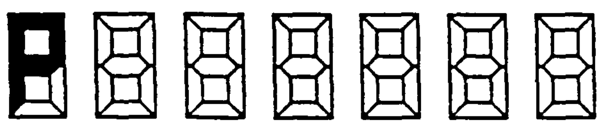
   SYSTEM RESPONSE: All motors receive power, and remain in their present position.

4. Press the red **RESET** button on front of the controller on the right side.

SYSTEM RESPONSE: The system is initialized which clears all memory locations and resets all outputs to the "off" condition. The gripper is cycled from "open" to "close" to "open". All other axes remain in their present position. The readout on the teach pendant displays



while the system is initializing and then the display switches to



indicate that the robot is in the PLAY mode. The list in Figure 2-4 indicates the keys that can be used in the PLAY mode.

Go Hard Home
Set Soft Home
Go Soft Home
LEARN/ENTER
Edit
RUN/HALT
*USER
ERASE/CLEAN
LOAD
SAVE
Control to Host
Aux Output

Turn Output
Toggle Output
Wait Input
No WAIT Input
END/PLAY

SHIFT
Slow/Fast
1-8 Motor keys

Figure 2-4

The power down sequence is the reverse of the power-up order. Use the following sequence to take the Rhino work cell in the teach pendant programming mode out of service.

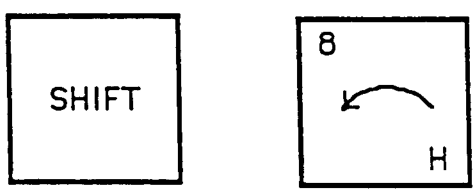
1. Turn "off" arm motor power.

2. Turn controller power "off".

3. Turn the computer "off"

Teach Pendant Operation

The teach pendant on the Rhino system includes a separate microprocessor, system memory, and software. The version of software present in the teach pendant is displayed when the following command sequence is entered using teach pendant keys.



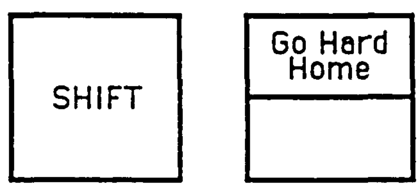
SYSTEM RESPONSE: The teach pendant display shows the current teach pendant software version.

The Rhino teach pendant in Figure 2-3 has 32 keys, a power "ON" indicator, a seven digit display, and a reset button. The pendant includes a "SHIFT" key, 15 keys for functions or system commands, and 16 keys for joint motion and I/O control. Each of the 15 function and system command keys has a dual purpose. If used alone, the lower half of the key is active, and when pressed along with the SHIFT key the function or command on the upper half of the key is entered. The reset button serves as an **EMERGENCY** stop during program execution.

HOME Position

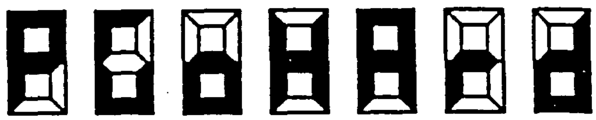
All industrial robots have a **HOME** position for the arm. Home is a defined or known position in the work envelope from which all new programs and stored programs start. A home position is necessary for the repeatability of the points taught in the program. For example, a robot loading a machine with parts from a parts feeder moves from the start position to the point in the work envelope where the tooling picks up a part. If the start position changes so will the position of the tooling as it tries to acquire a part. So unless the robot tooling starts from a known position every time, the programmed points will not be repeatable.

The Cincinnati Milacron family of robots has a single home position which must be taught during the power-up sequence using the command "Home,Set". The Rhino system has two types of **HOME** positions. The **HARD HOME** is a mechanical home position which is determined by limit switches located on the waist, shoulder, elbow, wrist flex, and wrist rotate axes. The **SOFT HOME** is a software home and can be set at any position in the work envelope. Hard home must be performed before a new move sequence is taught and before a stored sequence is loaded and executed. The soft home position is a point in the work envelope selected by the programmer because it is an efficient starting point for the desired move sequence. The hard home command is



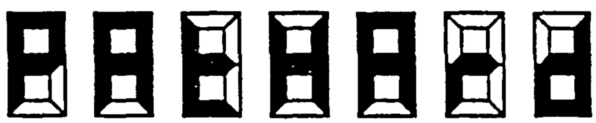
(Holding the SHIFT down <u>while</u> the function key is pressed causes the function described in the upper block of the key to be initiated. The function in the bottom block is activated without the SHIFT key.)

SYSTEM RESPONSE: The teach pendant responds with the following display,



and the robot starts a search for limit switches on the wrist flex, wrist rotate, elbow, shoulder, and waist axes. The gripper closes and then opens.

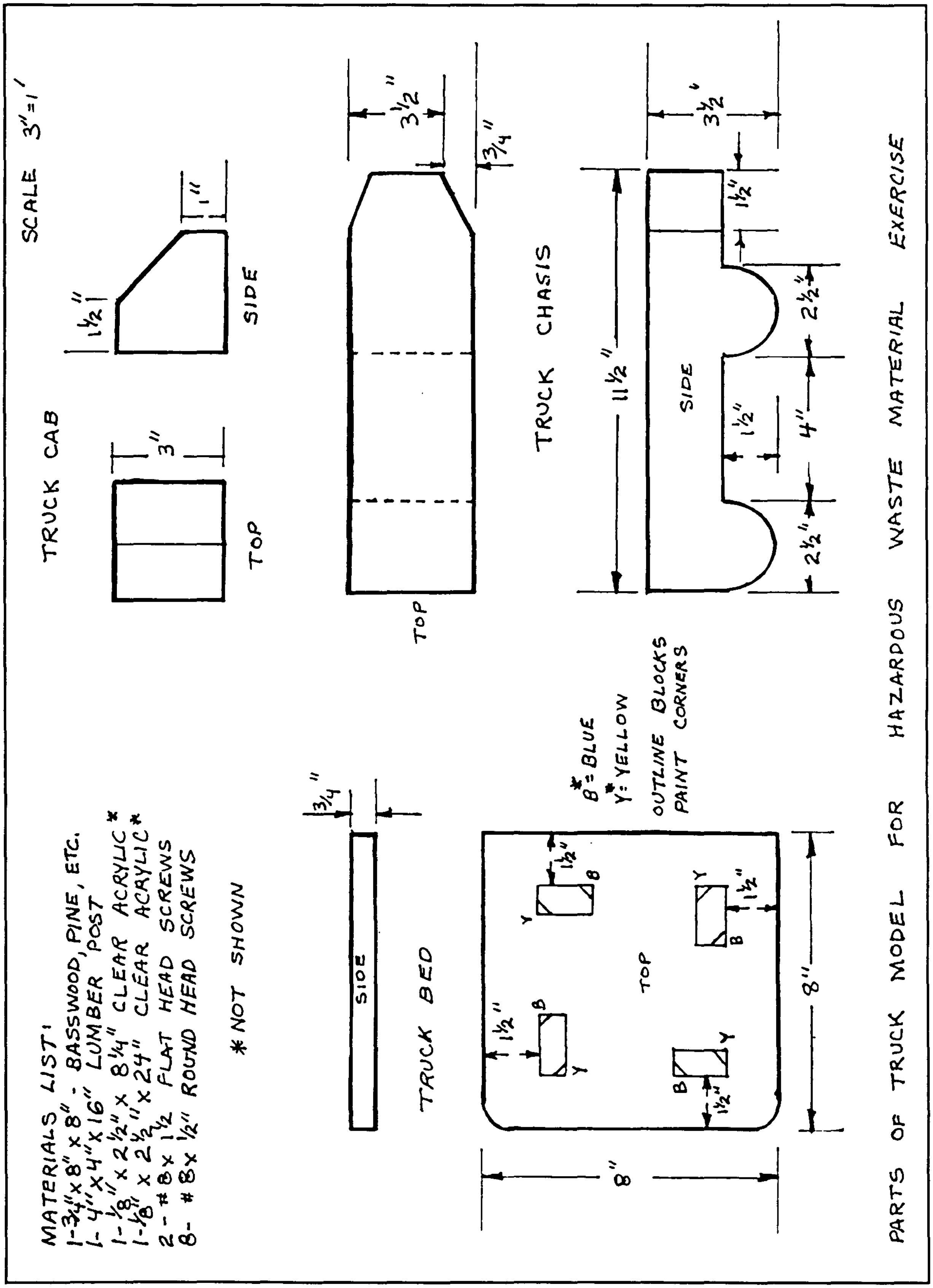
After the hard home position is reached the teach pendant displays



If the robot arm is in an unusual position when the Go Hard Home command is executed then hard home may not be reached by all axes. If this occurs the teach pendant displays

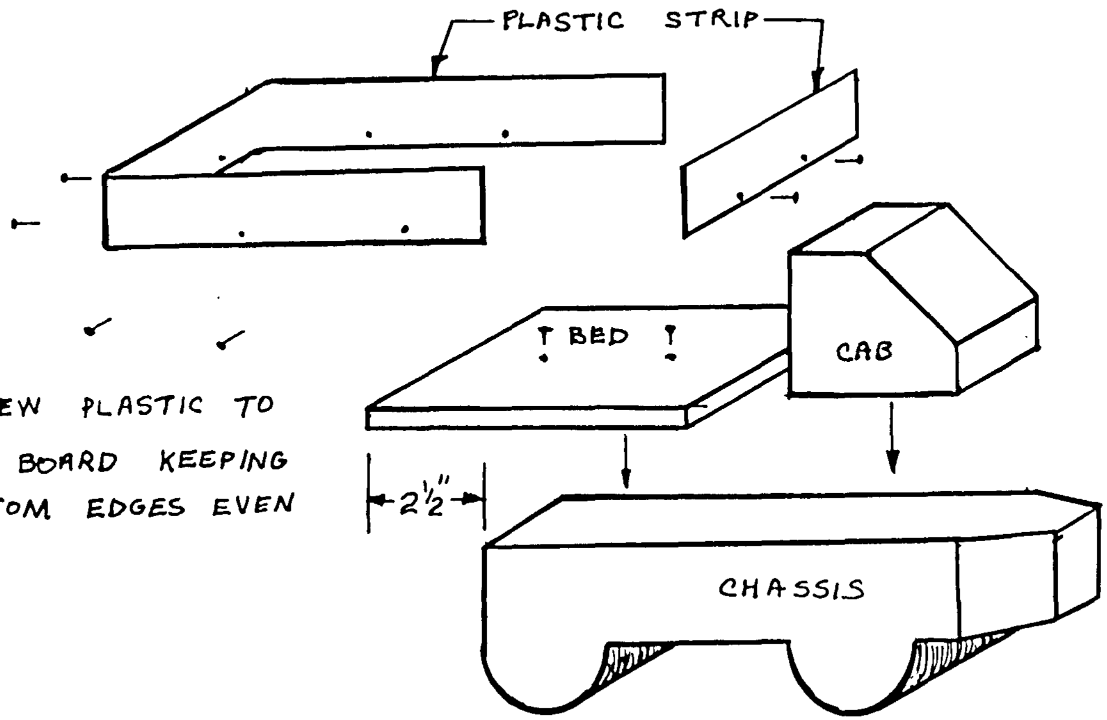
and additional Go Hard Home commands should be entered until the robot finds hard home on every axis.

The operation and application of the soft home command is included in experiment 3.



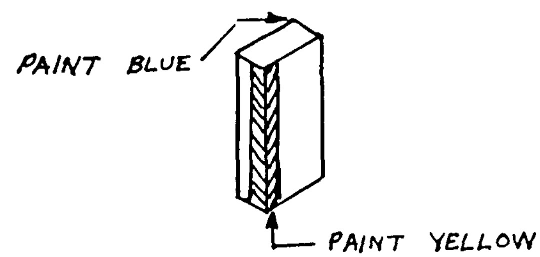
(Adapted from Robotic Technology, Utah State Department of Education)

MODEL TRUCK ASSEMBLY FOR HAZARDOUS WASTE MATERIAL EXERCISE

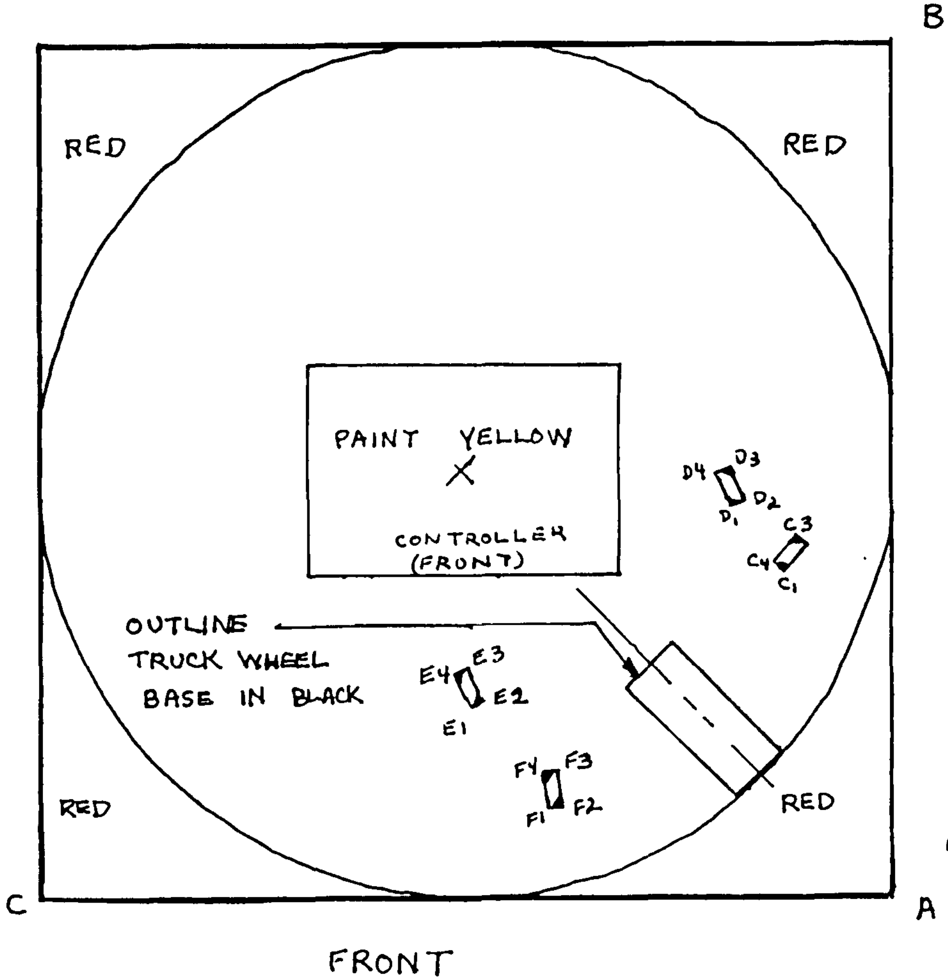


SCREW PLASTIC TO 3/4" BOARD KEEPING BOTTOM EDGES EVEN

1. CUT PARTS TO SIZE
2. GLUE CAB TO CHASSIS
3. BEND 24" ACRYIC STRIP TO FIT TRUCK BED
5. PAINT TRUCK BED WHITE
6 OUTLINE BLOCK POSITIONS ON TRUCK BED IN BLACK
7. PAINT BLUE & YELLOW CORNERS INSIDE BLOCK OUTLINES
8. PAINT CAB & CHASSIS BLACK
9. SCREW PLASTIC STRIP TO BED
10. ATTACH BED TO CHASSIS
11. CUT 4 PIECES OF 3/4" x 1½" ALUMINUM TUBING TO 3"
12. MASK OFF 3/4" ON OPPOSING CORNERS
13. PAINT BLUE OR YELLOW AS INDICATED



(Adapted from Robotic Technology, Utah State Department of Education)



MEASURE OFF OF MASONITE EDGE A-B OR A-C TO GET BLOCK PLACEMENT

BLOCK NUMBER	SIDE AB	SIDE AC	CORNER COLOR
C1	6 1/8	18	BLUE
C2	4 3/4	18 1/2	Ø
C3	5 5/16	19 3/8	YELLOW
C4	6 5/8	18 5/8	Ø
D1	7 7/8	20 1/8	YELLOW
D2	8 11/16	21 3/8	Ø
D3	9 9/16	20	BLUE
D4	8 3/4	19 7/16	Ø
E1	21 5/8	9 3/16	Ø
E2	20 3/4	9 13/16	YELLOW
E3	21 1/2	11 1/8	Ø
E4	22 7/16	10 11/16	BLUE
F1	21 1/16	6 3/16	Ø
F2	20 1/16	6 1/4	BLUE
F3	7 3/4	21 1/2	Ø
F4	7 5/8	22 7/16	YELLOW

USING A 4' x 4' PIECE OF HARDBOARD:

1. PAINT A 4' DIAMETER CIRCLE WHITE – SHOWS THE ROBOT'S OPERATING ENVELOPE.
2. PAINT CORNERS RED – SAFETY ZONE
3. OUTLINE TRUCK WHEELBASE AND BLOCK PLACEMENT IN BLACK
4. PAINT YELLOW & BLUE CORNERS IN BLOCK PLACEMENT SQUARES
5. MARK SPACE NEEDED FOR CONTROLLER IN CENTER OF SQUARE, CONTROLLER FACES A-C. PAINT YELLOW – ROBOT SITS ON TOP OF CONTROLLER

COMPONENT PLACEMENT FOR RHINO ROBOT XR-3 HAZARDOUS WASTE EXERCISE*

* MEASUREMENTS WILL CHANGE WITH ROBOT MAKE SURE ROBOT CAN REACH COMPONENTS

Student ID # ______________________ Date:___________

Did you enjoy your training experience?

Did you receive an introduction to the system (how to move objects, change views, etc.) from the lab person?

If yes, how long did this introduction last?

How many questions regarding the computer/computer system did you need to ask (questions about mouse, boot up, data glove, etc.).

How many questions regarding the robot (arm, waist, moving, etc.) did you ask.

Was the lab assistant readily available to answer all of your questions?

Estimate how many minutes the lab assistant actually instructed you.

Will this system work for training people on robot use? Why or why not?

Other comments: Please give all additional comments you wish to make regarding this experiment. Use the back or additional paper if necessary.

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