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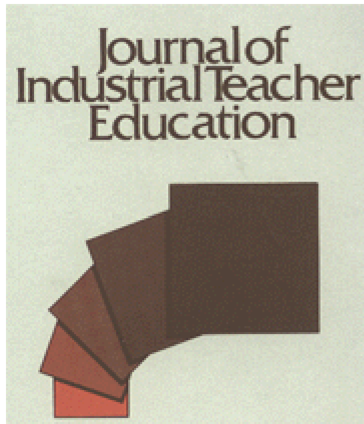

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Desktop Virtual Reality: A Powerful New Technology for Teaching and Research in Industrial Teacher Education

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The use of visual technologies for teaching and learning in industrial education has produced dramatic extensions of the once traditional lectures, demonstrations, and hands-on experiences. From the introduction of color photography to full-motion video to computer-generated presentations with graphics and animations, visual technologies have enhanced the preparation of workforce specialists and technicians by bringing into classrooms and laboratories a breadth and depth of realism that has enhanced comprehension, increased learning performance, and reduced training time. Occasionally, however, there arrives a training technology that causes a realization that "this changes everything." Such a technology is virtual reality (VR). The capabilities and possibilities for VR technology may open doors to new vistas in industrial and technical instruction and learning, and the research that supports them.

Introduction to Virtual Reality

The term "virtual reality" must be considered a consummate oxymoron. Massachusetts Institute of Technology's famous technology guru Nicholas Negroponte (1995) stated in his landmark book, *Being Digital*, that if, in fact, ". . . prizes were awarded for the best oxymorons, virtual reality would certainly be a winner" (p. 116). He asserted that more sense is made of the term if its two words are regarded as a pleonasm, a phrase in which the component words are seen as redundant equal halves. From this viewpoint, "VR can make the artificial as realistic as, and even more realistic than, the real" (pg. 116).

VR is not an entirely new concept; it has existed in various forms since the late 1960s. In its latest manifestation, desktop screen-based semi-immersive imagery under direct control of the learner, virtual reality has perhaps at last come within the realm of possibility for general creation and use by classroom teachers in industrial and technical education. This, in turn, points the way for its inclusion in industrial teacher education programs.

What is Virtual Reality?

VR has been defined in many different ways and now means different things in various contexts. VR can range from simple environments presented on a desktop computer to fully immersive multisensory environments experienced through complex headgear and bodysuits. In all of its manifestations, VR is basically a way of simulating or replicating an environment and giving the user a sense of being there, taking control, and personally interacting with that environment with his/her own body (Arts and Humanities Data Service, 2002; Ausburn & Ausburn, 2003a; Beier, 2004; Brown, 2001; Negroponte, 1995; Slater & Usoh, 1993).

In addition to simulating a three-dimensional (3D) environment, all forms of VR have in common computer input and control. It is generally agreed that the essence of VR lies in computer-generated 3D worlds (Arts and Humanities Data Service, 2002). Its interface immerses participants in a 3D synthesized environment generated by one or more computers and allows them to act in real time within that environment by means of one or more control devices and involving one or more of their physical senses (Ausburn & Ausburn, 2003a; Brown, 2001; Shneiderman, 1993). The result is ". . . simultaneous stimulation of participants' senses that gives a vivid impression of being immersed in a synthetic environment with which one interacts" (Brown, 2001).

Origin and Development of Immersive Virtual Reality

VR originated in the second half of the 1960s with the head-mounted display (HMD) as the first device that provided immersive experiences with computer-generated imagery. An HMD houses two small display screens and an optical system that channels the images from the screens to the eyes, while a motion tracker continuously lets an image-generating computer adjust the scene to the user's current view. After extensive development at NASA and the Department of Defense, HMD technology became commercially available 20 years later in 1989. At that time, VR was coined to describe these immersive visual environments (Beier, 2004; Negroponte, 1995).

VR thus originally referred to fully immersive experiences based on HMD technology. Another parent technology of current generation VR was the simulators commonly used for military training in circumstances where real-world training was difficult, expensive, or dangerous. With the advent of the HMD, the pre-VR simulators that made use of flat photography and mechanical gadgetry gave way to video technology, and finally to the flexibility and interactivity made possible by computer graphics and animation (Arts and Humanities Data Service, 2002).

The fully immersive VR initiated by HMD technology has today reached a very high degree of sophistication. Immersive VR can currently offer a convincing illusion of participation in a full-scale virtual world. Immersive technologies can now include 3D head-gear with stereoscopic vision for look around and walk through, auditory input, voice activation, data gloves and other tactile or haptic tools for manipulation and control of virtual objects, and even body suits wired with biosensors for advanced sensory input and feedback

(Ausburn & Ausburn, 2003a; Beier, 2004; Shneiderman, 1993).

While HMD paved the way for major advancements in VR, it was intrusive and uncomfortable, and often accompanied by mild to severe physical discomfort and nausea. The VR literature of the early 1990s is full of discussions of these problems. To overcome physical discomfort and encumbrance issues of HMD, alternative VR systems were developed and tested. The Binocular Omni-Orientation Monitor (BOOM) system developed by Fakespace uses a screen and a stereo optical system housed in a box attached to a multilink arm. The user looks into the box through two holes, sees the virtual world, and controls action through sensors linking the arms and box. More successful and currently popular is the Cave Automatic Virtual Environment (CAVE), developed by the University of Illinois at Chicago. In CAVE environments, the illusion of immersion is created by projecting stereo images on the walls and floor of a room-size cube. Participants wearing lightweight stereo glasses enter and walk freely within the CAVE room, while a head-tracking computer system continuously adjusts the stereo projection to the current position of the viewer (Beier, 2004).

A branch of the immersive VR family tree that has had a significant impact on industry and industry training is known as telepresence systems. These systems permit operation and control of devices and processes while working at-distance. They can currently be seen in telemedicine, teleoperation of industrial equipment, and telerobotic control of engineering, manufacturing and other processes (Shneiderman, 1993; Sheridan, 1992a, 1992b; Slater, Usoh, & Steed, 1994; University of Toronto, 2004.). Generally, telepresence systems are based on haptic or tactile input technology, immersing a participant in a real world captured by video cameras at a distant location and allowing remote manipulation of real objects via robot arms and manipulators (Beier, 2004; University of Toronto). A related branch of VR used for similar purposes is called augmented reality (AR). This technology combines the viewing of real-world or video-based environments with superimposed 3D virtual objects that can be manipulated by the viewer. Thus, AR supplements rather than replaces the user's real world (Beier, 2004; Shneiderman). The most recent advancement in AR is a wearable system in which users wear a backpack with a portable computer, see-through HMD, and headphones with motion trackers to place and manipulate virtual objects as they move within their real world (Halden Virtual Reality Center, 2004).

Development of Desktop VR

As virtual reality has continued to develop, applications that are less than fully immersive have developed. These non-immersive or desktop VR applications are far less expensive and technically daunting than their immersive predecessors and are beginning to make inroads into industry training and development. Desktop VR focuses on mouse, joystick, or space/sensorball-controlled navigation through a 3D environment on a graphics monitor under computer control.

Advanced Computer Graphic Systems

Desktop VR began in the entertainment industry, making its first appearance in video arcade games. Made possible by the development of sophisticated computer graphics and animation technology, screen-based environments that were realistic, flexible, interactive, and easily controlled by users opened major new possibilities for what has been termed unwired or unencumbered VR (Shneiderman, 1993). Early in their development, advanced computer graphics were predicted, quite accurately, to make VR a reality for everyone at very low cost and with relative technical ease (Negroponte, 1995). Today the wide-spread availability of sophisticated computer graphics software and reasonably priced consumer computers with high-end graphics hardware components have placed the world of virtual reality on everyone's desktop:

> Desk-top virtual reality systems can be distributed easily via the World Wide Web

> or on CD and users need little skill to install or use them. Generally all that is needed to allow this type of virtual reality to run on a standard computer is a single piece of software in the form of a viewer. (Arts and Humanities Data Service, 2002)

Virtual Reality Modeling Language

An important breakthrough in creating desktop VR and distributing it via the Internet was the development of Virtual Reality Modeling Language (VRML). Just as HTML became the standard authoring tool for creating cross-platform text for the Web, so VRML developed as the standard programming language for creating web-based VR. It was the first common cross-platform 3D interface that allowed creation of functional and interactive virtual worlds on a standard desktop computer. The current version, VRML 2.0, has become an international ISO/IEC standard under the name VRML97 (Beier, 2004; Brown, 2001). Interaction and participation in VR web sites is typically done with a VRML plug-in for a web browser on a graphics monitor under mouse control. While VRML programming has typically been too complex for most teachers, new template alternatives are now available at some VR web sites that allow relatively easy creation of 3D VRML worlds, just as current software such as Front Page® and Dream Weaver® facilitate the creation of 2D web pages without having to write HTML code.

Virtual Reality in Industry: The Application Connection

Use of VR technology is growing rapidly in industry. Examination of the web sites of many universities quickly identifies the activities of VR labs that are developing VR applications for a wide variety of industries. For example the university-based Ergonomics and Telepresence and Control (ETC) Lab (University of Toronto, 2004), the Human Interface Technology Lab (HITL) (Shneiderman, 1993; University of Washington, 2004), and the Virtual Reality Laboratory (VRL) (University of Michigan, 2004) present examples of their VR applications developed for such diverse industries as medicine and medical technology; military equipment and battle simulations; business and economic modeling; virtual designing and prototyping of cars, heavy equipment, and aircraft; lathe operation; architectural design and simulations; teleoperation of robotics and machinery; athletic and fitness training; airport simulations; equipment stress testing and control; accident investigation and analysis; law enforcement; and hazard detection and prevention.

Further indication of the growing use of VR in industry is provided by the National Institutes of Standards and Technology (NIST). Sponsor of the Baldrige Award for excellence, NIST is the U.S. government agency that works with industry to develop and apply technology, measurements, and standards. The NIST web site currently lists more than 60 projects in which it is providing grants to industries to develop and apply VR technology. These include medical technology, machine tooling, building and fire technology, electronics, biotechnology, polymers, and information technology (NIST, 2004).

Throughout the world of industry, VR technology is impacting the way companies do business and train their workers. This alone may be sufficient reason for introducing this high-impact technology in industrial teacher education. As it becomes increasingly necessary for skilled workers to use VR on the job, its use in pre-employment training becomes equally necessary. However, until the recent developments in desktop VR, creation of virtual learning environments was too complex and expensive for most industry educators to consider.

Desktop Virtual Reality Tools

New desktop VR technologies now make it possible for industrial teacher educators and the teachers they train to introduce their students to virtual environments as learning tools without complex technical skills or expensive hardware and software. Specifically, two desktop VR technologies offer exciting potential for the classroom: (a) virtual worlds created with VRML-type templates, and (b) virtual reality movies that allow learners to enter and interact with panoramic scenes and/or virtual objects.

VRML Virtual Worlds

With the arrival of template VRML tools, it is relatively easy to create virtual worlds for the Internet in which students can interact with environments and with other learners. With these templates, the need for learning VRML programming is bypassed and the development time for creating on-line virtual environments is shortened dramatically. Using this technology, instructors can create an industry environment such as a machine shop, a medical laboratory, an auto repair shop or assembly plant, an airport, a pharmacy, a hospital, or a construction site, or can allow their students to participate in existing environments already available. These virtual worlds are presented over the Internet through the services of a hosting organization's server. Learners enter, explore, learn, train, and interact in the worlds by means of an avatar, a computer-generated character or body double selected to represent the learners within the virtual environment (Ausburn & Ausburn, 2003a; Damer, 1997). In collaborative virtual environments (CVEs), users can interact not only with the environment itself, but also with each other via their avatars, thus giving them the opportunity to develop collaboration and virtual communities, which adds a new dimension to learning with virtual reality. CVEs also provide opportunities to learn what Murray (2000) called life "coping skills", such as interviewing, conflict resolution, and teamwork, all of which are highly sought in business and industry (p. 172).

An introduction to Internet virtual worlds is currently available on-line at Active Worlds. Educators who are interested in this VR technology can join the Active Worlds Educational Universe (AWEDU), already populated by a distinguished list of schools and universities, and experience on-line virtual worlds created with the template-based 3D Classroom Creator®. A visit to this VR environment via the downloadable AWEDU browser plug-in provides an introduction to this new VR technology and its potential uses in industry preparation. Applications include no-risk skill training, environment or process simulations, visualizations of complex concepts and locations, design testing, and developing problem solving and collaboration skills.

QuickTime VR Movies

Perhaps the most important current VR opportunity for industrial and technical educators is offered by Apple's QuickTime® VR movie format, now available for both Macintosh and Windows operating systems. QuickTime VR software packages such as PixMaker, PanaVue Image Assembler, and VRWorx let instructors create desktop VR environments for a modest software purchase, plus the cost of a standard digital still camera. Using this software plus Apple's QuickTime or new QuickTime Pro 6.4 file player, the learning curve to desktop VR movies is not steep; and the results are rapid and stimulating. The software functions by importing a series of digital still photos and then "stitching" and blending them to create seamless video movies with in-built learner control choices.

QuickTime desktop VR movies can be of three basic types (Ausburn & Ausburn, 2003a):

1. Panorama movies: Movies in which the viewer seems to be inside a 3D 360-degree physical environment and can move around within the environment as if walking through it;
2. Object movies: Movies in which the viewer seems to be standing in front of a 3D object and can pick it up, turn it, move it, and examine it; and
3. Mixed mode movies: Movies that combine more than one VR panorama and/or object, connected by hyperlinks or hot spots. Object movies can be set inside panoramas, and panoramas can be interlinked. Thus the viewer can travel within a complex

environment, move from place to place, and manipulate objects within the environment.

The primary distinction between these VR movies and standard videos is user control. In VR movies, the user takes control of the environment by means of a mouse, joystick, or other device. The user chooses when and where to move and what actions to take, rather than being controlled by the pre-production decisions of a videographer.

For industry and technical educators who wish to take their students into realistic learning environments, VR movies can open potentially powerful doors. Complex equipment, hard-to-reach locations, dangerous environments, and multi-factor on-the-job decision situations are common in most fields of industry training; all may become more accessible and meaningful via desktop VR movies. In these virtual environments, students can experience and learn by taking control of their own decisions and actions, just as they would in real-world environments. They can discover, practice, and apply technical skills, information and principles; and can realistically experience results and consequences of various actions without unwanted physical or financial risks.

Research on Virtual Reality in Industrial and Technical Education

The Challenges of VR Research

Research on applications of VR technology in industrial training is in its infancy. This presents both challenges and opportunities for instructors and researchers interested in this technology. The primary challenge is that there is not yet a sufficiently conclusive and prescriptive body of research data to guide the instructional design and classroom facilitation of VR technologies. Most of the published research in VR has focused on technical issues, demonstrations and case studies of various VR technologies, overviews of VR applications in education, discussions of how virtual worlds can be integrated into the curriculum and relate to the learning process, or how immersive and nonimmersive VR can promote understanding of complex concepts and support various aspects of constructivist pedagogy (Pantelidis, 1993, 1994; Winn, 2004). Thus, researchers and educators interested in the uses and impacts of VR technologies do not yet have either a sound theoretical framework or a strong body of empirical effectiveness data from controlled experiments from which to work.

Capabilities, Limitations, Uses, and Effectiveness of VR

While clear guidelines for successful use of VR environments in teaching and learning are not yet established, there has most certainly been a large body of research conducted on its applications. As it moved from a primarily technical emphasis to studies of what can be done with the VR medium, this research has generated enthusiasm and a generally favorable view among investigators of its potential as a powerful tool for education (Pantelidis, 1993; Riva, 2003; Selwood, Mikropoulos, & Whitlock, 2000; Sulbaran & Baker, 2000; Watson, 2000; Winn, Hoffman, Hollander, Osberg, Rose, & Char, 1997). In this research process, several important themes have begun to emerge.

Advantages and Uses of VR

Researchers in the field have generally agreed that VR technology is exciting and can provide a unique and effective way for students to learn when it is appropriately designed and applied, and that VR projects are highly motivating to learners (Mantovani, Gaggiolo, Castelnuova, & Riva, 2003; Winn, et al., 1997). From the research, several specific situations have emerged in which VR has strong benefits or advantages. For example, VR has great value in situations where exploration of environments or interactions with objects or people is impossible or inconvenient, or where an environment can only exist in computer-generated form (Mikropoulos, Chalkidis, Katsikis, & Kassivaki, 1997; Pantelidis, 1993, 1994). VR is also valuable when the experience of actually creating a simulated environment is important to learning (Pantelidis, 1993, 1994.) Creating their own virtual worlds has been shown to enable some students to master content and to project their understanding of what they have learned (Osberg, 1997; Winn, et al., 1997).

One of the beneficial uses of VR occurs when visualization, manipulation, and interaction with information are critical for its understanding; it is, in fact, its capacity for allowing learners to display and interact with information and environment that some believe is VR's greatest advantage (Pantelidis, 1994; Sulbaran & Baker, 2000; Winn, et al., 1997). Finally, VR is a very valuable instructional and practice alternative when the real thing is hazardous to learners, instructors, equipment, or the environment (Pantelidis, 1994; Sandia National Laboratories, 1999). This advantage of the technology has been cited by developers and researchers from such diverse fields as firefighting, anti-terrorism training, nuclear decommissioning, crane driving and safety, aircraft inspection and maintenance, automotive spray painting, and pedestrian safety for children (Government Technology, 2003; Halden Virtual Reality Center, 2004; Heckman & Joseph, 2003; McConnas, MacKay, & Pivik, 2002; Sandia National Laboratories, 1999; Sims, Jr., 2000).

Disadvantages and Limitations of VR

While virtual reality has advantages as an instructional technology, researchers have also pointed out its limitations. One important issue is the high level of skill and cost required to develop and implement VR, particularly immersive systems (Mantovani, et al., 2003; Riva, 2003). Very high levels of programming and graphics expertise and very expensive hardware and software are necessary to develop immersive VR, and considerable skill is needed to use it effectively in instruction. While the new desktop VR technology has dramatically reduced the skill and cost requirement of virtual environments, it still demands some investment of money and time.

Another set of limitations of VR environments stems from the nature of the equipment they require. A long-standing problem with immersive VR has been health and safety concerns for its users (Mantovani, et al., 2003; Riva, 2003) The early literature was top-heavy with studies of headaches, nausea, balance upsets, and other physical effects of HMD systems. While these problems have largely disappeared from current VR research as the equipment has improved, and appear to be completely absent in the new desktop systems, little is known about long-term physical or psychological effects of VR usage. A second equipment limitation of VR arises from the fact that it is computer-based and requires high-end hardware for successful presentation. Inadequate computing gear can dramatically limit the response time for navigation and interaction in a virtual environment, possibly destroying its sense of presence for users and damaging or destroying its usefulness as a simulation of reality (Riva; Sulbaran & Baker, 2000). This response situation, sometimes referred to as the "latency problem" of VR, can also arise from bandwidth limitations when VR is distributed over a network or the Internet (Riva; Sulbaran & Baker).

Instructional design issues create another set of challenges for VR environments. Riva (2003) pointed out that weak instructional design, along with the latency problems associated with technical limitations, can result in inadequate sense of presence in a virtual environment to adequately maintain the necessary sense of immersion and reality to allow virtual training to transfer to the real world. A study by Wong, Ng, and Clark (2000) concluded that a VR designer's understanding of a task, cognitive task analysis technique, and skill in translating these to a sound instructional design are critical in the success of a VR environment. A major review by Sulbaran and Baker (2000) of VR in engineering education also stressed the importance of solid instructional design, cautioning that the design must overcome the potential problems of overly complex navigation control, inconsistent or unengaging look and feel, and incompatibility between what an instructor wants students to focus on and what students may choose for themselves.

A final limitation of VR as an instructional tool was pointed out by Mantovani, et al. (2003) in their discussion of virtual reality training for health care professionals: This technology may be most appropriate to supplement rather than replace live instruction and experience. This view was also implied by Sulbaran and Baker's (2000) overview of distributed VR in engineering education in their statement that virtual training is not meant to replace instructors, but rather to provide them with a valuable alternative medium for conveying knowledge. The value of VR as a highly beneficial additional instructional tool, especially for preparatory learning and practice before entering dangerous, expensive, or environmentally sensitive occupational environments, is supported in reports from various industries (Government Technology, 2003; Heckman & Joseph, 2003; Sandia National Laboratories, 1999; Urbankova & Lichtenthal, 2002).

Effectiveness of VR

Based on several years of research evidence, enthusiasm for VR as an instructional technology appears to be running high among those who have given it a try. Watson (2000) stated that "Most would consider that . . . such systems provide strong potential . . . for the educational process" (p. 231). Similarly, Selwood, et al. (2000) claimed that research on VR suggests it has strong potential to be a powerful educational tool because it can exploit the intellectual, social, and emotional processes of learners. Winn, et al. (1997) believed that three factors contribute to the capabilities and impact of VR: (a) immersion, (b) interaction, and (c) the ability to engage and motivate learners.

A search of the literature on VR in instruction supports this enthusiasm. The field perhaps most impacted by VR, and most active in its research, is medical/dental education. Riva's (2003) extensive discussion of virtual environments in medical training agreed with previous researchers in the field that, despite limitations, its advantages and benefits have been revolutionary and, in some cases, more effective than traditional methods. A review of medical and dental training literature yields large numbers of research articles reporting beneficial applications of VR techniques (e.g., Imber, Shapira, Gordon, Judes, & Metzger, 2003; Jeffries, Woolf, & Linde, 2003; Moorthy, Smith, Brown, Bann, & Darzi, 2003; Urbankova & Lichtenthal, 2002; Wilhelm, Ogan, Roehrborn, Cadedder, & Pearle, 2002; Wong, et al., 2000).

Sulbaran and Baker (2000) added engineering education to the fields supporting the effectiveness of VR as an instructional tool. Their literature review supported the properties of VR, particularly when distributed freely via the Internet, as an important step forward. They concluded that the visual and interactive capabilities of virtual environments capitalized on the visual learning styles of most engineering students and met the need for interacting and experimenting visually with complex information for gaining understanding of engineering principles. They reported that their students who were taught via distributed VR showed high levels of engagement and knowledge retention.

While enthusiasm and support for VR appear to be generally high in the literature, several cautions must be noted. The first is that, as pointed out previously, many VR researchers and users feel the technology is most effective as a supplement rather than as a replacement for live training. It should be recalled that in the praises for VR reported here from such industries as automotive prototype design, auto spray painting, crane driving, and fire fighting, the emphasis was on VR as a precursor to live experience rather than as a replacement for it. For example, Heckman and Joseph (2003) pointed out emphatically that while VR has important advantages for training auto spray painters, the training is not complete until employees can demonstrate competency in a real paint booth. Similarly, Government Technology (2003) stated that VR training in firefighting is highly beneficial in safely preparing trainees for their first fire, but that really learning to fight fires requires training in actual blazes. In the health education field, several studies (e.g., Urbankova & Lichtenthal, 2002; Wilhelm, et al., 2003) have reported improved performance by learners using VR over a control group not exposed to the technology; but this was after initial instruction by faculty teachers.

A related caution is that, as Quinn, Keogh, McDonald, and Hussey (2003) pointed out, "Little has been published on its [VR] efficacy compared to conventional training methods" (p. 164). These researchers found, in fact, that in a comparison of VR and conventional training, many students did worse when exposed only to VR; and they concluded that VR was not suitable as the sole training method. A few studies have found VR to be an equal or better substitute for traditional training (Jeffries, et al., 2003; Wong, et al., 2000), but a final conclusion on this is far from warranted. Crosier, Cobb, and Wilson (2000) concluded from their study comparing VR with traditional instruction that the jury is still out on this issue; and the continued lack of directly comparative research reinforces this viewpoint.

A final caution in the area of VR effectiveness assessment is that the large majority of published research deals with immersive VR technologies, and there is almost nothing available yet on the effectiveness of the new desktop VR systems; yet this is the VR technology currently most accessible to industrial teacher education. A few studies do support the potential effectiveness of desktop VR. For example, Wong, et al. (2000) found QuickTime VR more effective than traditional paper-and-pencil training in operative dentistry. McConnas, et al. (2002) found that pedestrian safety was both learnable and transferable to real-world behavior for some children through desktop VR experiences. In nursing training, Jeffries, et al. (2003) found CD-ROM training with embedded VR segments as good as and more cost-effective than traditional instructor demonstrations and plastic manikin practice in teaching ECG skills. A strong stance in favor of desktop VR was made by Lapoint and Roberts (2000) in their study of its effectiveness in training forestry machine operators. They found that efficient new desktop systems did sustain efficient training of these operators and concluded that the basic principles of immersive VR systems can be transferred successfully to the desktop and thus increase student accessibility. While this limited research support of desktop VR is not conclusive, it does provide an encouraging starting point for the study of the newest form of VR as by far the most approachable for industrial teacher education in terms of required skill and expense.

Implementation and Methodology Challenges in VR Research

Several researchers have suggested problems that hamper VR research which must be solved before conclusive studies can be accomplished. These challenges include lack of adequate and comparable computing equipment for testing VR applications (Riva, 2003; Sulbaran & Baker, 2000), lack of standardization of VR systems and research protocols (Riva, 2003), difficulty in establishing equivalent control groups (Crosier, et al., 2000), and lack of solid theoretical frameworks for both design and evaluation of VR (Selwood, et al., 2000). These challenges have made it difficult to develop research based on direct experimental comparison of VR and more traditional instructional methods, carefully controlled trials and comparisons of specific VR applications, or longitudinal studies of VR usage in real classrooms. Issues such as these must be addressed before VR research can fully mature.

VR Research Opportunities, Approaches, and Models

While research in virtual reality has many challenges, it also presents a major opportunity. Research and research-based implementation of VR systems in industrial training and teacher education have a clean slate on which to write a unique literature all their own. Here is a high-interest technology that offers great potential for workforce preparation, shows significant signs of blossoming adoption in numerous industries, and has not yet developed a mature research base. Added to this situation is the fact that desktop VR technology has finally emerged in formats that are now realistically available, both financially and technically, for general classroom use. The result is a magnitude of opportunity that seldom presents itself to the combined efforts of cutting-edge researchers and practitioners.

Research on and with VR in industry education can be approached profitably from several perspectives. Primary focuses might, for example, include descriptions and evaluations of innovative VR applications that bring to learners (a) simulation of industry environments and experiences that are difficult, dangerous, or unavailable for them to enter in the real world; (b) entry into innovative environments that are impossible to explore in reality, such as the inside of a computer or an engine; or (c) participation in interactive and collaborative industry situations that learners would otherwise have no opportunity to experience. Another worthwhile focus might be analysis of successful collaborations between schools and industry partners to develop VR materials appropriate for specific occupational preparation.

These studies might take a qualitative approach. Such research could take the form of case studies or other rich qualitative descriptions of classroom or laboratory applications of desktop VR movies or on-line virtual worlds. These might include teacher and student reactions, perceptions, feelings, and motivational impacts of VR on teaching and learning experiences and outcomes. Other studies might take a more quantitative approach, focusing on comparative analysis of such learning performance variables as time on learning the task, speed of skill mastery, and quality of performance mastery in VR and traditional environments.

Regardless of the general approach selected by researchers for new studies on VR in industry and technical education, it is important to avoid the simplistic trap that plagued early research in instructional technology. The one-size-fits-all model, based on a research paradigm dedicated to finding the best technology or discovering whether a given technology works, is naive. The authors have pointed out before that this approach was left behind in the 1960s and 1970s when instructional technology was " . . . leaving behind its immature searching for the 'best' medium of instruction and establishing its legitimacy as a field well grounded in the principles and practices of instructional psychology" (Ausburn & Ausburn, 2003b, p. 3). Research on VR in industry and in industrial teacher education should not return to this outdated thinking, but rather should adopt the more productive model of contemporary instructional technology inquiry.

This more sophisticated research model is far more multi-factor in concept. It asks not whether a technology works or is better, but rather for what purposes and for whom it may be effective. This model is well grounded in the aptitude-treatment-interaction (ATI) research conceptualization popularized in the 1970s by Cronbach and Snow (1977). In this model, the interest is on not only the broad effects of a technology, but, more importantly, on interactions between interrelated aspects of specific learning tasks, learner aptitudes or characteristics, and the features and capabilities of a technology.

Application of the ATI model would lead to research comparing the outcomes of various types of VR for different types of curriculum components and learning objectives, or on analysis of the effects of VR elements on learners of different backgrounds, technology skills, learning styles, genders, and ages. Age may be a promising learner variable in multi-factor VR research in industry education. Both pre-service and in-service industry training programs must address learners across a wide age spectrum, and some career training instructors must serve both adult and younger students in the same class. Several authors have raised the prospect of a generational "digital divide", suggesting that age-related differences in skills, comfort, and expectations in digital environments may be a significant factor in both classrooms and workplaces (Frand, 2000; Howe & Strauss, 2000; Negroponte, 1995; Oblinger, 2003; Papert, 1996; Tapscott, 1998; Zemke, 2001; Zemke, Raines, & Filipczak, 1999). An example of multi-factor VR research focusing on learning task differences is provided by studies currently under way at Washington University's Human Interface Technology Lab. Winn (2004) reported that this research is investigating the comparative effectiveness of immersive and nonimmersive VR to support different aspects and degrees of constructivist pedagogy and to improve understanding of difficult science concepts and principles. Other interactive research questions might address properties of VR that may have what the authors have defined as supplantational properties, or the ability to " . . . either capitalize on learners' strengths or to help them overcome their weaknesses" (Ausburn & Ausburn, 2003b, p. 3).

Implications and Recommendations for Industrial Teacher Education

Virtual reality is clearly making its presence felt as a potentially important technology for technical and industrial training. Those who have investigated VR appear to be impressed with its unique capabilities and optimistic about its value as an instructional tool. Numerous industries are turning to VR to boost training success; and reports are indicating that it does, indeed, have important contributions to make. The emergence and apparent success of VR in numerous industry environments is probably reason enough for it to be introduced in industrial teacher education. Unfortunately, in the past the high costs of VR systems and the skill demands of both programming and implementing VR kept everything but reading about it out of reach of most teachers and teacher educators. Now, however, VR in its new desktop manifestations is making the capabilities of this technology accessible to most classrooms.

The growth of VR in industry training and work processes, the emerging evidence of its appeal and effectiveness, its high research potential, and its new accessibility at the desktop suggest that VR technology should now be finding a place in industrial teacher education. To begin this process, the authors suggest that the following activities are appropriate in industrial teacher education programs.

1. Acquaint industrial teachers with the basic characteristics of virtual reality and how these are thought to promote engagement and learning.
2. Discuss with industrial teachers the benefits, strengths, limitations, and problems with VR and its implementation in teaching and learning.
3. Provide an overview for industrial teachers of the types of VR systems such as HMDs, BOOMs, CAVEs, haptic systems, desktop QuickTime VR, and Internet-based virtual worlds.
4. Have industrial teachers research the uses of various VR systems in their own industries and share this information with each other.
5. Model desktop VR and its possible uses for industrial teachers by using it in coursework and discuss with them how they might apply it in their own programs.
6. Include VR in curriculum development and
7. instructional methods courses for industrial teachers and encourage them to explore VR technologies and how to use them effectively.
8. Make desktop VR development tools available in instructional technology courses for industrial teachers and assist them in hands-on development of instructional segments of their own.
9. Encourage industrial teachers to engage with their teacher educators in authentic classroom-based research on the effectiveness of desktop VR.

Conclusion

Virtual reality may be emerging as a key communication and learning technology for the 21st century. A decade ago in their landmark book, *Glimpses of Heaven, Visions of Hell: Virtual Reality and Its Implications*, Sherman and Judkins (1993) called VR the "most important communication medium since television . . . " (p. 6) and asserted that as VR technology got better and cheaper, it would profoundly affect life, both as entertainment and at work. Others have claimed that as VR technology evolves, its applications will literally become unlimited and will reshape the interface between people and information (Beier, 2004), and that VR is rapidly becoming a practical and powerful tool for a wide variety of applications (Arts and Humanities Data Service, 2002). Futurist James Canton (1999) even asserted that life will eventually be a combination of real and virtual worlds and that one day no one will be able to differentiate between the two.

Time has yet to reveal whether these predictions are true or not; but whatever its future may be, VR has already developed a strong and growing presence in education and in industry. The published research base on educational applications is growing in both volume and sophistication. A trip to the Internet quickly reveals real-world VR applications in the marketing, real estate, and travel/tourism industries. It can now also be seen in such diverse industry applications as dealership training by Volkswagen, prototyping of the interior of the Chrysler Neon and of concept cars by the U.S. Big Four automakers, design of new planes by Boeing Aircraft, design of its new terminal by Northeast Airlines, development of telepresence systems for virtual robotics control, a virtual trip through the inside of a computer for telecommunications training, technical skill development via a virtual lathe, training of forestry machine operators, assembly line training at Motorola, plant operations and maintenance training, automotive spray painting, aircraft inspection and maintenance, crane driving and safety, and firefighting training.

The emergence of desktop VR now makes it possible for industrial educators to add this powerful high-impact technology to their classroom instructional mix, and to build a unique research base in the field. It has been the experience of the authors that teachers and researchers in industrial education are certainly ready to do so. Desktop VR may be a technology whose time has come for both research and practice in industrial education. With recent breakthroughs in technical and cost accessibility, the door to the world of virtual reality is standing wide open. For industrial teacher educators and researchers, it's only a matter of walking through.

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