AN EXPLORATION OF DESKTOP VIRTUAL REALITY AND VISUAL PROCESSING SKILLS IN A TECHNICAL TRAINING ENVIRONMENT

By

LYNNA J. AUSBURN * FLOYD B. AUSBURN ** PAUL KROUTTER ***

* Associate Professor and Program Coordinator of Occupational Education, College of Education, Oklahoma State University, USA.
** Adjunct Faculty in Occupational Education Studies, College of Education, Oklahoma State University, USA.
*** Administrative Captain, Broken Arrow Police Department, Broken Arrow, Oklahoma State University, USA.

ABSTRACT

Virtual reality (VR) technology has demonstrated effectiveness in a variety of technical learning situations, yet little is known about its differential effects on learners with different levels of visual processing skill. This small-scale exploratory study tested VR through quasi-experimental methodology and a theoretical/conceptual framework based on supplantation theory, cognitive load theory, Dale's Cone of media concreteness, communication theory, and Lowenfeld's visual/haptic perceptual typology. The study compared the differential effects of VR and traditional still-image presentations of surgical operating room environments to students with high- and low-visual perceptual styles. Descriptive statistics and two-way ANOVAs were used to examine main and interaction effects on six learning performance and opinion variables. Several significant main effects and disordinal interactions suggested that communication channel noise and cognitive load may disrupt supplantation-concreteness benefits of VR, particularly for low- visual learners. Follow-up qualitative data suggested these overload issues may have dissipated when the VR presentation was moved into a classroom learning environment.

Keywords: Virtual Reality, Virtual Environments, Perceptual Style, Visualizing Ability, Aptitude-treatment Interaction, Supplantation, Cognitive Load, Media Concreteness.

INTRODUCTION

Virtual reality (VR) technologies are dramatically expanding the possibilities for processing, using, and sharing information. These technologies have been the subject of a considerable body of research, and are now generally accepted as having strong potential for technical, professional, and workplace education (Ausburn & Ausburn, 2004, 2008a, 2008b; Ausburn, Ausburn, Cooper, Kroutter, & Sammons, 2007; Ausburn, Martens, Dotterer, & Calhoun, 2009; Riva, 2003; Watson, 2000). A review of literature by Ausburn *et al.* (2007) reported that many occupations and industries as diverse as medicine and dentistry, aviation, welding, equipment design, law enforcement, firefighting, vehicle prototyping, lathe operation, hazard detection, crane driving, automotive spray painting, and forestry equipment operation are now turning to VR to provide effective and cost efficient ways of training and working.

Virtual reality also appears to offer training efficiency, transfer of training, and motivational properties. Bollmann and Friedrich (n.d.) pointed out the advantages of VR when real-world training is dangerous, difficult, or expensive. They asserted the game-like interface of many VR presentations can be exciting and stimulating, leading to greater learner interest and ultimately to better learning performance. In a review of four studies of VR-based training, Bollmann and Friedrich also supported the effectiveness of transfer of training from virtual to real-world situations.

The term *virtual reality* (VR) has undergone many changes since its introduction in the late 1960s as immersive experiences with complex computer-generated imagery via head-mounted displays (HMDs). It now refers to a variety of computer-based experiences ranging from fully immersive environments with complex HMD gear, body suits, and biosensors, to realistic PC-based scenes under user control. In all its forms, VR is basically a way of simulating or replicating a 3D environment via computer-generated imagery and giving users a sense of "being there," and personally controlling and interacting physically with that environment (Ausburn, *et al*., 2009). VR technologies create 3D spaces known as *virtual environments (VEs)* that users can "walk through," explore and experience personally. They are particularly compelling for obtaining and sharing knowledge when they have a strong sense of "presence," simulating locations with as much fidelity as possible and conveying to users a feeling of actually having *been* somewhere rather than just *seeing it* (Di Blas & Poggi, 2007).

Research on instructional uses of VR has been extensive and positive. However, it has had several limitations. First, it has tended to be frequently anecdotal and lacking in sound theoretical foundations. To offer generalizable and predictable instructional design guidance for effective uses of VR in training and knowledge sharing environments, research must move beyond a descriptive case study approach. It must move past focusing on *whether VR works* - the research clearly demonstrates that it *can* - and avoid the naïve question of whether VR is the "best" medium. What is far more productive is multifactor research on how VR *interacts* with certain kinds of learners and certain learning tasks. These multifactor, interactive research designs were described by Cronbach and Snow (1977) in their classic Aptitude-Treatment Interaction (ATI) research model and are highly appropriate for VR research (Ausburn & Ausburn, 2004, 2006; Ausburn et al., 2009). These research designs do not ask merely whether VR is a "good" knowledge medium or whether it is "better" than other media or than physical reality; they seek rather to discover for *whom* and for *what* learning and knowledge-sharing purposes VR might be most effective. The ATI model suggests that individual differences should be important variables in research on the effectiveness of VR technologies, yet Waller (2000) stated that "*… little research has examined the role of user characteristics and abilities in determining the effectiveness of … virtual environments …* " (p. 309).

A second issue in VR research has been a nearly exclusive focus on technically complex and costly immersive technology systems, with a dearth of reported research on the instructional effects of new desktop VR applications based on QuickTime, Flash, and Java technologies. Immersive VR systems and VEs are both technically and fiscally demanding. However, new high-quality desktop VR technologies are much simpler and more reasonable in cost, enabling the benefits of VR on standard PC hardware:

Desktop VR creates and delivers VEs in … on-screen 'movies'… that users can 'enter' and explore interactively by moving a mouse or other navigational device. The user determines what movements to make and explores the imagery on the computer screen as if actually moving within a place in the physical world. Movement can include panning and rotating the scene to simulate physical movements of the body and head, and in and out to simulate movements toward and away from objects or parts of the scene. (Ausburn et al., 2009, p. 2)

Additionally, this form of VR can be easily distributed on CD or online, and requires only a simple software viewer and average technical skills by learners. The importance of desktop VEs as an online training and knowledge-sharing medium was strongly supported by Holton and Baldwin (2003) and by Edmonds (2007), who asserted that this technology could "… take the Internet to the next level, enabling new forms of socialization, communication, collaboration, and commerce" (p. 1).

While a few research studies have reported positive results for new desktop VR technologies (Ausburn & Ausburn, 2008b; Jeffries, Woolf, & Linde, 2003; LaPoint & Roberts, 2000; McConnas, MacKay, & Pivik, 2002; Scavuzzo & Towbin, 1997; Seth & Smith, 2002; Wong, Ng, & Clark, 2000), these are still small in number and fall far short of establishing firm empirical support for instructional uses of desktop VR. This lack of research support for desktop VR is problematic for instructional uses in technical and professional education and knowledge sharing because it is these new PC-based systems that bring VR and VEs within the technical and financial reach of teaching institutions and corporate environments. The need for experimentally-based and theoretically-grounded research on the effectiveness of desktop VR and its interactions with individual differences in learning styles provided the impetus for the exploratory study reported here.

Theoretical and Conceptual Framework

The theoretical framework for this study combined supplantation theory; its application in current cognitive load theory; Dale's Cone of Experience for media concreteness; communication theory; and Lowenfeld's typology of visual versus haptic perception. This theoretical framework was operationalized within the conceptual and methodological frame of Cronbach and Snow's Aptitude-Treatment-Interaction (ATI) research design model. The result was an ATI study that tested working hypotheses based on predictions from a specific combination of interrelated threads from instructional design theory.

Supplantation Theory

Salomon (1970) originally defined *supplantation* as the explicit and overt performance or alteration of a learning task requirement that learners would otherwise have to perform covertly for themselves. More recently, Ausburn and Ausburn (2003) defined supplantation operationally in the context of designing technology-based instruction as "… the use of an instructional treatment to either capitalize on learners' strengths or to help them overcome their weaknesses" (p. 3). Supplantation-based instructional design is based on an interaction of the three critical components identified in the Cronbach and Snow (1977) ATI research model: (a) a *learning task* with specific requirements, (b) *learners* with specific capabilities/aptitudes related to the task, and (c) an *instructional treatment* that bridges any existing gap between the two. At the psychological heart of supplantational instructional design is the notion that when learner characteristics are related to specific learning task requirements, an instructional treatment can be expected to have a positive effect on learner performance when it helps learners perform task requirements by *bridging gaps* between the task requirements and learner capabilities (Ausburn & Ausburn, 2003, 2004, 2008b).

In a learning task requiring spatial orientation and memory for details in a complex scene, the task is made more difficult when presented via a series of still images by the need to hold and manipulate in memory complex sets of visual details and relationships from image to image. However, when the task is presented via virtual reality, the mental imagery retention and manipulation requirements are *supplanted* by the presentation medium, which accomplishes these cognitive functions overtly and explicitly for the learner. The VR task presentation could therefore be predicted to lead to better learning performance than a presentation based on the still images that are currently used in many textbooks and instructional presentations intended to familiarize learners with complex visual environments.

Cognitive load Theory

A specific application of supplantation that relates to VR's media characteristics is supported by the more recent theory of cognitive load. Developed by Sweller (1988) from the information processing theories of Miller, *cognitive load* refers to the extent to which human cognitive resources are consumed by activities that facilitate learning, or the "… mental energy needed to think about or process information" (Lohr, 2008, p. 51). Miller (1956) demonstrated that human information processing was limited in capacity, and that if short-term or working memory was overloaded, cognitive processing and transference to long-term memory could be undermined. Building on Miller's work, Sweller (1988,1999) proposed that optimum learning occurs when working memory load is kept to a minimum to facilitate changes to long-term memory. He applied this cognitive load concept specifically to instructional design of material that is cognitively complex and technically challenging. According to cognitive load theory, cognitive processing resources can be unnecessarily overloaded by having to integrate information from one location with information from another, causing a *split attention* effect. Therefore, working memory load associated with having to mentally integrate several sources of information should be eliminated by *physically integrating the sources* (Chandler & Sweller,1991; Sweller & Chandler, 1994). These cognitive load principles appear to support the efficacy of the supplantation ability of VR to overtly integrate the visual information from multiple images into a single unified visual field.

Dale's Cone of Experience

A second line of theoretical support for the efficacy of VR comes from the icon of instructional design theory known as Dale's Cone of Experience. Based on Piagetian psychology's proposition of concrete versus abstract reasoning, Dale's Cone proposed that (a) various types of learning experiences and media representations vary in their *concreteness*, (b) more concrete forms of experience and media are truer and more complete representations of reality, and (c) more concrete media representations can facilitate learning, particularly when reality is complex and unfamiliar to learners (Dale, 1954). One of the primary characteristics of VR is the fidelity of its presentation of the reality of a 3D environment and the spatial relationships of items within it (Seth & Smith, 2002). The more accurate and realistic experience of a complex visual scene through VR than would be possible with still imagery could add to the supplantation benefits of the VR medium. The combination of supplantation (and its inherent reduction of cognitive load) and experiential concreteness theoretical foundations led Ausburn and Ausburn (2008b) to a substantive theory for VR efficacy that could be called a *supplantation-concreteness hypothesis*. They did, in fact, test this hypothesis empirically and demonstrated that in a learning task requiring mastery of a 3D scenic environment, a desktop VR treatment yielded superior scenic orientation, recall of details, and learner confidence than did a still imagery treatment.

Communication theory and channel noise

While the Ausburn and Ausburn (2008b) study supported their supplantation-concreteness theory for desktop VR, there was a missing factor. The VR environment used in their study (i.e., interior rooms in a house) was universally familiar and technically simple, containing no unfamiliar objects, labels, or "hot spots" interconnecting multiple locations and objects. In an actual technical training environment, the VR scene would likely be unfamiliar to learners, rich in novel items and visual labels, and possibly navigationally complex. This situation could invoke a theoretical element that might conflict with, and perhaps overwhelm, the benefits of the supplantation and concreteness inherent in the VR. This conflicting element introduces communication theory into the study's framework, specifically the element of *channel noise.* Shannon and Weaver introduced the concept of channel noise in their foundational model of the communication process (Shannon, 1948; Sloane & Wyner, 1993; Weaver & Shannon, 1949), which has long been considered a key component in the development of information theory. In the Shannon and Weaver model, which was primarily concerned specifically with *technological communication*, an intended message traveling through a channel or medium between a sender/encoder and a receiver/decoder can experience interference and disruption due to *noise* in the communication channel. Several types of noise were proposed by Shannon and Weaver, including physical/mechanical noise, channel overload/noise, and semantic noise. In the case of the VR medium, channel noise and semantic noise appear the most likely causes of miscommunication. *Channel noise*, caused by a highly complex visual field, could possibly disrupt the instructional message found in a VR presentation. Cognitive load theory also asserts that cognitive processing load increases with the amount of information to be processed (Quiroga, Crosby, & Iding, 2004; Sweller, 1988), supporting the notion that the detailed and complex visual field presented in VR could interfere with its cognitive processing. *Semantic noise*, which Berlo (1960) discussed in his communication model as relating to variations and mismatches in knowledge, experience, characteristics, and biases between sender and receiver, might also disrupt cognitive processing of a VR presentation due to individual differences between sender and receiver. All of these factors might exert negative influences on learning performance with VR instructional treatments that could counter the positive effects from supplantation, cognitive load reduction, and media concreteness.

Lowenfeld's theory of visual/haptic perceptual types

The final element in the framework of this study was a learner variable Lowenfeld called *perceptual type* (Lowenfeld, 1945,1957; Lowenfeld & Brittain, 1987). Ausburn and Ausburn (2003) provided the following descriptions of Lowenfeld's visual and haptic percpetual types in their study of the differential effects of supplantation in simultaneous vs. sequential still images in a task requiring visual location:

[Visuals] have a tendency to transform kinesthetic and tactile experiences into visual ones and to mentally form, manipulate, and hold visual imagery…. Haptics … do not discriminate visual detail well, nor do they integrate visual details into wholes, visualize kinesthetic or tactile experiences, or mentally maintain visual images. (pp. 8-9)

These cognitive characteristics of visual and haptic learner types suggest that they may differ in their need for the image retention supplantation and visual cognitive load reduction in VR and thus benefit from it to different extents. They might also differ in their susceptibility to visual noise and cognitive overload in the VR communication channel. Both these interaction effects could differentially affect the learning performances of visuals and haptics under VR and still image presentation of a complex visual environment. It might be expected that visuals would generally perform better than haptics on a task requiring complex visual field analysis. It might also be expected that haptics would both have greater need for the supplantation-concreteness of the VR treatment and also be more susceptible to the negative influence of its channel noise and cognitive load, thus leaving uncertainty about the nature of possible interactions between perceptual types and VR versus still imagery.

The complete theoretical and conceptual framework for this study was complex, combining elements from the theories of supplantation instructional design, cognitive load, media concreteness, communication theory, and visual/haptic percpetual types into an Aptitude-Treatment-Interaction conceptual design. The complete framework is shown graphically in Figure 1.

Purpose and Hypotheses

The purpose of this study was to compare the effectiveness of desktop VR with traditional still color images in presenting a complex scenic environment in surgical technology training to learners of the visual and haptic perceptual types. Surgical technology was an appropriate choice as the technical training field for this research because VR has had a particularly rich history of development and research in the medical field. Several researchers (Ausburn & Ausburn, 2004, 2008b; Ausburn, Ausburn, Cooper, Kroutter, & Sammons, 2007; Riva, 2003) have reported that medical/dental education is the field most impacted by VR research and that its benefits have been revolutionary.

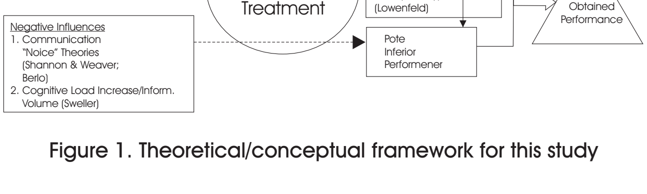

Figure 1. Theoretical/conceptual framework for this study

Specifically, this study addressed six aspects of learning outcomes (i.e., dependent variables) by comparing scores of visual and haptic learners who received a desktop VR presentation of an operating room (OR) environment with those who received a still images presentation of the same scene: (i) accuracy of scenic orientation, (ii) recall of scenic details, (iii) perceived confidence in scenic comprehension, (iv) perceived difficulty of learning experience, (v) time on learning task, and (vi) time on test of scenic orientation.

Main effects and interaction null hypotheses examined with descriptive statistics and then tested inferentially with 2-way analyses of variance were:

- Learners receiving a VR presentation of an OR environment perform no differently than those receiving a still imagery presentation on the six dependent variables.
- Visual learners perform no differently than haptic learners on the six dependent variables.
- There is no interaction between instructional presentation mode and learner perceptual type on the six dependent variables.

Methodology

General Research Design

Following procedures described below, the study used a quasi-experimental design to analyze main effects and interactions on the six dependent variables. Independent variables were VR/still imagery task presentations and visual/haptic learner perceptual type. The research design was a post-test-only, extreme groups design, with two levels of experimental treatment rather than a treatment/control configuration. A small purposive sample of nursing students was tested for visual/haptic perceptual type. Approximately equal numbers of visuals and haptics were identified and then randomly assigned to receive either VR or still imagery presentation of two operating room scenes. The groups were given the experimental treatments, then their learning performances and perceptions about the learning experience were compared with descriptive statistics and two-way ANOVAs. While the sample for this study was very small, the ANOVAs were conducted in order to explore more fully the nature of the main effects and interaction trends observed in the obtained descriptive data.

Finally, as a follow-up to this experiment, the question of how surgical technology instructors and students perceived the VR presentation of the operating room scenes in a classroom instructional environment rather than a controlled experimental setting was investigated. This was accomplished using simple qualitative techniques.

Subjects

The subjects were 31 young adult (i.e. not receiving high school credit) Licensed Practical Nursing (LPN) students in a large urban career and technical education center who were attending classes and available for voluntary participation. LPN students were selected because they were involved in training for the health occupations and would thus have an interest in the training operating rooms (ORs) depicted in the instructional treatments, but were not studying surgical technology and therefore had never seen the ORs used in the treatments.

Procedures

This study used presentation treatment implementations, learning task instrumentation, and data-gathering procedures developed by Ausburn and Ausburn (2008b) in a previous study comparing desktop VR and still imagery presentations of a generic non-technical scenic environment.

Presentation treatments

A desktop VR panorama movie and a set of eight color still photographs of each of two training operating rooms (ORs) were produced to serve as the instructional treatments for the study. The same digital camera with the same lens was used for shooting both treatments, and identical visual information was present in both sets of materials. Both presentations contained labels identifying various equipment and items within the ORs. In the VR presentation, numerous clickable "hot spots" were available to allow the learner to jump from one OR to the other and to explore various items and views within each OR. Two PowerPoint® presentations were developed, one to present each treatment via desktop computer under learner control. The two PowerPoint® presentations contained identical instructions to the subjects.

Learning task instrumentation

The learning performance and perception variables were operationalized with instruments patterned after those developed by Ausburn and Ausburn (2008b). The task instrument completed by each subject comprised five sections. The first measure was identified as *scenic orientation.* This was operationalized as a three-part multiple-choice test requiring subjects to position or locate themselves within an operating room (OR) and identify the location of designated objects relative to their own position. This was consistent with Hunt and Waller's (1999) definitional assertion that "a person is oriented when he knows his own location relative to other important objects in the environment, and can locate those objects relative to each other" (p. 4). Part A of the orientation test comprised 15 test items related to an OR containing a video laparoscopic system. Part B comprised 11 item related to an adjoining OR containing an electrocautery system. Part C comprised four items requiring comparison of the two ORs. Performance measures recorded were number of correct responses on each test section and total number of correct responses (out of 30) across all three parts. A sample question is shown in Figure 2.

You walk to the haed of the bed and are standing facing the anesthesia screen. Which 2 items are located on the side of the bed that is to your right:

A. IV pole and ring stand set-up
B. Ring stand set-up and kick bucket
C. Suction canister and IV pole
D. Suction canister and kick bucket

Figure 2. Sample orientation test item

The second performance measure was identified as *recall of scenic details.* This was operationalized as the number of correct and non-duplicative items found in *both* ORs the subject could recall and list within a time of one minute. The one minute time limit was found in a previous study (Ausburn & Ausburn, 2008b) to successfully differentiate recall of details in a VR scene.

The third and fourth measures were identified as *perceived confidence level in scenic comprehension* and *perceived difficulty of the learning task.* These were operationalized as the subjects' self-reported rating of confidence in their understanding of the OR scenes and their rating of how difficult they felt the learning activities to be. These perceptions were measured using 5-point Likert-like scales. The scale for confidence was 1 = absolutely no confidence; 2 = a little confidence; 3 = moderate confidence; 4 = good confidence; 5 = absolute confidence. The scale for difficulty was 1 = extremely easy; 2 = easy; 3 = a little difficult; 4 = difficult; 5 = extremely difficult.

Two additional performance measures were recorded that related to *time* taken by the subjects. *Learning time* was operationalized as time in seconds taken in studying the ORs, with a maximum of 10 minutes (600 seconds) allowed. *Testing time* was operationalized as time in seconds taken to complete the three scenic orientation parts of the multiple-choice orientation test.

The 31 LPN students were first tested in two groups for perceptual type using an updated version of Lowenfeld's original film-based *Successive Perceptual Test I (SPTI)* (Lowenfeld, 1945; United States Army Air Corps, 1944). This test was developed for use in the World War II Aviation Psychology Program as part of the pilot selection and training process, and is based on a primary distinction between visuals and haptics. Ausburn and Ausburn (2003) explained that “while visuals have the tendency and ability to integrate partial perceptions into a whole, haptics are satisfied to internalize the separate segments of partial impressions and show neither tendency nor ability to integrate them into whole units” (p. 9). *SPTI* consists of three practice items and 35 actual test items. In each item, subjects are shown a pattern a small section at a time behind a moving slot. They are then shown five similar variants from which they must select the one that exactly matches the pattern they saw behind the moving slot. The version of *SPTI* used was a new Flash-based video version developed by Study (2001) as a computer-based duplicate of the original WWII film version.

Using extreme-group design to minimize within-groups variance and maximize between-groups variance, subjects in the top one-third of the group (*n* = 11) were identified as High Visuals (HVs) and those in the bottom one-third (*n* = 10) were identified as Low Visuals/Haptics (LVs). The middle one-third (*n* = 10) were eliminated from the study. Subject attrition resulted in the loss of 3 subjects, leaving 18 actual participants in the experiment. The remaining HVs (*n* = 9) and LVs (*n* = 9) were then randomly assigned to receive either the still imagery or the VR instructional presentation of the ORs. The final subject distribution is shown in Table 1.

Members of the research team worked with subjects individually on the instructional treatments and tasks, using a standardized written protocol to facilitate uniform data collection. Before viewing the instructional treatment, each subject was briefly trained on how to operate the computer-based still image or VR presentation using photos and a VR movie of an unrelated scenic environment that was non-technical and simpler than the OR scenes (e.g., the interior of a house). After this brief training, each subject was allowed up to 10 minutes to study his/her assigned presentation of the OR scenes and then completed the multiple choice test of scenic orientation, the timed detail recall activity, and the Likert-like scales of confidence and task difficulty. Time spent (maximum of 10 minutes or 600 seconds) on learning and on completion of the multiple choice test (in seconds) were

	Presentation Treatment		
Perceptual Type	Still Images	Virtual Reality	TOTAL
High Visual	n = 4	n = 5	n = 9
Low Visual	n = 5	n = 4	n =9
TOTAL	n = 9	n = 9	n = 18

Table 1. Distribution of Subjects by Perceptual Type and Presentation Treatments

also recorded. All data for each subject were recorded on a standardized data sheet. The data were then coded and entered into an SPSS file for statistical analysis with descriptive statistics and two-way ANOVAs. A significance level of .10 was selected for this study due to its small sample size and exploratory nature.

As a follow-up to the experimental part of the study, the VR presentation was given to a team of two surgical technology teachers at the technology center. They were asked to use the presentation for instruction and self-study as they wished with their incoming new students who had not participated in the experiment and to record their comments and ideas and those of their students about the VR presentation of the OR scenes. These comments were subsequently collected and subjected to content analysis to compare results of in-class instructional use of the VR with the findings of the experiment

Findings

To analyze the obtained data, descriptive statistics were first calculated for the subject perceptual and treatment groups on the dependent performance and perception variables. The descriptive statistics for all dependent variables in all groups are shown in Table 2.

Even though the sample was very small in this exploratory study, two-way ANOVAs were performed for each of the six dependent variables to further explore main and interaction effects implied in the descriptive statistics. Because of the small sample and highly exploratory nature of the study, a significance level of $p = .10$ was selected for this study; a p-level of .20 was accepted as indicative of a trend that could merit further investigation, particularly when effect sizes were large.

No significant main or interaction effects were obtained at $p = .10$ or less for time spent on operating room (OR) learning presentation, timed number of recalled scenic details, or total score on the multiple choice test of scenic orientation. However, closer examination of the three-part multiple choice test for scenic orientation with additional ANOVAs revealed that while there were no significant main effects or interactions for the parts involving a single OR or for the total score on all three parts, there was a significant interaction ($p \leq .10$) with a large effect size of greater than

Measure	Perceptual Type Group	Presentation Treatment Group	N	Mean	SD
Scenic Orientation Score, Part A (Laparoscope OR)	Low Visuals	Still Images	5	7.60	1.95
	Low Visuals	VR	4	7.00	3.56
	Total Low Visuals		9	7.33	2.60
	High Visuals	Still Images	4	9.50	3.87
	High Visuals	VR	5	9.20	2.28
	Total High Visuals		9	9.33	2.87
		Total Still	9	8.44	2.92
		Total VR	9	8.22	2.95
Scenic Orientation Score, Part B Electrocautery OR)	Low Visuals	Still Images	5	5.40	2.19
	Low Visuals	V R	4	4.00	1.41
	Total Low Visuals		9	4.78	1.92
	High Visuals	Still	4	5.00	2.45
	High Visuals	VR	5	5.00	1.41
	Total High Visuals		9	5.00	1.80
		Total Still	9	5.22	2.17
		Total VR	9	4.56	1.42
Scenic Orientation Score, Part C (Comparison of Ors)	Low Visuals	Still Images	5	2.40	1.34
	Low Visuals	VR	4	1.25	1.26
	Total Low Visuals		9	1.89	1.36
	High Visuals	Still Images	4	1.00	.82
	High Visuals	VR	5	2.20	.45
	Total High Visuals		9	1.67	.87
		Total Still	9	1.78	1.30
		Total VR	9	1.78	.97
Scenic Orientation Score, TOTAL	Low Visuals	Still Images	5	15.40	4.39
	Low Visuals	V R	4	12.25	5.38
	Total Low Visuals		9	14.00	4.82
	High Visuals	Still Images	4	15.50	4.65
	High Visuals	VR	5	16.40	3.78
	Total High Visuals		9	16.00	3.94
		Total Still	9	15.44	4.22
		Total VR	9	14.56	4.77
Timed Number of Recalled Scenic Details	Low Visuals	Still Images	5	4.60	1.95
	Low Visuals	V R	4	3.75	1.50
	Total Low Visuals		9	4.22	1.72
	High Visuals	Still Images	4	5.25	1.89
	High Visuals	VR	5	4.60	.89
	Total High Visuals		9	4.89	1.36
		Total Still	9	4.89	1.83
		Total VR	9	4.22	1.20
Time Spent on OR Learning Presentation (in seconds)	Low Visuals	Still Images	5	473.00	138.64
	Low Visuals	V R	4	5.41.50	117.00
	Total Low Visuals		9	503.44	126.68
	High Visuals	Still Images	4	478.50	127.63
	High Visuals	VR	5	566.20	75.58
	Total High Visuals		9	527.22	105.36
		Total Still	9	475.44	125.41
		Total VR	9	555.22	90.33
Time Spent on Orientation Test (in seconds)	Low Visuals	Still Images	5	530.00	130.61
	Low Visuals	V R	4	611.25	96.35
	Total Low Visuals		9	566.11	117.66
	High Visuals	Still Images	4	749.50	148.36
	High Visuals	VR	5	593.00	132.69
	Total High Visuals		9	662.56	154.47
		Total Still	9	627.56	173.69
		Total VR	9	601.11	111.26
Perceived Confidence Rating (5-pt. Scale)	Low Visuals	Still Images	5	3.20	.45
	Low Visuals	V R	4	1.75	.96
	Total Low Visuals		9	2.56	1.01
	High Visuals	Still Images	4	2.75	.50
	High Visuals	VR	5	3.00	.71
	Total High Visuals		9	2.89	.60
		Total Still	9	3.00	.50
		Total VR	9	3.44	1.01
Perceived Task Difficulty Rating (5-pt. Sacale)	Low Visuals	Still Images	5	3.20	.45
	Low Visuals	V R	4	4.00	.82
	Total Low Visuals		9	3.56	.73
	High Visuals	Still Images	4	3.25	.50
	High Visuals	VR	5	2.80	.84
	Total High Visuals		9	3.00	.71
		Total Still	9	3.22	.44
		Total VR	9	3.33	1.00

Table 2. Descriptive Statistics for all Performance and Perception Variables

.14 (Green & Salkind, 2008) between perceptual type and presentation method on the four-question part of the test dealing with orientation with regard to *both* ORs simultaneously ($F_{1,17}$ = 5.82; p = .03; η^2 = .29). In this disordinal interaction, the LVs did better with the still image treatment (M = 2.4) than with the VR treatment (M = 1.25), while the HVs did better with the VR treatment (M = 2.20) than with the still image treatment (M = 1.00). This may indicate that on this complex visual integration task, the LVs were more susceptible to the channel overload noise and increased visual cognitive load in the VR treatment, thus losing the value of the supplantation-concreteness that benefited the Hvs.

A significant disordinal interaction ($F_{1,17}$ = 3.781; p = .07; η^2 = .21) and a main effect trend (p ≤ .20) ($F_{1,17}$ = 2.709; p = .12; η^2 = .16), both with large effect sizes, were observed for total time taken on the OR orientation test. In this interaction, the HVs worked less time on the test after seeing VR (M = 593 sec.) than after seeing still images (M = 750 sec.), while the LVs worked less time after still images (M = 530 sec.) than after VR (M = 611 sec.). In the main effect, the HVs took more time overall on the orientation test (M = 663 sec.) than the LVs (M = 566 sec.), with the longest time of any group coming from the HVs with still images. These data are difficult to interpret without further information. The HVs may have benefited more than the LVs from the VR presentation, or they may simply have persisted with the test much longer after seeing still images because their greater mental image retention ability allowed them stay with the testing task while the LVs gave up.

The learner perception variables also yielded some significant results with large effect sizes, both for main effects and interactions. On the perceived confidence score, the still image treatment produced better results overall (M = 3.00; 5 = greatest level of confidence) than the VR treatment (M = 2.44) ($F_{1,17}$ = 3.56; p = .08; η^2 = .20). A significant disordinal interaction was also found ($F_{1,17}$ = 7.14; p = .02; η^2 = .33). Examination of this interaction revealed that the perceived superiority of the still image treatment came entirely from the LVs, who felt less confident with VR (M = 1.75) than with still images (M =3.20). By contrast, the HVs actually felt slightly more confident with VR (M = 3.00) than with still images (M = 2.75). This finding appeared to support the notion that the LVs were more susceptible to VR's channel noise and increased visual cognitive load and the resultant loss of the supplantation-concreteness benefits of VR.

The perceived task difficulty score also yielded a significant main effect and interaction with large effects sizes. Overall, the LVs perceived the task to be more difficult (M = 3.56; 5 = greatest difficulty) than the HVs (M = 3.00) ($F_{1,17}$ = 3.24; p = .09; η^2 = .19). A significant disordinal interaction was also found ($F_{1,17}$ = 3.83; p = .07; η^2 = .22). Examination of this interaction revealed that the LVs felt the task was more difficult with VR (M = 4.00) than with still images (M = 3.20), while HVs found the task easier with VR (M = 2.80) than with still images (M = 3.25). Once again, this supported the notion of greater negative impact of VR channel noise and visual cognitive load and loss of supplantation-concreteness benefits by the Lvs.

Content analysis of the comments and ideas of the surgical technology teachers and their students about the VR presentation of the OR scenes when it was moved from the controlled experimental setting to a classroom instructional setting provided two major findings. First, there was not a single negative comment about the VR; no concerns were expressed about visual field complexity or navigational issues. Second, the teachers and students generated nine different ideas for additions to the VR OR scenes, including attaching video showing "how to" skills, adding more item labels, and adding pop-up text boxes with more information. All the suggested additions would *add both visual and navigational complexity to the scenes.* Concerns about channel noise and cognitive overload from a complex visual field or navigational interface were not in any way evident in these comments and ideas. It therefore appeared that when the VR presentation was moved out of a controlled research environment and into a less structured classroom instructional environment where teachers and learners could take as much time as they wished to learn to operate the VR and to explore its complete content, issues of channel noise and cognitive load may have disappeared and the supplantation-concreteness of VR may have returned to dominance.

Conclusions, Implications, and Recommendations for Further Research

This study was highly exploratory. It was limited by its very small and non-random sample and will have to be replicated with a larger sample to yield reliable results. Also, no data were collected regarding previous computer experiences of the subjects, which could have impacted the results. However, the study did serve several useful purposes and offered several tentative conclusions about the use of desktop VR in a learning or knowledge-sharing environment with HV and LV learners to guide further research. First, the study re-examined Ausburn and Ausburn's supplantation-concreteness hypothesis for the efficacy of desktop VR in a learning environment. In their original study (2008b), they found support for this hypothesis when a simple, generic scenic environment was used (i.e., a house interior). However, the addition in the present study of channel overload noise and cognitive load in the form of a much more visually and navigationally complex VR environment encompassing two operating rooms appears to have caused override of the supplantation-concreteness benefits of VR, particularly for learners of the Low Visual percpetual type. This study suggests that these learners may be more susceptible to the disruptive effects of channel and cognitive overload and that such overload can supersede supplantation-concreteness. For LV learners, it may be especially important to provide adequate practice and time-on-task when using VR presentations of complex scenes to mitigate these overload effects.

The findings of disordinal interactions between HV and LV perceptual types and VR versus still images supports the proposition that complex VR scenes such as the operating rooms used in this study may differentially affect learners with high and low levels of visualizing skills. It may be that when channel and cognitive overloads override the supplantation-concreteness benefits of VR, it is learners with high visual ability that benefit most from VR rather than those with low visual ability who theoretically should benefit most from VR's supplantation of mental image retention and its supposed cognitive processing reduction . This is further indication that channel noise and cognitive field overload can override supplantation-concreteness.

Finally, the qualitative data collected in the study appear to point to a difference in the effects of complex VR when it is moved out of a controlled experimental environment into a classroom instructional setting. The facts that not a single problem with VR was reported in the classroom setting and that all suggestions from the teachers and students called for *more* visual and navigational complexity in the VR program suggest that the issues with channel and cognitive overload may disappear when learners are given sufficient time to master the VR navigation and to fully explore its details. This reinforces the need for allowing adequate training and learning time when using instructional VR. When sufficient time is allowed, potential visual and cognitive overload problems may fade and allow the supplantation-concreteness of the VR medium to re-assert its benefits.

Establishing the efficacy of desktop VR as a training and knowledge-sharing technology and developing guidelines for its effective use has important implications for technical education and workplace learning. Complex scenic environments such as laboratories, equipment and facilities interiors, crime scenes, hospitals, workshops, etc. are common learning situations. If desktop VR that is relatively inexpensive and easy to produce and to distribute digitally can be demonstrated to prepare learners to enter real-world versions of these environments safely, efficiently, and effectively as suggested by Bollman and Friedrich (n.d.), this could have a strong impact on the way training is accomplished.The authors have found strong enthusiasm for desktop VR among the instructors and learners who have used it. This enthusiasm, plus the studies that have supported its efficacy as a learning tool, lead to the recommendation that research on its optimal design and implementation/distribution should be continued in a focused line of inquiry that will eventually lead to consistent guidelines for designing effective desktop VR that can then be compared to training in physical reality. Studies should continue to examine relationships of supplantation-concreteness and channel/cognitive overload, and interactions of VR with various learner variables and instructional tasks. Studies should also search for techniques (such as sufficient learning time, navigational guidance, and interface design) that might increase the supplantational characteristics of VR and for techniques (such as progressive or controlled disclosure of details) that might attenuate the effects of channel and cognitive overloads. The findings of this study also suggest that at least some VR research should be situated in naturalistic classroom or personal learning environments where complex real-world interactions of learners, tasks, and instructional variables can be explored both quantitatively and qualitatively.

A team of researchers at Oklahoma State University in the United States is currently conducting line-of-inquiry studies in effective design, implementation, and distribution of desktop VR technology in job-specific training and knowledge-transfer. We view our initial studies as first steps in developing theoretically sound ATI-based research models for discovering effective desktop VR instructional design guidelines through the view of VR as what Squire (2006) called "... *designed experiences,* in which participants learn through a grammar of *doing* and *being*" (p. 19). Desktop VR is an emerging instructional technology that has wide applications for learning, profound potential for impact on learning and instruction, and as-yet limited research exposure, making it an excellent opportunity for technology researchers. To borrow a metaphor from the technology itself, the door is standing wide open; researchers need only to click on the hotspot, step through, and discover what may be waiting on the other side.

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ABOUT THE AUTHORS

Dr. Lynna J. Ausburn is an Associate Professor and Program Coordinator of Occupational Education, College of Education, Oklahoma State University, Stillwater, Oklahoma, USA. She holds a Ph.D. in Educational Media and Technology from the University of Oklahoma. She was an Instructional Designer and Education administrator in Australia for 14 years, and has worked on educational development projects in numerous countries with agencies such as World Bank,USAID, and UNESCO. She is incoming President of the University Council for Workforce and Human Resource Education in the United States.

Dr. Floyd B. Ausburn is retired from Monash University, where he was the academic in charge of Educational Technology in the College of Education for 14 years. He is now a Specialist Adjunct faculty in Advanced Digital and Virtual Environments in the Occupational Education program at Oklahoma State University, Stillwater, Oklahoma, USA. She holds a Ph.D. in Educational Media and Technology from the University of Oklahoma. He has been a project specialist in numerous countries for World bank, USAID, UNESCO, and the Australian Department of Foreign Affairs.

Captain Paul Kroutter has been in Law Enforcement for 31 years. He is currently the Administrative Captain in Internal Affairs and Planning and Research for the Broken Arrow Police Department in Oklahoma in the United States. He holds a Master of Science Degree in Criminal Justice and is a Ph.D. candidate in Occupational Education at Oklahoma State University. He is also a member of the Board of Education and the Education Foundation of Tulsa Technology Center in Tulsa, Oklahoma.