FORAGING FOR SPATIAL INFORMATION:

PATTERNS OF ORIENTATION LEARNING

USING DESKTOP VIRTUAL REALITY

By

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Title of Study: FORAGING FOR SPATIAL INFORMATION: PATTERNS OF ORIENTATION LEARNING USING DESKTOP VIRTUAL REALITY

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Abstract: The purpose of the study was to provide a description of how learners use desktop VR systems for orientation learning that instructional designers could use to improve the technology. The study used a mixed method, content analysis approach based on a theoretical framework that included principles of self-regulated learning (SRL) and orientation learning. Twelve participants used desktop virtual reality (VR) systems to explore the virtual surround of a residential space. A screen-recording program captured participants' navigation movements and think-aloud verbalizations. Participants' recorded think-aloud verbalizations were coded to identify the orientation learning and SRL events they used during the session. Analysis of the participant movement data revealed that eight of the participants generally moved in a single direction through the surround, whereas the remaining four moved in a direction and then reversed that direction. Movement patterns of some participants were found to be different at the beginning and end of their VR session, and some participants tended to navigate through certain areas of the surround more slowly than through other areas. Some participants tended to view the scene at a constant field of view level, whereas other varied the level. Additionally, some participants tended to view a particular area of the scene with narrower or wider fields of view, but others varied the field of view level across the scene. A model of orientation learning events was derived from content analysis of the think-aloud transcripts showing that participants engaged in four major types of learning categories: identifying, locating, regulating, and contextualizing. Participants were classified into four groups according to relative frequency distributions of the event categories. The study concluded that use of SRL events varied amongst the participants, and that the participant used a diverse set of movement and learning event patterns. Further conclusions noted that virtual scene objects possessed meaning for learners, and that thought verbalizations indicated that some of the learners attained a sense of presence in the VR environment. Finally, the study concluded that qualitative techniques such as thought verbalizations may provide a new paradigm for measuring presence in virtual environments.

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CHAPTER I

INTRODUCTION

Background and Theoretical Foundation

Virtual Reality

Virtual reality (VR) computer systems, which can be operated with standard personal computer hardware, provide career and technical education (CTE) learners with excellent opportunities to independently explore and orient themselves to new environments, especially complex technical environments that may not be routinely accessible for training. VR systems provide this capability by generating a visual representation of an abstract or real three-dimensional environment that may be dynamically manipulated by the learner though interface controls, thereby creating a simulated effect of being present in a real physical environment (Blade & Padgett, 2002a). A VR representation of a hospital operating room suite, for example, could be used to familiarize student surgical technicians with the layout of an occupational setting that would typically not be available for training purposes due to scheduling constraints (Ausburn, Ausburn, & Kroutter, 2010; Ausburn, Fries, et al., 2009; Ausburn, Martens, Washington, Steele, & Washburn, 2009). Similarly, a VR crime scene could be used to teach trainee police officers to investigate a location without risking damage to valuable evidence

(Krouter, 2010), or a VR workplace scene could be used to familiarize disabled adults who are returning to work with their new place of employment in order to ease their anxiety (Washington, 2013).

VR systems are available in a large number of different configurations, ranging from costly immersive systems that utilize special computer graphics processors and advanced interface devices such as head mounted displays, motion simulators, and haptic feedback gloves to affordable desktop-based systems that utilize standard personal computer hardware and readily available software packages. Visual representations of the physical space that are generated by VR systems may be produced from either computer graphics programs or from digital photographs of the physical environment (Vince, 2004), The current study examines the VR system type based on standard personal computer hardware that displays visual representations sourced from digital photographs of the physical space. This VR system type is generally identified as a desktop photorealistic VR system, or simply *desktop VR*.

Desktop VR is a good choice for use in schools and CTE centers due to its relatively low initial cost, realistic portrayal of the physical space, and a straight-forward production process that can be performed with digital photography equipment and readily available software that does not require computer programming skills to configure or operate (Ausburn & Ausburn, 2008a). In addition, desktop VR systems are now commonly implemented with Web-based technologies such as Adobe Flash and HTML5 (Reinfeld, 2016), which facilitates their ability to be accessed with common Internet browser software. Regarding the best choice of platform for orientation learning Hunt and Waller (1999) recommended that “for the purposes of environmental learning we may not need a Star Trek holodeck – a desktop computer will do just fine” (p. 71).

The user interface of a typical desktop VR system is perhaps one of the sparsest and non-directive of any type of computer-based learning environment (CBLE). Learners see just an initially static image of the virtual environment, a few basic interface controls, and possibly a wayfinding aid tthat enables them to navigate through the virtual scene. The high degree of learner-control inherent in desktop VR systems makes it a good fit for active discovery learning (Lee, Wong, & Fung, 2010), but places a significant burden on the learner to guide and manage the exploration of the environment that is at the core of orientation learning. The learner control burden inherent in desktop VR creates a natural link to self-regulated learning as a conceptual foundation for study of this technology. Unlike other CBLEs such as intelligent tutoring systems (ITS), desktop VR systems do not explicitly model and highlight learning objectives, sequence instruction, provide assessments or feedback, or facilitate reflection (Collins, 2006; Koedinger & Corbett, 2006). In order for VR systems to be effective instruction tools for "environmental mastery" (Ausburn & Ausburn, 2008a) learners must independently and dynamically determine how to learn new environments, monitor their learning progress, adjust learning strategies, and assess how well they have met their learning objectives. The need to provide more active support in VR systems to orientation learners has been discussed for some time; for example, a proposed roadmap for research regarding virtual environments and spatial training recommended over ten years ago that the integration of virtual environments and ITS should be investigated (Durlach et al., 2000), but no record of this proposed research being pursued appears in the literature. A prerequisite to providing active support is to understand how learners use existing VR system configurations for orientation learning. A search for this understanding is the focus of the current study.

Orientation Learning

Learners who are *oriented* to an environment are able to locate important objects in a space and understand the spatial relationships between the objects in the space and between the objects and themselves The portion of a physical space that an observer can see from a stationary position within a space is called a scene, and the entire space, composed of multiple scenes, is called a surround (Hunt & Waller, 1999). As one cannot see an entire space from a single stationary position, a learner must initiate, monitor, and control movement in order to survey the entire surround and construct a spatial representation of the surround in memory from the individual scenes, a process that has been characterized as "foraging for spatial information" (Allen, 1999, p. 554). Orientation is based on two types of reference systems, egocentric and allocentric. Egocentric orientation refers to establishing the location of an object relative to one's body, whereas allocentric orientation refers to establishing the location of an object relative to another fixed object or a coordinate system such as latitude and longitude (Montello, 2005).

Orientation is closely related to the broader concepts of *navigation* and *wayfinding*. Navigation is the broader of the two terms that refers to the selection and execution of wayfinding strategies that enable organisms and intelligent machines to move in either a local or distance space (Montello, 2005). Although navigation is often thought of as processes that involve movement over long distances, Montello's inclusion of local space in the definition of navigation qualifies the orientation learning of a local surround as a form of navigation. Wayfinding refers to the goal-direction and intentional cognitive processes associated with navigation, but is often used in the literature as a synonym for locomotion or movement (Darken, 1995).

Three major process-oriented models of wayfinding have been put forth over the past thirty years by Passini (1984), Jul and Furnas (1997), and Chen and Stanney (1999). The model developed by Passini, an architect, was concerned exclusively with real-life wayfinding in physical spaces, whereas the later models specifically addressed virtual environment-based (VE) wayfinding. Although the terminology varied across the models, all featured a core set of repeating processes whereby the learner gathered data about the spatial environment from the human senses, compared the gathered information to existing cognitive spatial representations and possibly updated the representation, and ultimately decided to either move in some way or obtain additional information to support the movement decision process. Attainment of the navigational goal terminates the model processing.

The general process and information flows put forth in wayfinding models can be applied to orientation learning. In learning the orientation of a real room, learners might view the scenes in a variety of ways, perhaps by surveying the room from a central location, or by moving about its periphery. A learner might move through the room at a steady rate or perhaps linger at an area of the room that contains a particularly interesting cluster of objects he or she might want to examine in more detail. As the learners move through the space, they use their spatial abilities, defined as "the cognitive process to represent, generate, and recall symbolic, non-linguistic information" (Linn & Petersen, 1985, p. 1482), to develop and reference a mental construct called a cognitive map that is used to represent the spatial relationships amongst the objects that they viewed (Taylor, 2005). Little is known about the actual cognitive process that humans use to update the cognitive map, but it requires learners to use cognitive abilities to monitor the presence of objects, calculate directions and distances, and memorize the knowledge that has been learned about the objects (Allen, 1999).

At the start of the orientation learning process, the learner's cognitive map contains little information, but it is iteratively refined, elaborated, and revised with new information as the learner moves around the surround and views different parts of the environment. Updates that are made to the cognitive map by the learner over the course of the session may, therefore, dynamically influence how the learner moves about the surround for the remainder of the sessions (Kitchin & Blades, 2002). At some point, a learner will judge that he or she has learned the environment and end the session.

Although desktop VR provides an accessible and realistic environment for learning occupational settings, it does have some limitations compared to using the real-life physical space for the same purpose. The major limitation of desktop VR is that the scenes that comprise the surround are always rendered on the computer display from the perspective of a single point that corresponds to the generally central location of the camera used to photograph the surround. To effectively navigate through the surround, the learner must realize that he or she is essentially located at the center of a "sphere of reality" (Ausburn & Ausburn, 2010) and can only view different sections of the surround by using the system's pan controls to rotate his or her central observation point of view, without translation, in either a clockwise or counterclockwise direction. Due to this limitation, some wayfinding strategies that might have been used in real-life orientation learning, such as moving about the periphery of the room, are not possible in the virtual environment.

Desktop VR systems at least partially compensate for the single view perspective by providing several additional capabilities that are not available in real-life orientation scenarios. In addition to panning in the clockwise and counter clockwise directions, the learner can zoom in to examine details of a scene or zoom out to obtain a broader perspective of the scene. The learner can also change the level of the scene's horizon with the tilt up and tilt down commands, and return to the initially displayed surround, the home position, with a single button click (Reinfeld, 2016). Many systems also display a wayfinding aid (Burigat & Chittaro, 2007) that graphically depicts the location of the currently displayed scene upon a schematic diagram of the surround.

By using combinations of the available rotate, pan, and tilt commands, a learner can navigate about the virtual representation of the target surround to learn the spatial relationships amongst the object and oneself and ultimately obtain "environmental mastery" (Ausburn & Ausburn, 2008a, p. 54) that is an essential prelude to working in a complex technical environment. Although only three basic operations are available for moving about a virtual surround and all scene views are restricted to single fixed point perspective, the researcher has informally observed that learners apply these operations in a wide variety of ways, often using different approaches based upon what part of the surround is being viewed, or how long they have viewed the surround. This individual variance of wayfinding strategies amongst learners and within individual sessions is not surprising given the dynamic, decision-based nature of wayfinding models.

Self-Regulated Learning

Self-regulated learning (SRL), a learning theory based upon metacognitive processes (Dunlosky & Metcalfe, 2008), is defined as "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" (Pintrich, 2000, p. 453). A reasonable assumption is that the primary SRL activities of planning, monitoring, controlling, and reflecting are executed in order, but Pintrich (2000) noted that observed SRL event sequences exhibit complex, non-linear patterns inconsistent with expected order. The inherent focus of SRL on managing the learning process, has been applied as a framework to examine general studying strategies (Winne & Hadwin, 1998), as well as subject-specific learning strategies in areas such as reading, writing, and mathematics (Dunlosky & Metcalfe, 2008).

Research in self-regulated learning has recently been applied to CBLEs. Although some CBLE systems such as ITS provide a wide range of support facilities that assist learners by highlighting objectives, other systems such as hypermedia and VR lack the structure of the ITS and are essentially “non-linear, multi-representational, open-ended learning environments” (Azevedo, Johnson, Chauncey, & Graesser, 2011, p. 102). The lack of specific facilities in open-ended CBLEs that can help a learner manage the learning process, therefore, requires a learner to self-regulate the learning process, no matter the system type or target knowledge. Although Pintrich (2000) stated that all learners are capable of self-regulating, the extent to which they practice the basic SRL activities of planning, modifying, controlling, and reflecting varies widely by learner. Accordingly, unstructured and open-ended CBLEs may need to provide the learner with some type of assistance, such as presession training or scaffolds, to facilitate self-regulation. Providing SRL support for hypermedia-based learning of complex science subjects has shown that learners who use metacognitive processes made better strategy decisions, scored higher on subject assessments, and formed more complete mental models when compared to those who did not use metacognitive processes (Azevedo, Guthrie, & Seibert, 2004; Azevedo, Moos, Greene, Winters, & Cromley, 2008).

SRL has been increasingly applied to non-academic concepts such as video game design (Zap & Code, 2009) that closely resemble VR-based orientation learning. In support of the applicability of SRL to different types of learning, Winne (1995) asserted that “regulation is inherent and universal in nonreflexive learning, but its forms and, therefore, its effects are malleable because SRL depends on knowledge” (p. 223). For the case of orientation learning of occupational settings, that declarative knowledge takes the form of a potentially detailed and complex set of spatial relationships that exist amongst a set of objects and the observer. Given Winne’s assertion, there is little reason to discount SRL as a viable approach to helping orientation learners better manage and execute the environmental mastery process in VR-based systems. In addition, support for examining the role of metacognition in the specific domain of wayfinding has been expressed by Kitchin and Blades (2002) who acknowledged that little research has been done in examining wayfinding from a metacognitive perspective; they state that such an approach would be useful to apply to “the strategies and combination of strategies that people use to learn spatial information” (p. 53).

Theoretical/Conceptual Framework

This study used a conceptual framework that is based on theories of self-regulated learning and orientation learning, as depicted in Figure 1. The study’s conceptual framework integrates the essential features of both theories to outline the fundamental processes and information flows that occur during orientation learning in a desktop VR environment.

The framework is composed of three major components: the learner, the desktop VR system, and a schematic model of the learner’s cognitive and metacognitive processes. The schematic is divided into a metacognitive area on the left containing the four major SRL actions and a cognitive area on the right containing the cognitive map, associated updating process, and the movement decision process associated with orientation learning.

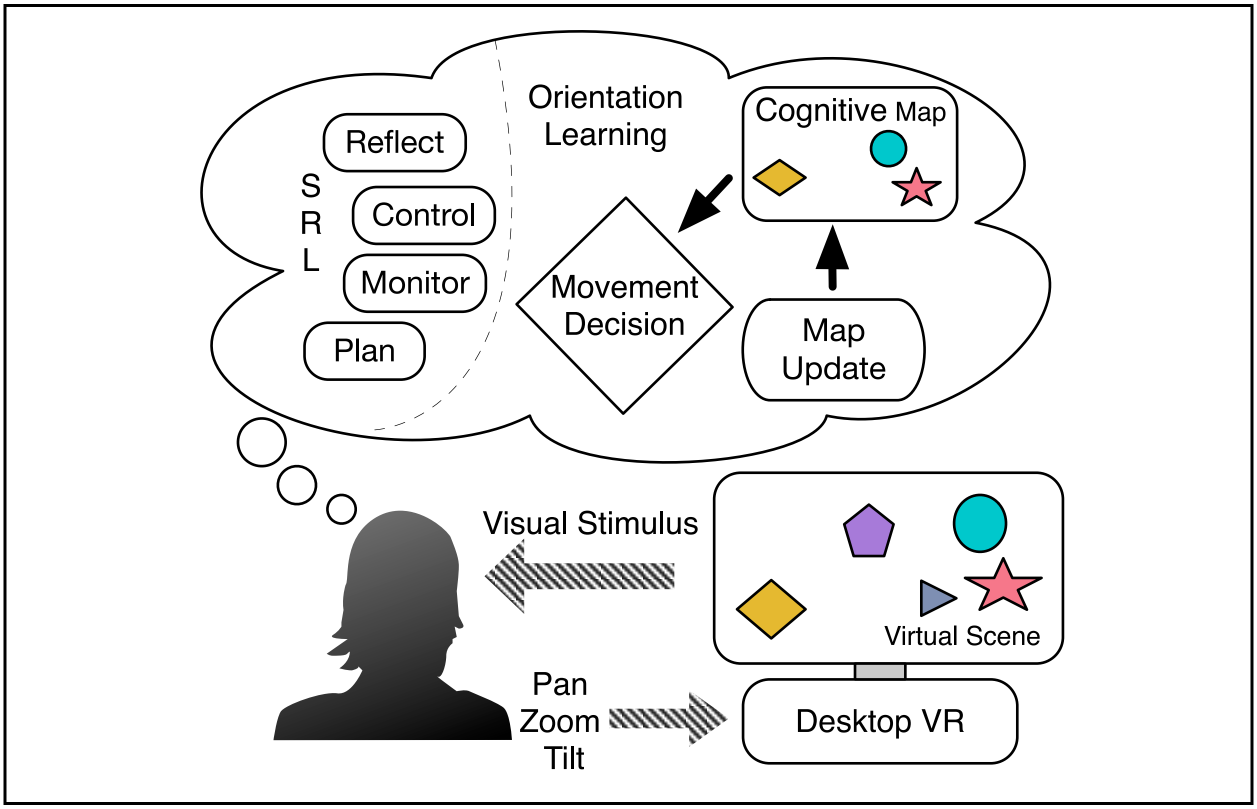

Figure 1. Conceptual framework based on theories of self-regulated learning and orientation learning.

As shown in Figure 1, the learner views the displayed virtual scene from the desktop VR scene and uses that information to construct a cognitive map that represents the spatial relationships between the objects in the entire scene. By asking the learner to verbalize their thoughts with a think-aloud protocol as was done in this study's methodology, the user's perceptions of the viewed scene's objects and their spatial relationships that will be used as the basis for formation of the cognitive map can be identified. As the user continues to move through the surround to view the other constituent scenes and update the cognitive map representation of the surround, the think-aloud transcripts capture the cognitive rationale underlying those movement decisions. The think-aloud transcripts will also capture any regulating events that occur during the orientation learning process. The movements the learners initiate using VR system interface controls are determined by analyzing second-by-second snapshots of the computer monitor images that are captured by screen recording software.

Statement of the Problem

Although desktop VR systems provide a comprehensive set of controls for moving about the virtual surround, they do not provide capabilities for helping the learner to manage the process of becoming oriented to the space. This lack of support might contribute to problems such as high cognitive load or disorientation that some learners experience when using desktop VR (Ausburn et al., 2010). Paradoxically, the minimal affordances of desktop VR systems that provide the learner with a high degree of control that encourages active discovery learning (Lee, Wong, & Fung, 2010) also place a significant burden on the learner to guide and manage the orientation learning of often spatially complex and highly technical environments associated with occupational settings.

Other computer based-learning systems such as hypermedia share the unstructured nature of desktop VR. Recent research in hypermedia has investigated how SRL principles might assist users towards managing learning in complex system environments. Training sessions as short as 30 minutes have been shown to increase students' learning in hypermedia systems (Azevedo & Cromley, 2004), as have conceptual scaffoldings that were designed according to SRL principles (Azevedo & Hadwin, 2005; Moos & Azevedo, 2008). Similar SRL-based techniques may be applicable to desktop VR systems. Almost nothing is currently documented in the research literature regarding how learners navigate in VR environments, apply SRL strategies, or use available system controls to obtain orientation learning objectives. This lack of information hampers understanding of orientation learning in VR environments and, therefore, sound instructional design. This lack of instructional design guidance defines the problem for this study. As a first step in exploring the possibility of using SRL principles to improve orientation learning, this study analyzed learners' think-aloud transcripts to determine the nature of SRL events specific to orientation learning, as well as the extent of individual SRL event usage. Knowledge gained from this study concerning learners' use of SRL events in VR-based orientation learning could be used to guide further investigation regarding the application of specific techniques such as SRL-based training or scaffolds to VR-based orientation learning.

Purpose of the Study

The purpose of the study is to provide VR instructional designers with information about how learners navigate in VR environments that can be used to design a more effective VR experience. This information will lead to a better understanding of the how learners navigate within the virtual surround, how they perceive objects and spatial relationships amongst the scene's object, how they regulate the orientation learning process, and the nature of the major problems they encounter when using a desktop VR system for orientation learning. Increased understanding of learner behavior will enable instructional designers to formulate concrete, evidence-based requirements that will serve as the foundation for improved instructional design of desktop VR systems used for orientation learning.

Research Questions

To address the study's purpose of providing a baseline description of how learners use desktop VR systems for orientation learning, the study considers six research questions. The first set of research questions addresses how learners move through the virtual surround.

Research Question 1

What patterns of movement were used by the participants to rotate through the VR scene during the orientation learning session?

Research Question 2

What field of view (FOV) levels were used by the participants to view the VR scene?

Research Question 3

What is the relationship between the heading and FOV levels used by the participants in the VR scene?

The second set of questions addresses the type of processes and information that learners use during the orientation learning session and the problems encountered.

Research Question 4

What cognitive and metacognitive learning events did the participants use during the orientation learning sessions?

Research Question 5

What patterns of learning events did the participants use during the orientation learning sessions?

Research Question 6

What problems did the participants experience during the orientation learning sessions?

Data Sources and Analysis

As shown in Table 1, both quantitative and qualitative data sources were used to address the research questions. Questions one through three were addressed by using data that was sourced from video screen recordings of the participants' movements in the virtual scene. The researcher developed computer programs to analyze the recordings to produce a quantitative database that described the position and FOV of the participants. Further analysis of this database content produced time series plots, histograms, and scatterplots. Questions four and five were addressed by using audio recordings of the participants' think-aloud verbalizations made during the orientation learning sessions. The researcher transcribed and coded this qualitative content, organized the code into categories, and used code category counts to produce visualizations in the form of histograms and star charts. Question six was addressed by analyzing qualitative data collection from interviews conducted after the orientation learning session.

Table 1

Data Sources and Analysis Techniques to Address Study Research Questions

Question	Data Source	Analysis / Product
1	FOV and heading positions of scenes for each second of orientation learning session, as derived from computer analysis of screen activity recording snapshots	Times series per participant
2		Faceted histograms of FOV
3		Faceted scatterplots of FOV vs heading
4	Coded and classified orientation learning session think-aloud transcripts	Histograms of coded event categories
5		Star chart per participant
6	Coded and classified critical incident interviews	Problem summary with impacts

Note. Faceted products present a plot of given type for each participant in a single arrayed diagram. Star charts provide a visual representation of the proportion of coded event categories each participant used.

Definitions of Key Terms

Allocentric: Establishing the orientation of an object relative to another object or a fixed coordinate system such as latitude and longitude (Montello, 2005).

Critical Incident: An observable human activity with clear intent that occurs in a situation with definite consequences (Flanagan, 1954).

Field of View: Angular distance of the visual field, expressed in degrees.(Blade & Padgett, 2002a).

Desktop Virtual Reality: A VR system installed on readily available, high-end personal computer systems (Ausburn, Martens, Dotterer, & Calhoun, 2009).

Egocentric: Establishing the orientation of an object relative to one's body (Montello, 2005).

Hypermedia: A computer based learning environment based on hyperlink technology which can contain textual information, static diagrams, audio, and digitized video clips to provide a visually rich and interactive learning environment (Moos & Azevedo, 2008).

Immersion: A quantifiable description of technology that indicates the extent to which visual displays are inclusive, extensive, surrounding, and vivid (Mania & Chalmers, 2001).

Navigation: The selection and execution of wayfinding strategies that enable organisms and intelligent machine to move in either a local or distant space (Montello, 2005).

Orientation: The state of knowing the location of objects in an environment relative to the location of an observer and other objects (Hunt & Waller, 1999).

Presence: Failure to notice the presence of a presentation technology or medium when an experience is delivered with a technology-based medium (Ijsselsteijn, Freeman, & De Ridder, 2001); the sense that a person is actually physically *in* a technology-based environment; the "reality" in virtual reality (Ausburn & Ausburn, 2010).

Scaffold: Software features that support a learner to accomplish a task he or she is unable to perform in a mindful, non-automatic manner (Quintana, Krajcik, & Soloway, 2002).

Scene: The portion of a space that can be seen be a stationary observer. Scenes are comprised of objects and provide a visual stimulus to the observer (Hunt & Waller, 1999)

Self-Regulated Learning: Processes that learners use to regulate cognition, generally consisting of preparatory, task completion, and appraisal phases (Puustinen & Pulkkinen, 2001).

Surround: The series of scenes that can be viewed by a stationary observer rotating through 360º (Hunt & Waller, 1999).

Think-Aloud Protocol: Verbalizations of self-generated symbols during problem solving (Ericsson & Simon, 1999).

Time Series: A time-ordered sequence of (time, state) pairs. (Ribler, Mathur, & Abrams, 1995). *Note:* In the context of this study, a state represents the heading position of a displayed virtual scene.

Virtual Environment: A computer simulation of a spatial location that enables user navigation within its boundaries (Ausburn, Martens, Dotterer, et al., 2009).

Virtual Reality: Technologies that enable the display of virtual environments (Ausburn, Martens, Dotterer, et al., 2009).

Visualization: Graphical displays of data that are formatted to assist in exploration, examination, and analysis (Few, 2009).

Wayfinding: The cognitive component of navigation (Darken & Peterson, 2002).

Assumptions and Limitations

Assumptions

The study made several assumptions regarding participant behavior to facilitate comparison across cases. Procedures are in place within the study's protocol to ensure the assumptions are met during the conduct of the study.

(1) The study participants understood the objectives of the orientation learning session and performed on a best-effort basis. The study's protocol guided the researcher to state the learning objectives prior to starting the orientation learning session and provide opportunities for participants to ask questions about the objectives.

(2) The study participants understood that the purpose of the think-aloud protocol was to provide concurrent verbalization of thoughts on a continuous basis throughout the entire

orientation learning sessions. The study's protocol guided the researcher to explain to the participants that they should verbalize what they are thinking on a continuous basis and that they will be prompted to continue talking if they fall silent during the orientation learning session. In addition, the protocol specified that each participant completes a think-aloud warmup exercise prior to starting the orientation learning session.

(3) The study participants were proficient in controlling the desktop VR software. Prior research has shown the interface proficiency is a major factor in VR-based wayfinding performance (Ausburn & Ausburn, 2010; Waller, Hunt, & Knapp, 1998); consequently, the study needed to ensure that all participants could operate the system in a routine manner to facilitate meaningful cross-case comparisons. To ensure a basic level of computer proficiency, the study recruited participants from CTE accounting and information technology programs that require students to interact with personal computers on a routine basis. In addition, the study's protocol contained a detailed tutorial script that the researcher used to explain and demonstrate operation of the desktop VR software using a virtual surround that was similar in nature and scale to the one used during the orientation learning session. After the system demonstration was completed, participants had up to 15 minutes to practice using the controls and ask the researcher any questions regarding operation of the VR system.

(4) The study participants were familiar with the objects in the VR surround, eliminating technical or specialist knowledge as a confounding variable. The surround used during the training and orientation learning session were of residential living spaces that contained common household objects. No special technical knowledge, therefore, was required to recognize the objects in the scene.

Limitations

The study had the following limitations:

(1) Data regarding movement controlled with the VR system's tilt commands were not collected, due to the lack of instrumentation in the VR software to record these data.

(2) To protect participant confidentiality, demographic data were reported in aggregate form only. Participants were not identified by any demographic variables such as gender, age, education level, or VR experience.

(3) Due to the small number of. participants (12) in the study, the description of orientation is not likely to be exhaustive nor generalizable to a larger population.

Significance of the Study

This study is significant to the study of VR- based orientation learning because of its emphasis on description and its synthesis of metacognitive-based theory from educational psychology with the cognitive-based principles of wayfinding. Much of the empirical research in the field of wayfinding has focused on measuring task performance, rather than describing physical behaviour or cognitive rationale for wayfinding decisions (Ruddle & Lessells, 2006). Description of movements addressed by research questions one, two, and three, and of cognitive and cognitive processes addressed by research questions four and five provide an additional significant perspective to understanding VR-based orientation learning. The inclusion of metacognitive-based SRL theory into the study's conceptual framework is significant because it adds a dimension to the orientation learning process that may help learners to better manage what is sometimes a complex learning process. The current study takes first steps in exploring the applicability of SRL to orientation learning by seeking to identify what regulatory events are used and the extent to which those events are used by individual learners as part of its overall description of orientation learning processes and information flows.

To date, none of these issues has been addressed in the VR literature, and almost nothing is known about how learners master orientation learning in virtual environments. Therefore, this study represents a novel step forward in developing understanding of learning processes in desktop virtual reality.

CHAPTER II

LITERATURE REVIEW

Virtual Reality

Historical Development

Virtual reality (VR) is often considered a new technology, but its development is actually relatively lengthy. One of the first virtual reality systems is considered to be the Sensorama Simulator, which was invented by filmmaker Morton Heilig (Blade & Padgett, 2002b), as seen in Figure 2. The Sensorama, which was patented in 1962, had a form factor that resembled an arcade photo booth and used 3D movies as well as stereo sound, puffs of air, released scents, and vibrations transmitted through the operator's seat and arm rest to deliver an experience that was as close to "being there" as possible (U.S. Patent No. 3,050,870, 1962). The inventor realized that the device's delivered experience could be useful in education, reflecting the principle of media concreteness as a learning facilitator as put forth in Dale's Cone of Experience (Dale, 1954), and offered the following benefit of the Sensorama in the specifications section of the patent application:

> A basic concept in teaching is that a person will have a greater efficiency of learning if he can *actually experience a situation* [emphasis added] as compared with merely reading about it or listening to a lecture. For example, more can be learned about flying a supersonic jet airplane by actually flying one, or a student would understand the structure

> of an atom better through visual aids than mere word descriptions. Therefore, if a student can experience a situation or an idea in about the same way that he experiences everyday life, it has been shown that he understands better and quicker, [*sic*] he is drawn to the subject matter with greater pleasure and enthusiasm. When the student learns in this manner he retains for a longer time.(U.S. Patent 3,050,870, 1962, column 2, line 43)

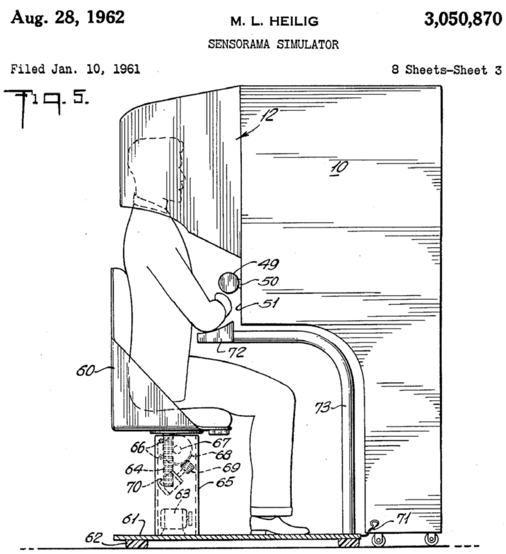

Figure 2. Side elevation view of Sensorama Simulator. Source: www.uspto.gov.

Sensorama was a visionary idea, but the technology base was soon made obsolete by advanced computing technology. Development of computer graphics in the late 1960s, such as Ivan Sutherland's pioneering *Sketchpad* drawing program that was developed as part of his doctoral dissertation program, established the foundation for computer-based VR systems (Blade & Padgett, 2002b). In reviewing the evolution of VR systems, Ausburn and Ausburn (2004) noted that development efforts often concentrated on highly immersive VR systems that used specialized hardware such as head-mounted displays (HMD) or room-sized stereoscopic projection theaters, sometimes referred to as CAVEs, that tracked the user's position in the space. These highly immersive VR systems, as well as several types of Internet-based multi-user virtual environments (MUVEs) such as *Second Life* and *World of Warcraft*, have been the foundation for many successful training platforms in a large variety of industries and sectors and have dominated the virtual reality research stream (Ausburn & Ausburn, 2008a; Ausburn, Martens, Dotterer, et al., 2009; Stone, 2002). Some of these technically complex VR system became extremely elaborate and costly and included advanced HMDs, tactile gloves with touch sensors, and event full sensory-rich body suites. More recently, however, advances in computer graphics technology have created less immersive systems such as desktop VR, and these can also provide an effective industrial and occupational training platform that is both affordable and relatively straightforward to develop using standard digital photography techniques, off-the-shelf personal computers, and specialized VR software (Ausburn & Ausburn, 2004, 2008a, 2008b, 2010). With its visual representation based on photorealism, desktop VR provides a high degree of environmental accuracy or *fidelity* that is of essential importance to most industrial training and occupational education. Interest in studying desktop VR-based applications has increased recently, with published studies examining such diverse areas of workplace education as orientation learning (as applied to police crime scene and surgical technologist training), procedural knowledge, transfer of training, medical simulation training, and pre-employment anxiety reduction and occupational identity (Ausburn, Ausburn, Dotterer, Washington, & Kroutter, 2013). Critical to the success of desktop VR has been its increasing ability to achieve a sense of presences for its users, as defined and discussed below.

The Presence Concept in VR

Defining presence. Despite the major difference in technical complexities and costs, the one key attribute that all VR systems have shared from Sensorama to the present day is the sense of presence they provided to their users. Ijsselsteijn et al. (2001) defined *presence* as the "extent to which a person fails to perceive or acknowledge the existence of a medium during a technology mediated experience" (p. 181), but acknowledge that agreement is lacking amongst scholars regarding the defining characteristics of the concepts. Ausburn and Ausburn (2010) characterized presence as a feeling of having actually visited a place, or of "being essentially the 'reality' in virtual reality" (p. 3) and cited qualitative comments from desktop VR study participants to assert that it was achieved in desktop VR learning studies and did contribute to the learning power of that technology.

Measuring presence. As one might imagine of a nebulous but ubiquitous concept such as presence in VR, measurement techniques abound (Sadowski & Stanney, 2002). Sadowski and Stanney (2002) classified presence measurement techniques as being either subjective, including rating scales, subjective reports, comparison-based predictions, and cross-modality matching, or objective, including behavioral and physiological measures. Several researchers have asserted that the inherent nature of the concept of presence and approaches towards its measurement may be fundamentally incongruent. Ausburn and Ausburn (2010), for example, indicated that a qualitative approach may be needed to better understand and measure presence, but noted that qualitative approaches have not been commonly used to study virtual environments. Along similar lines, Turner and Turner (2006) noted that the philosophical positions of sociologists and humanistic geographers who study the relationship of presence and place are quite different from that of most virtual reality researchers, leading to a dissonant situation regarding measurement of presence, that they succinctly characterized as follows:

> So here we have it: presence and sense of place are a first-person perspective while the models of presence are objective and scientific. This is not a problem for the social scientist or the technologist but for both. (p. 216)

Overall, the literature on presence in VR indicates that at the present time, presence is highly sought in the technology and frequently considered one of its defining characteristics (Ausburn & Ausburn, 2010), yet it is without a widely recognized or accepted instrument or strategy for its measurement or evaluation. VR researchers appear to acknowledge the criticality of presence in the medium and the key role in its appeal and value, while at the same time being unable to define it operationally or to agree on its accurate measurement. This dilemma remains one of the major functional issues in VR research.

Wayfinding and Navigation

Basic concepts and definitions of navigation, wayfinding, and orientation learning were introduced in Chapter 1. Briefly, the following definitions were established for this study:

<u>Navigation</u>: The selection and execution of wayfinding strategies that enable organisms and intelligent machine to move in either a local or distant space (Montello, 2005).

<u>Wayfinding</u>: The cognitive component of navigation that guides the selection of tactical and strategic processes that guide movement, based on dynamically built and referenced mental representations of a space (Darken & Peterson, 2002).

<u>Orientation</u>: The state of knowing the location of objects in an environment relative to the location of an observer (egocentric) and other objects (allocentric) (Hunt & Waller, 1999).

Two additional orientation learning topics that are relevant to this study are cognitive maps and wayfinding models. These topics are discussed in following sections.

Cognitive Maps

As learners experience a virtual environment, they build and reference a cognitive spatial representation of the environment in memory called a cognitive map (Taylor, 2005). Although the spatial representation is referred to as a "map," there is not universal agreement that the cognitive representation is as orderly and structured as a typical cartographic map (Kitchin, 1994). Some scholars rejected the analogy of a cognitive map being similar to a static cartographic map and consider the term “cognitive collage” (Tversky, 2005, p. 12) to be a more accurate indicator of its dynamic, incomplete, and fragmentary nature.

The spatial knowledge that is derived from cognitive maps by navigators is generally considered to be of three main types: (1) landmark knowledge; (2) route knowledge, also known as procedural knowledge; and (3) survey knowledge, also known as configuration knowledge (Kitchin & Blades, 2002). Landmark knowledge is the most basic type of knowledge, acquired through direct observation of a physical object or a surrogate visual representation, as would be the case of seeing the object portrayed in a photograph or in the scene of a virtual environment. Both procedural knowledge and configuration knowledge require landmark knowledge as their foundation (Darken & Peterson, 2002). Route knowledge is represented as a set of instructions that direct a navigator along a specific route (Chen & Stanney, 1999) and is often represented as a graph or network that is dynamically constructed during the wayfinding process where physical locations are represented by the the graph’s node and the paths between locations are represented by links that join the graph’s nodes (Thorndyke & Hayes-Roth, 1982). Survey knowledge is the highest form of spatial knowledge representation. As a representation of the configuration of a physical or virtual space, it is most like a birds-eye or map-like view of the space. A navigator who has survey knowledge can use the configuration information to estimate distance and relative directions between points and can plan routes that have not been personally traversed (Kirasic, Allen, & Siegel, 1984; Thorndyke & Hayes-Roth, 1982).

Wayfinding Models

The study of wayfinding and navigation is a strongly interdisciplinary area that has been studied from the perspectives of urban planning, architecture, computer and information science, psychology, industrial engineering and human factors, and geography. Several of the major models that have originated from scholars in these diverse fields are described in this section. Although several of the models share a core framework built upon decision making and associated information flows, others serve to introduce perspectives that highlight a number of important aspects of wayfinding theory and practice beyond process.

Urban planner Kevin Lynch (1960), who was a former apprentice at Frank Lloyd Wright's Taliesin school of architecture (The MIT Press, n.d.), was an early pioneering influence on the disciplines of orientation and wayfinding. Lynch tended to view orientation from a broad perspective that emphasized environmental features rather than process. From his study of the layout and features of the cites of Los Angeles, Boston, and Jersey City, Lynch (1960) determined that sections of cityscapes could be classified into five major elements that he identified as (1) paths (areas that one moves along, such as a street or railroad section), (2) edges (linear forms, often used as boundaries, that are not used for travel), (3) districts (sections of the cityscape with common features or purposes), (4) nodes (junctions and concentrations of travel), and (5) landmarks (prominent physical points of spatial reference). Lynch stated that an environmental feature had three essential characteristics: identity, structure, and meaning. Identity established the uniqueness of the feature; structure established the spatial relationship that existed between the feature, other features, and the observer; and meaning provided some practical or emotional connection that was personally valuable to the observer. Using these three essential characteristics of an environmental feature as a starting point, Lynch (1960) developed the concept of *imageability*, "that quality in a physical object which gives it a high probability of evoking a strong image in any given observer" (p. 9), retaining identity and structure (but not meaning) as the primary elements of the taxonomic framework he used for the identification and classification of the five different cityscape elements.

Another early wayfinding model was developed by Romedi Passini (1984), an architect and urban designer, who analyzed verbal protocols of persons navigating the Montreal subway system and adjacent underground shopping complexes. He defined wayfinding as a spatial problem-solving process that involved the development of decision plans and their subsequent conditional execution based upon testing perceived and expected images derived from environmental observations. In a later work Arthur and Passini (1992) elaborated the initial description of wayfinding by identifying seven basic wayfinding tasks and the associated cognitive resources needed to perform the tasks. Although most of the tasks involved the learning and planning of routes, one of these seven tasks, “understanding the overall layout of a visited setting,” which required cognitive resources of “identifying the underlying principle of spatial organization” (Arthur & Passini, 1992, p. 37) closely corresponded to orientation learning as defined in the present study. Being architects and urban designers, Arthur and Passini focused their attention on cityscapes and noted that some buildings in a cityscape were more memorable than others, a concept similar to Lynch’s imageability. The four factors they listed that made a building memorable were (1) form, including contour, shape, and architectural uniqueness; (2) visibility and accessibility; (3) function; and (4) symbolic significance, especially of a cultural or historical nature.

Jul and Furnas (1997), who organized a small computer- human interface (CHI) workshop sponsored by the Association for Computing Machinery (ACM) for specifically addressing navigation in electronic information systems, documented a wayfinding model that was developed and presented at the workshop by attendees Darken, Nigay, Robertson, Spence, and Vincow. The model, which was documented in a flowchart diagram, consisted of the starting task of forming a goal, followed in sequential order by tasks of deciding strategy, acquiring data, and scanning the environment. The process flow originating from the scanning task was directed through a loop of subtasks that included assessing whether more information was needed, forming a conceptual model of the observed environment as a cognitive map, and executing an action, before finally returning to the scanning operation. The model's diagram also showed an alternate process path that went directly from the assessment task to the action task without passing through the task of forming a conceptual model. The action execution task was depicted as both an endpoint that resulted in some movement or locomotion towards meeting the goals of the navigation and as an intermediary node in a feedback loop that directed information obtained in the scanning cycle towards possible revision of any of the previously executed tasks of forming goals, deciding strategy, or acquiring data. Operations documented in this model's scanning loop, closely resembled the decision-oriented approach of the Passini (1984) model of scanning the environment, checking perceptions against cognitive representations of the environment, and then moving.

Jul and Furnas (1997) also reported on the distinction between situated and planned wayfinding strategies, as presented by Czerwenski in the CHI navigation workshop. Situated wayfinding strategies are generally used when the navigator is near the goal and involve the use of incomplete information specific to the situation and local landmarks. In contrast, planned strategies are developed prior to commencement of the navigation task and rely on symbolic survey knowledge such as maps. Czerwenski noted that some navigators may have an individual preference for one of the two strategies, or these strategies may be interchanged according to the situation, such as switching from a situated strategy of following signs after becoming lost to a strategy of consulting a map to regain orientation to the goal.

A comprehensive wayfinding model specifically directed towards virtual environments was developed by industrial engineering and human factors specialists Chen and Stanney (1999). This model, as seen in Figure 3, featured three major processing components: (1) information generation, which was primarily concerned with building the cognitive map from sensory data and previously inferred information; (2) decision making, which was primarily concerned with making a wayfinding plan based on information developed in the navigator's cognitive map; and (3) execution of the wayfinding plan. Feedback loops were included in the model to connect the major processes, in a similar manner to the CHI workshop model reported by Jul and Furnas (1997). Chen and Stanney (1999) further divided the model into two areas to emphasize the distinctions between the cognitive and locomotive components of navigation. The area labelled as *Wayfinding* contained depictions of the cognitive operations associated with the cognitive mapping and decision making processes, while the other area labelled as *Navigation*, contained the motion-based operations as implemented by the decision execution process. Reflecting its more comprehensive nature, several components were included in the Chen and Stanney model that previously discussed models had not directly considered, including learners' motivation, experience, and spatial ability; search strategy; and the virtual environment's layout and structure, all pictured in the area of the model labelled *Other Factors*. In addition, the Chen and Stanney model explicitly included several features, notably the environment and human sense, that were implied in the processes related to environmental information gathering included in the Passini (1984) and Jul and Furnas (1997) CHI workshop model.

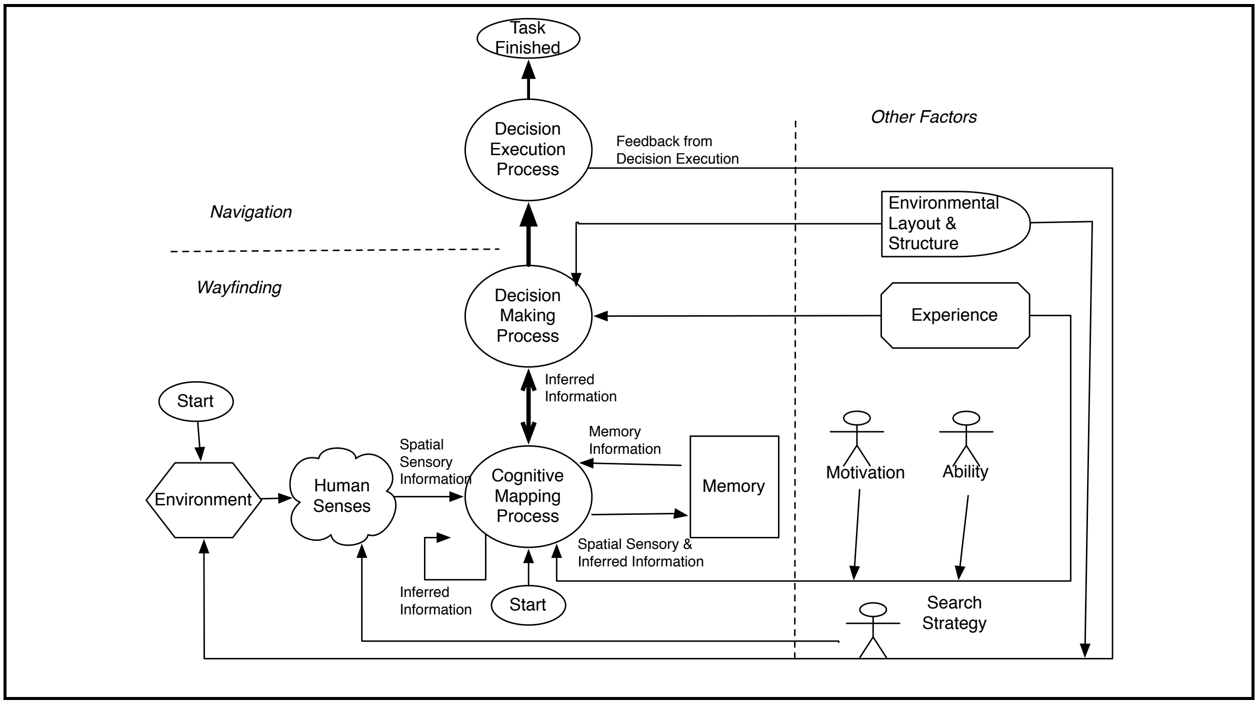

Figure 3. Chen and Stanney wayfinding model. Adapted from “A Theoretical Model of Wayfinding in Virtual Environments: Proposed Strategies for Navigational Aiding,” by J. L. Chen and K. M. Stanney, 1999, *Presence: Teleoperators and Virtual Environments, 8*(6), p. 675. © 1999 by the Massachusetts Institute of Technology. Reprinted with permission.

Allen (1999), a professor of geography, developed a taxonomic model that classified various types of wayfinding into functional tasks and identified associated strategies, information types, and cognitive processing required to complete those tasks. Allen (1999) defined *explore*, one of the major functional tasks, as “traveling into unfamiliar territory for the purpose of learning about the surrounding environment” (p. 554), a definition that captures the essential nature of the orientation learning process. The other major functional tasks included the *commute*, which involves routine travel over a familiar route between known locations, and the *quest*, which involves travel to a distant location that is planned by using symbolic spatial information such as a map. Allen used a multi-level, many-to-many mapping to describe the relationships between wayfinding tasks (commute, explore, and quest), wayfinding means (locomotion, piloting, path integration, and navigation by cognitive map), and cognitive resources (landmark memory, movement memory, landmark-movement memory, sequence memory, and cognitive map) used to support the wayfinding means. Arthur and Passini (1992) had presented a similar mapping of wayfinding tasks to cognitive resources, but Allen advanced this concept by depicting a more detailed multi-level mapping rather than the simple direct mapping depicted in the earlier relationship.

Although specific task terminology may have been different across the process-oriented models of Passini, the CHI workshop, and Chen and Stanney, all of them featured complex and iterative decision cycles that pictured the navigator as obtaining information about the environment from human senses or inferred information, comparing that information to existing spatial representations or a conceptual model in the form of a cognitive map, and acting on that information to either execute a locomotive action or obtain additional information to further support the wayfinding process. Cognitive processes form an important component of wayfinding, but additional perspectives are needed to fully understand and describe the wayfinding process. These major additional perspectives discussed in the literature have included learner characteristics and virtual environment design (Chen & Stanney, 1999); object-oriented notions of imageability and memorability (Arthur & Passini, 1992; Lynch, 1960); the situated and possibly personally preferred nature of different types of navigation strategies (Jul & Furnas, 1997); and the complex relationships between wayfinding functions, means, and cognitive resources (Allen, 1999).

Metacognition and Self-Regulated Learning

The concept of metacognition originated from the work performed by Flavell (1979) in the area of child development psychology in the mid-1970s and is commonly described as "cognitions about other cognitions"(Dunlosky & Metcalfe, 2008). The study of metacognition generally focuses on three major areas: metacognitive knowledge, metacognitive monitoring, and metacognitive control (Dunlosky & Metcalfe, 2008). Metacognitive knowledge is the collection of facts and beliefs about cognition, such as how learning might be improved through some specific technique such as mnemonic formation. Metacognitive monitoring is the process of evaluating the progress and state of a cognition, such as how well one is learning a particular concept. Lastly, metacognitive control is the process of regulating cognition, for example, deciding to use a different strategy to learn a particular concept.

Self-regulated learning (SRL) has been viewed from several different theoretical perspectives, including information processing, metacognition, and social cognition (Puustinen & Pulkkinen, 2001). The framework developed by Pintrich (2000) offers a definition of SRL that incorporates the major features of most SRL models: "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment" (p. 453). The Pintrich (2000) model of SRL made four major assumptions. First, learners were assumed to take an active role in the construction of the individual learning goals and selection of the appropriate strategies to reach those goals. Information used to make decisions regarding goals and strategies comes from external sources such as the context of the learning environment as well as from the learner's internal cognitive and metacognitive processes. Second, learners were assumed to be able to exercise control over their cognition, behavior, and motivations, as well as some aspects of their external environment, but not all learners will exercise this control at the same level. Third, some standard or criteria that can be used as a setpoint in the regulation processing was assumed to be available. Learners use this standard as a point of comparison against their present learning state and constructed learning goals and make decisions regarding the next course of action based on that comparison. Finally, SRL was assumed to act as a mediator between learning outcomes and the individual characteristics of the student and the learning environment.

Pintrich's (2000) model of SRLwas structured as a two-dimensional framework that included four phases of learning as one dimension, and four areas of regulation in the other dimension. The four phases of learning were presented as a general heuristic that included planning, monitoring, control, and reflection. A reasonable assumption might be that the phases occur in a linear fashion, but the Pintrich model explicitly noted that they may occur in considerably more complex patterns. The four areas of regulation that comprise the second dimension of the model include standard psychological domains of cognition, motivation/affect, behavior, and context.

A more process-oriented view of SRL than Pintrich's was set forth in the COPES (Conditions, Operations, Products, Evaluations, and Standard) model, which Winne and Hadwin (1998) originally introduced as a framework for examining the academic studying strategies of high school and college students. The original model has been revised (Winne & Perry, 2000) and has come to be viewed over the last ten years as a general model of self-regulated learning (Puustinen & Pulkkinen, 2001). Similar to the Pintrich (2000) framework, the COPES model posited that learning generally proceeds in a series of four ordered phases: (1) defining the task, (2) setting goals and planning, (3) enacting strategies and tactics, and (4) adapting metacognition. COPES was described as a "recursive, weakly sequenced system" (Winne & Hadwin, 1998, p. 281), which implies that a cycle of phases might be interrupted mid-cycle for another cycle to begin, and so forth to any arbitrary depth, consistent with Pintrich's characterization of the complexity of learning phase order. COPES went considerably beyond the general characterization of SRL in the Pintrich (2000) framework, however, by specifying a complex flow of information centered around the metacognitive operations of monitoring and controlling (Winne & Hadwin, 1998), as seen in Figure 4.

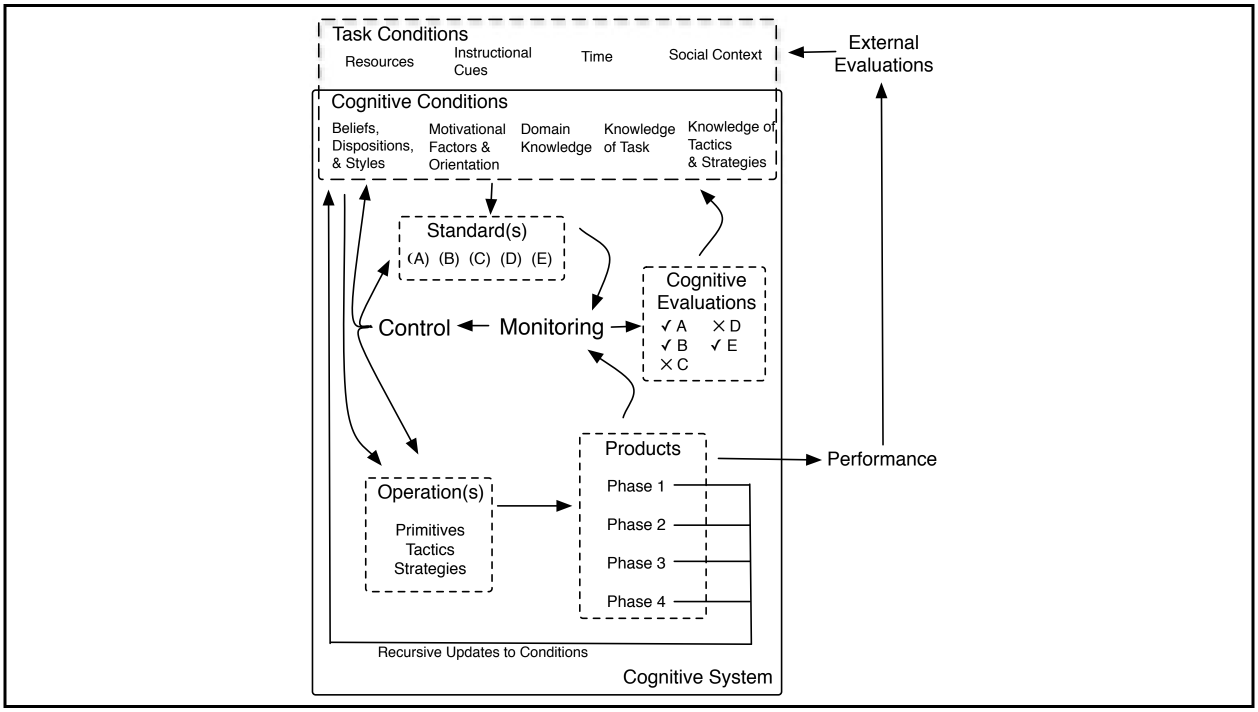

Figure 4. Major processing components of the COPES model with associated information flows. Adapted from "Studying as Self-Regulated Learning," by P. H. Winne and A. F. Hadwin, 1999, In D. J. Hacker (Ed.), *Metacognition in Educational Theory and Practice*, p. 282. Reprinted with permission.

The COPES model's identifying acronym corresponds to its basic components of *Conditions*, *Operations, Products, Evaluations,* and *Standards* that represent different types of information processed (i.e., generated or read) during SRL operations (Winne & Hadwin, 1998). In the COPES model, conditions are a broad set of cognitive, social, cultural, and environmental factors that are evaluated by a learner to determine how to proceed with a particular cognitive task or operation, which may range from being very general in nature (strategies) to being quite specific (tactics and primitives). Products represent the various types of information produced by operations for particular phases of learning, and standards are information types that serve as the evaluative criteria for metacognitive monitoring operations. The ultimate output of the model, the learner's performance, is derived from the products and subject to external evaluations, which flow back into the model as updates to the task conditions. From the general flow of process and information, it can be seen that there is a distinct resemblance between the decision-oriented processes of monitoring and controlling presented in the COPES model and the wayfinding models of Passini (1984), Chen and Stanney (1999), and Jul and Furnas (1997).

Metacognitive Approaches in New Learning Environments

Staring in the mid-1990s, computer based learning environments were changing from simple linear displays of information that used the basic interface paradigm of "Press the Space Bar to Continue" (Jones, Farquhar, & Surry, 1995, p. 12) to more complex "open-ended learning environments (OELEs)" (Hill & Hannafin, 1996, p. 271) such as hypermedia that gave more control to the learner. Instead of presenting learners with a single static perspective base of information for learning, these new systems, which Hill and Hannafin (2001) latter termed "resource-based learning environments (RBLEs)" focused on giving learners the tools to locate and analyze a variety of resources from multiple sources and perspectives (p. 38).

Proposals to use metacognitive approaches as a framework for helping learners meet the challenges of the new OELEs started to appear in the instructional design and educational psychology literature at this time. From the system design perspective, Jones et al. (1995) developed a set of interface design guidelines based on metacognitive principles of monitoring and control that included clearly stating the purpose of the system, guiding learners to select the appropriate learning strategy within the system, and monitoring both the learners' progress toward stated objectives and the effectiveness of their selected learning strategies. From the quantitative perspective, Hill and Hannafin (1996) conducted a small exploratory study (n = 14) that examined the relationship between learners' metacognitive knowledge and the set of strategies they used to search the Web with the then new Netscape browser. Today's Internet browsers that have evolved from Netscape are so ubiquitous that it is hard to think of them as revolutionary tools, but this 1996 study considered the browser to be a prime example of the new type of computer-based learning environment, characterizing it as being an open-ended, user-centered system that required the learner to engage in generative activities to discover the range of information resources it could potentially offer. The researchers collected data by using self-reporting surveys as well as concurrent and stimulated think-aloud protocols to measure the learners' degree of disorientation, self-efficacy, and the amount of knowledge they had learned about metacognitive strategies and system knowledge (i.e. using Netscape) and subject knowledge (i.e. search results). Results of the study indicated that the participants had used a large variety of strategies, and that their choice of strategies had been influenced by levels of metacognitive, system, and subject knowledge, as well as personal perceptions of self-efficacy and disorientation. Hill and Hannafin (1996) concluded that if learners were to successfully learn to use OELEs, then the singular directed strategy emphasized in the educational system needed to be replaced with an approach that emphasized divergent and independent thinking, and that successful learners would be those who could orient themselves and build functional models of the systems.

The rapid growth and popularization of the Internet and associated Web-based hypermedia systems in the 21st century accelerated the introduction and growth of OELEs into the educational system. Azevedo (2005) expressed concern that the potential of OELEs, which he called computer-based learning environments (CBLEs), as effective learning tools might not be realized, asserting that "our understanding of the underlying learning mechanisms that mediate student's learning with such environments lags in comparison to the technological advances that have made these same environments commonplace in homes, school, and at work" (p. 200). He advanced SRL as the metacognitive-based framework that could provide a better understanding of the complexities and difficulties learners encountered when using CBLEs such as hypermedia and adopted the SRL framework of Pintrich (2000) and the COPES model (Winne, 2001) as the conceptual framework for his studies.

One of the earlier studies conducted by Azevedo, Guthrie, et al. (2004) examined how high school students (n = 24) used hypermedia (the Microsoft *Encarta* encyclopedia) to learn about the human circulatory system. Pre- and post-tests were administered to measure differences in the sophistication level of the students' mental model of the circulatory system that they gained over the 45-minute learning session. In addition, the researchers used the think-aloud protocol to capture students' thought processes during the session. After coding and analyzing the transcripts, the researchers developed a taxonomy of SRL event variables that were organized into five major categories: (1) planning, (2) monitoring, (3) strategy use, (4) task difficulties and demands, and (5) interest level. Students who had the higher gains in mental model development of the circulatory system were found to have used more effective strategies, planned learning by activating prior knowledge, monitored learning progress, and planned the time and amount of effort expended in learning the subject content. In contrast, students who had lesser gains in mental model development used about the same amount of effective and ineffective strategies, planned learning by merely recycling subgoals in working memory, often sought help, and rarely monitored their learning or planned time and effort for completing the lesson.

Given that the first study found significant learning gains associated with SRL use, a succeeding study examined how students could increase their use of SRL through presession training (Azevedo & Cromley, 2004). For this study, undergraduate college students (n = 131) used hypermedia to learn about the circulatory system. Prior to starting their learning session, the experimental group participants were individually tutored regarding the use of SRL. Tutorial materials consisted of a high-level diagram that depicted Pintrich's framework of SRL as well as a list of the SRL event variables that had been gathered during the previously discussed study. Each of the event variables was accompanied by a specific example of its use. Comparison of pre- and post-test scores, as well as data from the think-aloud protocol showed that the experimental group made significantly larger gains in understanding and also used more of the SRL events that were shown to them during the training session than did the control group.

Azevedo et al. (2008) continued their study of high school students (n = 128) using hypermedia to learn about the circulatory system. For this study, presession training was not provided for either group; rather, a human tutor was made available to learners in the experimental group, which they termed as the externally regulated leaner (ERL) group, as contrasted to the SRL control group, which did not have access to the tutor. A tutoring script was developed for the human tutor to prompt students to perform regulatory events such as activating prior knowledge, planning effort and time, monitoring progress towards learning goals, and selecting and using a set of effective strategies. Results of the study indicated that the experimental group outperformed the control group in their development of the circulatory mental model and they used more SRL events and effective strategies than the control group during the learning session. The ERL tutor can be essentially thought of as a scaffold, which is a feature that supports a learner to accomplish a task he or she is unable to perform in a mindful, non-automatic manner (Quintana, Zhang, & Krajcik, 2005). At this point, the research team had found that introducing presession training and in-session prompting regarding SRL events had resulted in improved learning performance and a more effective and efficient patterns of SRL use.

Other researchers also studied SRL-based training and prompting in hypermedia, but found less clear results. Bannert and Reimann (2011) studied undergraduate psychology students (n = 80) who used hypermedia to study operant learning theory and general concepts of motivation. The study combined the conditions of SRL-based training and prompting into two experiments. One experiment used a prompting-only experimental condition, and the other used and training-plus0prompting condition. The general methodology resembled the Azevedo and colleague's studies, using pre- and post-tests to measure learning and gathering process data with the think-aloud protocol to assess learner SRL event patterns. In addition, this test measured additional variables related to motivation and disorientation. No SRL support was provided to the control groups in either experiment. Results for the first experiment (prompting only) indicated that the experimental group used more SRL events, but no differences between the experimental and control groups were found for learning performance, disorientation, and motivation variables. Results for the second experiment indicated that the experimental group used more SRL events and had better learning performance, but no differences between the experimental and control group were found for the disorientation and motivation variables.

Later studies by Azevedo and colleagues focused on *MetaTutor,* which is an advanced hypermedia system designed to use computer software to implement the SRL training and prompting functions that were delivered by human agents in previously described studies. *MetaTutor* uses SRL-based adaptive scaffolds delivered by animated pedagogical agents (e.g. Baylor, 2002; Martens, 2009) based on the diagnosis of the learner's progress, task, and current content being studied, and is automatically faded when no longer required (Azevedo, Cromley,

& Seibert, 2004; Azevedo, Cromley, Winters, Moos, & Greene, 2005; Azevedo & Hadwin, 2005; Azevedo, Witherspoon, Chauncey, Burkett, & Fike, 2009). Training is currently provided on the system by demonstrating best practice SRL events with interactive videos. *MetaTutor* was used by high school and undergraduate college students without adaptive scaffolds to gather baseline data regarding SRL usage patterns, revealing that the students used few SRL processes when no support was provided. Analysis of think-aloud sessions from initial users of *MetaTutor* showed that activation of learning strategies accounted for nearly 80% of SRL activity at the rate of two per minute, while metacognitive judgements accounted for only about 15% of the activity, at a rate of one judgement every four minutes, based on hour long learning sessions (Azevedo et al., 2009).

Summary

Developments in computer technologies that have been undertaken since the last quarter of the 20th century have led to a cost effective platform, desktop VR, that is well-suited to occupationally-based orientation learning. Although VR has been extensively studied, some core issues in the field that impact VR's usefulness as a learning technology, such as the definition of and measurement of presence, are continuing active areas of debate and research. Concurrent with VR technology development, scholars in a variety of disciplines have developed several models that explain how humans learn about spaces, both real and virtual. These wayfinding models, however, do not directly incorporate potentially beneficial aspects of metacognitive-based learning into their view of the wayfinding process. Some newer open-ended learning technologies, however, have examined how metacognitive-based learning principles such as SRL can improve technology-based learning. The current study will explore how learners used desktop VR orientation learning as an initial step towards examining how SRL principles might enhance learners' VR-based orientation learning experience,

CHAPTER III

METHODOLOGY

This chapter describes the methods used in the study to collect and analyze data. The chapter is organized into four major sections: design, sampling, instrumentation, and procedures. The design section identifies the study's major methodological approach and discusses the reasons for its selection. Next, the sampling section discusses the techniques that were used to select and recruit the study's participants and summarizes the group's demographics. Following the sampling section, the instrumentation section describes the four major tools used to collect the study's data: computer screen recording, the think-aloud protocol, an orientation learning exercise, and a demographic questionnaire. Finally, the procedures section describes the techniques and equipment that were used to build the study's VR-based orientation learning environment, and to collect and analyze the data that were generated from the participants' interactions with the built VR environment.

Design

A mixed methods content analysis design was used in this study. Creswell and Plano Clark (2011) stated that mixed methods research has the following core characteristics: uses both qualitative and quantitative data collection and analysis techniques based on research questions;

may integrate the two forms of data in a concurrent, embedded, or sequential manner; and may emphasize one form of data over the other. Furthermore, they state that the mixed methods procedures are shaped by a philosophical worldview, may be used for a single study or phases of a larger study, and are combined to serve as the plan for conducting a study. These characteristics are present in the current study, as discussed below.

Content analysis is defined as "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff, 2004, p. 18). Applying this definition to the current study, three content analysis procedures were used to infer information from three distinct texts to address the study's research questions. The first procedure, participant movement content analysis, used a quantitative text consisting of time series of heading positions and FOV levels to infer patterns of movement that the participants used during the orientation learning session, thereby addressing research questions one to three. The second procedure, orientation learning event content analysis, used a qualitative text consisting of transcripts of think-aloud verbalizations made by the participants during the orientation learning activity to infer the cognitive and regulatory event that the participants used during orientation learning on a collective and individual basis, thereby addressing research questions four and five, respectively. Finally, the third procedure, critical incident content analysis, also used a qualitative text consisting of transcripts of critical incident interviews conducted with each participant after completion of the the VR-based orientation learning activity to infer the major types of problems orientation learners experience when using desktop VR, thereby addressing research questions six. The texts that were used for each of the three content analysis procedures were not directly collected during the VR orientation learning session; rather, they were generated by computer program analysis of video recordings made of the participant's computer screen activity and through transcription of the audio recordings made of the concurrent think-aloud verbalizations and the critical incident interviews.

Reflecting the researcher's worldview of pragmatism, the primary reason for choosing a mixed methods approach was based on the the premise that the study's different research questions are best answered by different types of data (Bryman, 2006). Research questions one to three, which were concerned with describing the movements participants used during orientation learning, were best answered with quantitative data such a heading positions and FOV levels, whereas research questions four to six, which were concerned with cognitive and SRL processing during orientation learning, as well as the participant's perception of encountered problems, were best answered with qualitative data such a thought verbalizations and participants' interview replies.

This study used a variant of the mixed methods approach called parallel convergent design that considered the qualitative and quantitative strands to have equal priority in the study (Creswell & Plano Clark, 2011). The parallel convergent design features concurrent execution of the qualitative and quantitative data collection and analysis strands, followed by an additional "mixing" step that merges the results of the different strands into a form that facilitates interpretation of the study. To implement the convergent parallel design, the study used three content analysis procedures previously described: participant movement content analysis, a quantitative strand, orientation learning event content analysis, a qualitative strand, and critical incident content analysis, another qualitative strand. Each of three procedures were designed to be independently executed with no procedure depending on intermediate results from the other. To implement the mixing operation of the design, each of the two qualitative strand content analysis procedures "quantitized" (Teddlie & Tashakkori, 2011) their analysis results by calculating frequency counts of codes assigned to qualitative categories and subcategories. This frequency calculation technique is an established practice in qualitative content analysis (White & Marsh, 2006) and enabled the results of all strands to be presented in a quantitative format. Presentation of the results in a quantitative format enhanced the description of how learners use desktop VR for orientation learning by providing information about the extent to which the components of orientation learning (movement patterns, learning events, problems) were used, rather than just the nature of the component.

Sampling and Approvals for the Study

The present study used purposive sampling to select participants for the case study. Purposive sampling is based on the assumption that selection of participants should be based on criteria that facilitate focus on the study's central purpose (Patton, 1990). Consistent with its descriptive purpose, the researcher planned to use a maximum variation sampling approach (Teddlie & Yu, 2007) to recruit a set of participants who would likely exhibit a broad set of orientation learning patterns. As recent reviews of VR research have shown that gender is a significant factor in wayfinding performance(Ausburn, Martens, Washington, et al., 2009; Martens & Antonenko, 2012), the researcher planned on recruiting an approximately equal proportion of men and women as a control for this variable.

The descriptive nature of the study precluded specification of sample size based on statistical criteria such as power and confidence intervals. Qualitative methodology suggests that sampling terminate at which point information redundancy is encountered (Merriam, 1998). From a more practical perspective, Patton (1990) recommended that researchers propose a minimum sampling size during the study planning, with size "based on expected reasonable coverage of the phenomenon given the purpose of the study and stakeholder interests" (p. 186).

As with the present study, many human-computer interaction (HCI) studies examine how people interact with computers to accomplish tasks and also share the think-aloud protocol technique for data collection with the present study (Lazar, Feng, & Hichheiser, 2010). Guidelines from HCI research, therefore, were used to generate a reasonable estimate of sample size for this study. In a review of think-aloud usability studies, Nielsen (1994) found that 86% of the usability problems were found with six subjects and accordingly recommended that usability tests could be effectively conducted with between three to five participants. Although the present study focused on a more ambiguous task of description as compared to the well-defined tasks of finding usability errors typical of HCI studies, Nielsen's guidelines provided a reasonable starting point for determining the size of the study to be approximately ten to twelve participants.

Given the high degree of potential usefulness of desktop VR to career and technical education (CTE) (Ausburn & Ausburn, 2008a, 2010; Ausburn, Martens, Washington, et al., 2009), the study recruited participants from a CTE student population. Participants were recruited from two local CTE institutions: the Tri-County Technology Center (TCTC) in Bartlesville, Oklahoma, and the Oklahoma State University Institute of Technology (OSUIT) in Okmulgee, Oklahoma. Prior to conducting recruitment sessions, the researcher obtained written permission from the TCTC superintendent of instruction and the OSUIT vice president of academic affairs to recruit adult students over the age of 18 years to participate in the study, as documented in Appendix A. A researcher-developed recruitment script and associated letters of permission from the CTE administrators were submitted to the Oklahoma State University (OSU) Institutional Review Board (IRB) as part of the study's plan to conduct human subject research. Approval to conduct the study (ED 13160) was received on October 9, 2013, as documented in the IRB approval letter included in Appendix B.

After receiving IRB approval, the researcher arranged to visit each research site for two days during the months of October and November of 2013 to recruit participants and conduct the study. On the morning of the first day of each site visit, the researcher read the approved recruitment script verbatim, as seen in Appendix A, and answered questions regarding the study from three information technology classes at OSUIT and two accounting classes at TCTC. Five participants were recruited from OSUIT and seven were recruited from TCTC to participate in the study, which was conducted at on-campus facilities during the remaining day and a half of each site visit.

Demographic Profiles

A potential risk to participant confidentiality in this study was the study's small sample size of twelve participants, which increased the possibility of deducing a participant's identify from demographic data collected as part of the study. The study's use of voice recording provided an additional source of data that could be used in conjunction with demographic data to reveal a participant's identify. To manage the confidentiality risk, demographic data collected during the study were not linked to participant identifiers and are reported only in aggregate form without details for the individuals, and the audio tracks of the ScreenFlow recordings were extracted and destroyed after transcription.

All of the study's participants were high school graduates enrolled in career tech programs at TCTC or OSUIT. The participant group was young, with eight of the twelve aged between 18 and 24 years, three aged between 30 to 34 years, and one aged between 35 and 39 years of age. Half of the group identified their gender as female and half as male. The participants had a mixed level of VR system experience, five participants had no experience, five had used a VR system between one and five times, and two had used a VR system more than ten times.

Instrumentation

Four instruments were used in the study to collect data regarding the participant's interaction with the VR system during an orientation learning session: (1) the computer session recorder, (2) the think-aloud protocol, (3) the orientation learning exercise, and (4) the critical incident interview. Descriptions of each instrument follow:

Computer Session Recorder

The study utilized the Telestream ScreenFlow computer program (Telestream, 2014) to make a video recording of the how each participant moved through the VR scene. Screen flow was configured by the researcher to record the computer screen's image at a rate of 30 frames per second. In addition to making a video recording of the computer screen, the program also recorded the participants' voices as they verbalized their thoughts during their session using the think-aloud protocol. The ScreenFlow program was also utilized during the critical incident interview to record the participants' responses to the interview questions and to provide a record of the orientation learning session that each participant could optionally use to facilitate review and identification of critical incidents.

Think-Aloud Protocol

The concurrent think-aloud protocol, defined as verbalizations of self-generated symbols during problem solving (Ericsson & Simon, 1980, 1999), was used to collect participants' introspective verbalizations of their thought process during orientation learning sessions. Although research in VR orientation and wayfinding has generally used metrics based on performance and behaviour rather than cognitive rationale (Ruddle & Lessells, 2006), concurrent think-aloud protocols have been successfully used in several studies that have examined virtual reality training environments (Gamberini, Cottone, Spagnolli, Varotto, & Mantovani, 2003; Grammenos, Mourouzis, & Stephanidis, 2006). As compared to retrospective think-aloud approaches such as stimulated recall (Henderson, Henderson, Grant, & Huang, 2010; Lyle, 2003), the primary advantage of a concurrent approach is that verbalizations accurately reflect associated cognitive processes used during the task because they are taken near-immediately from short-term memory (STM) with only a minimal (possibly none) amount of additional encoding needed to transform the cognitive process into a verbal format (Ericsson & Simon, 1999). Time elapsed between the heeding of a cognitive report and its verbal reporting is critical because STM has a limited capacity and information entering STM has a short life before it is replaced or moved to long-term memory (LTM) where it is more difficult to retrieve (Ericsson & Simon, 1980, 1999; Gilhooly & Green, 1996). Although proponents of the stimulated research approach (e.g., Henderson et al., 2010) suggested that the verbalization process inherent in concurrent think-aloud protocols impacts thought processes and associated task performance, a meta-analysis of nearly 100 think-aloud studies indicated that the think-aloud protocol has practically no effect on performance as compared to performing the task silently (Fox, Ericsson, & Best, 2011). The non-reactivity of concurrent protocols, coupled with potential validity threats of fabrication and forgetting in retrospective protocols (Russo, Johnson, & Stephens, 1989), were the major factors leading to the decision to use the concurrent variety of think-aloud protocols in this study. The researcher followed practical advice presented by Green and Gilhooly (1996) to develop a clear set of instructions that introduced the think-aloud protocol concept to participants and to provide a suitable warm-up exercise, as documented in the study's research protocol (Appendix F).

Orientation Learning Exercise

The study utilized a three-part orientation learning exercise, as seen in Appendix C, to measure how well participants had learned the virtual scene they had viewed with a desktop VR system. The instrument was originally developed by Ausburn and Ausburn (2008a) for a study that measured orientation learning differences between a participant group that learned a scene by viewing a series of photographs and another that learned the same scene from a desktop virtual reality system.

Part one of the instrument tested a participant's scenic orientation, based upon the conceptualization of orientation learning as the process used to gain knowledge about a scene's objects and the spatial relationship of the objects to each other and to the leaner (Ausburn & Ausburn, 2008a). Each of the 15 multiple choice questions first states the location of a specific object or the learner within the scene, and then asks the learner to select the position of another object, relative to the location of either the original object or the learner, from four possible choices. Participants were given 15 minutes to complete part one of the instrument.

Part two of the instrument measured how well a participant recalled details of the scene. Participants were asked to recall as many objects as possible from the scene, exclusive of large furniture pieces, and list them within a one-minute time limit. The score for this part of the instrument was determined by tallying the participant's responses that matched objects present in the scene.

Part three of the instrument measured the participant's perceived confidence level in his or her understanding of the scene's details and in completing the questions in parts one and two of the instrument. Confidence levels were measured on a five-point Likert scale ranging from 1 (no confidence) to 5 (absolute certainty).

Researchers of VR-based orientation conducting studies in the domain of surgical technologist training adapted the general structure of the instrument but modified the questions in part one to reflect the composition of the studies' scenes of hospital operating rooms (Ausburn et al., 2010; Ausburn, Martens, Washington, et al., 2009).These researchers also added an additional question to the third part of the instrument that asked the participant to rate perceived level of difficulty in learning the orientation of the rooms and answering the instrument's questions in parts one and two. Difficulty levels were measured on a five-point Likert scale ranging from 1 (extremely easy) to 5 (very difficult).

As the scene used in the present study was nearly identical to the scene used in the original Ausburn and Ausburn (2008a) study, the researcher needed to only slightly change one of the original instrument's part one questions to match the current configuration of the scene The location of a lamp that was the subject of one of the questions had been moved since the original study was conducted, so the question was reworded to reflect the new location of the object. Data collected from the results of these exercises were not directly used to address the present study's research questions; rather, these exercises were included in the study's design to describe the participants' overall range of object orientation and object recall performance, as well as overall perceptions regarding their confidence and difficulty in completing the orientation learning. Object orientation exercise scores from part one ranged between 1 and 15 out of a possible 15 with a median of 12.5, mean of 11.75, and standard deviation of 4.25. Object recall exercise scores ranged between 4 and 10 with a median of 6, mean of 6.58, and standard deviation of 2.11. As seen in Table 2, the object orientation scores are skewed right with 75% of the participants scoring at least 12 out of a possible 15 points on the test, indicating that as a group the participants were well oriented in the VR scene. The object recall distribution, also seen in Table 2, showed that 75% of the participants could recall in the narrow range of between 4 and 7 objects.

Table 2

Distribution of Object Orientation and Object Recall Exercise Scores (n = 12)

Score	Object Orientation		Object Recall	
	f	*%*	*f*	*%*
0 - 1	1	8.3	0	0.0
2 - 3	0	0.0	0	0.0
4 - 5	0	0.0	4	33.3
6 - 7	1	8.3	5	41.7
8 - 9	0	0.0	1	8.3
10 -11	1	8.3	2	16.6
12 -13	4	33.3	0	0
14 -15	5	41.7	0	0.0

Confidence self-rating scores ranged between 2 and 5 with a median of 4, mean of 3.75, and standard deviation of 0.97. The difficulty self-rating scores ranged between 1 and 4 with a median of 2, mean of 1.92, and standard deviation of 1.00. As seen in Table 3, the confidence ratings are skewed right with 75% of the participants rating their confidence at the two highest levels of 4 or 5, whereas the difficulty ratings are skewed left with 75% of the participants rating task difficulty at the two lowest levels of 1 or 2. These scores indicate that most of the participants felt they were confident they understood the VR scene and found the learning task relatively easy.

Table 3

Distribution of Confidence and Difficulty Self Ratings (n = 12)

Rating	Confidence		Difficulty	
	f	%	*f*	%
1	0	0.0	5	41.7
2	2	16.6	4	33.3
3	1	8.3	2	16.6
4	7	58.3	1	8.3
5	2	16.6	0	0.0

Although no formal reliability or validity tests have been performed on this instrument, a comparison of the scores from the present study (n = 12) with those of the group (n = 40) in the original study that used the VR treatment reveals similar results, as seen in Table 4, thus providing a preliminary indication of acceptable reliability.

Table 4

Comparison of Instrument Section Scores Between Present and Original Study

Instrument Section	Present Study		Original Study	
	M	*SD*	*M*	*SD*
Part 1: Scenic Orientation	11.75	4.25	10.95	3.23
Part 2: Recall of Scenic Details	6.58	2.11	7.08	3.81
Part 3: Perceived Confidence Level	3.75	0.97	3.63	1.03

Demographic Questionnaire

The demographic questionnaire, as seen in Appendix D was used to record the participant's birth year, gender, highest attained education level, and VR experience level, expressed by the number of time the participant had previously used a VR system. For the highest attained education level, a participant could select from categories of *Did not complete high school*, *High school diploma*, *Associate's degree*, *Bachelor's degree*, or *Graduate degree*. For the VR experience level, the participant could select from categories of *None*, *Between 1 and*

5 times, *Between 5 and 10 times*, and *More than 10 times*. Data collected with this instrument were reported above in the Demographic Profile section of this chapter.

Procedures

The researcher used three major procedures for creating the VR scene, collecting data, and analyzing data. Descriptions of each procedure follow and include technical details of VR production and presentation.

VR Scene Production

The researcher used two different VR scenes in the study. One scene was used prior to the orientation learning session to train the participants on the VR interface and the other was used as the scene for orientation learning session. Different scenes were used for these two functions to avoid a learning effect that would have been present if the same scene were used for both training and data collection purposes. Although scenes of specialized technical environments are generally used in career and technical education orientation learning, both of the study scenes instead depicted non-technical residential living and dining room areas. The use of non-technical scenes in the study eliminated the need for participants to possess a specialized set of skills to interpret the study scene, thus broadening the potential number of participants and eliminating technical knowledge as an uncontrolled variable. Although the orientation learning scene was of a non-technical residential nature, it was a visually rich and complex scene that presented a number of objects of various types and size arranged within several different spaces within the scene. Screen shots of both the training and learning session VR scenes are presented in Appendix E.

The researcher created the training VR scene using a five-step process: (1) photographing the scene, (2) enhancing scene exposure, (3) creating a scene panorama image, (4) creating a

Flash-based VR scene, and (5) customizing the scene. For the case of the orientation learning VR scene, a colleague who was highly skilled in photography and VR scene creation had photographed a residential scene and produced a panorama that he shared with the researcher for use in this study. The researcher used the final two steps of the process presented above to create and customize the orientation learning VR scene from the previously created panorama.

Photographing the scene. A Nikon Digital Single Lens Reflex (DSLR) camera, model D40, was used to take digital photographs of the training scene, which was located in the researcher's home. A 30-110 mm Nikon zoom lens was used at the 30mm focal length, focused to infinity. Photographs were formatted by the camera as JPEG image files. The camera was mounted to a tripod-mounted Panosaurus panorama head, a device that minimizes parallax distortion by ensuring that the camera's optical plane remains at the center of rotation (Rubottom, n. d.). Photographs of the scene were taken by rotating the camera on the panorama head through the scene's full 360º panorama from a centrally-located tripod in 30º increments for three passes. For the first pass, the panorama head was adjusted so the camera was position on the level vertical plane. For the remaining passes, the head was adjusted so the camera was positioned in the vertical plane at 45º above level plane, and then at 45º below level plane. Each photograph was taken at bracketed exposure levels of -2 EV, 0 EV, and +2 EV (Meyer, 2013), for a total of 108 photographs.

Enhancing exposure levels. The exposure-bracketed photographs were processed with Photomatix Pro High Dynamic Range (HDR) software (HDRSoft, 2015). This step is not strictly necessary to produce a VR scene, but it improves the overall image quality of the scene. The Photomatix Pro software essentially blends the bracket exposures to produce a more even exposure level across the scene, eliminating or minimizing light and dark spots.

Creating scene panorama. The PTGui program (New House Internet Services BV, n. d.) was used to stitch together the individual photographs of the scene into a single panorama image rendered as a TIFF file. The panorama image displays the full 360º of the scene's horizontal plane and full 180º of the scene's vertical plane in a two-dimensional image.

Creating the VR scene. The VR scene was created by dragging the TIFF panorama file onto the krpano tools multi-resolution virtual tour application called MULTI-RES VTOUR (Reinfeld, 2016). The tools application analyzes the panorama file and produces images files with multiple resolutions that are dynamically loaded by the Flash-based krpano player application when the scene is viewed at different field of view (FOV) levels. The dynamic nature of the krpano multiple resolution approach allows large virtual scenes of high quality to be displayed without overburdening the computer's memory and causing lags in the response time to user control of the scene on the screen. The resulting VR scene is packaged as a folder containing Adobe Flash VR movies, the Flash-based krpano Player application, and a single HTML page. Loading the HTML page into a Web browser with a Flash plugin bootstraps the krpano Player, which displays the initial opening portion of the scene as well as a palette of icons that are used by the participant to control how a he or she virtually moves through scene.

Customizing the scene. The krpano tools allow the VR scene to be customized with a variety of parameters. For this study, the researcher customized the default, maximum, and minimum FOV levels (zoom) and also added a custom wayfinding widget. Based upon trial and error, the researcher judged that configuring the VR scene to a starting default FOV level of 90º, and minimum and maximum FOV levels at 30º and 140º, respectively, provided the clearest images over a wide range of FOV levels. The customized default FOV level of 90º was just slightly narrower than the system-supplied default FOV level of 100º, but this configuration appeared to provide a better initial viewing angle for sections of the virtual scene that contained many smaller objects. The wayfinding aid that was added by the researcher was modelled after a radar scope, as seen in Figure 5. This radar widget superimposed a shaded sector on a schematic diagram of the scene to indicate the portion of the scene currently observable on the computer screen from the viewpoint of the system operator (i.e., the study participant). A red circle located near the center of the widget represents the observation location of the operator, which corresponds to the location in the physical scene where the camera was mounted to photograph the scene. The radar widget was designed to serve as an orientation aid by identifying what portion of the virtual scene is currently displayed on the computer screen. Current FOV level is represented by the angle subtended by the shaded section, and current heading is represented by the rotational position of a line that bisects the angle formed by the shaded sector. Besides indicating what portion of the currently displayed VR scene, the radar widget could also be used as a navigation control by dragging the shaded sector in a clockwise or counter clockwise direction to a desired portion of the scene to be viewed.

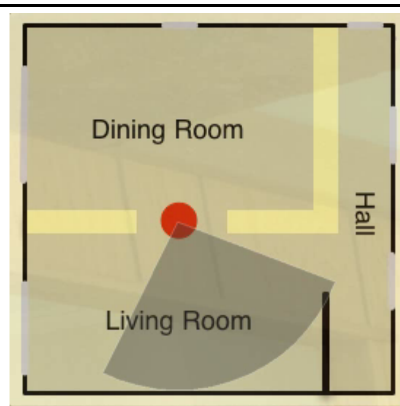

Figure 5. Radar widget wayfinding aid. The shaded area indicates that a portion of the living room scene at a heading of 159º and FOV of 94º is currently displayed on the computer screen.

Data Collection

Apparatus. The hardware used to collect the study's data consisted of an Apple MacBook Pro computer (4 x 2 GHz Intel i7 Core processor, 16 GB memory, AMD Radeon HD GPU, 256 MB VRAM), a USB-attached Apple keyboard, a USB-attached Apple mouse, a Dell U2711 27" LCD monitor (32-bit color, 2560 x 1440 resolution), and a USB-attached Blue Snowball microphone. The MacBook Pro used the OS X Mountain Lion (v10.7) operating system. Other major software included the Telestream ScreenFlow (v4.0) screen casting program that was used for audio and video recording, and the Safari browser that was used to display the VR scene managed by the krpano Player. To ensure participant privacy, all collected data files were stored on FileVault2 encrypted drives and no network interfaces were active during data collection.

Research protocol. Data collection procedures used in the study were documented in a detailed research protocol script presented in its entirety in Appendix F. The OSU IRB approved the study's research protocol on October 10, 2013 (ED 13160). The protocol included the following major sections: (1) introduction, (2) think-aloud protocol training, (3) VR interface training, (4) orientation learning session, (5) orientation learning exercise, (6) critical incident identification, and (7) demographic survey. Summaries of each section follow.

Introduction. In this first section of the protocol, the researcher reviewed the purpose of the study and informed the participant of the major activities of the study. In addition, the researcher assured the participant that full instruction would be given prior to each major activity and provided the participant with the opportunity to ask questions about the study before proceeding.

Think-aloud protocol training. Next, the researcher introduced the participant to the "think-aloud" protocol, which involved verbalizing one's thoughts as the VR system was used to learn the layout of the rooms and the location of objects within the rooms. The researcher stated that he would prompt the participants with the phrase "keep talking" if the verbalizations stopped for more than five seconds. As the final step in this process, the participant completed a think-aloud warm-up exercise of visualizing a house and thinking-aloud while moving through the rooms to count its windows.

VR interface training. In the third section of the protocol, the researcher demonstrated the use of the VR system to navigate through a virtual scene that was a similar setting to the scene used in the orientation learning session. Participants were shown how to use both control palette icon buttons built into the VR system as well as mouse and keyboard operations to execute pan, tilt, and zoom commands. Other system functions demonstrated by the researcher included resetting the VR scene to the initial starting point and hiding the control palette. Lastly, the researcher explained the purpose of the system's radar widget and its use as an alternative pan control. At the end of the demonstration, the participant was given a chance to practice using the VR system for up to 15 minutes and to ask the researcher any questions about its operation.

Orientation learning session. As an introduction to the orientation learning session, the researcher reminded the participants of the objective to learn the layout of the living and dining room scene and the locations of objects therein. The researcher also restated to the participant that there was no single right way to accomplish this task and that one could navigate through the scene at whatever pace and manner thought best to learn the layouts. In addition, the researcher emphasized that the participant must verbalize thoughts, as had been previously practiced in the warmup. Finally, the researcher reminded the participant that both voice and computer screen recording were being made, that the time limit for the session was 30 minutes, and that the participant should inform the researcher he or she felt the layout of the rooms had been learned well enough to answer questions about the layout and the location of objects in the rooms. If the participant had no questions about the exercise, the researcher started the ScreenFlow audio and computer screen recording program. When the participant stated he or she had learned the layout, the researcher stopped the recording and saved it to a file.

Orientation learning exercise. During this section of the protocol, the participant completed the object orientation, object recall, and confidence and difficulty self-rating exercises. These exercises were described in the Instruments section of this chapter, and copies are presented in Appendix C.

Critical incident identification. During this section of the protocol, the participants were asked to recall critical incidents, defined as observable activities with clear intent that occur in a situation with definite consequences (Flanagan, 1954), they may have encountered during the orientation learning session. The participant could review the recordings made in the previous section of the protocol to refresh his or her memory about when an incident might have occurred. A series of interview questions, described in the Instrumentation section of this chapter, were asked of the participant to ascertain details regarding the incident and its consequence in the orientation learning session. Participants' responses to the questions were recorded using the audio recording facilities of the ScreenFlow program and saved to a computer file.

Demographic survey. In the final step of the session, the participant was asked to complete the demographic survey described in the Instrumentation section of this chapter. In accordance with privacy procedures set forth in the study's IRB application, participant identifiers were not used to mark the question response sheet.

Collection time frame and location. Data collection took place during October and November of 2013 over the course of two consecutive days at each research site. Contacts at both the OSUIT and TCTC research sites arranged for the researcher to use unscheduled conference rooms, well-lit and free of outside noise and distraction, as locations for the study's data collection sessions.

Data Analysis

The study used three major data analysis procedures: (1) participant movement content analysis, (2) orientation learning event content analysis, and (3) critical incident content analysis. Participant movement content analysis procedures addressed study research questions one to three relating to orientation learning movement patterns. The orientation learning event content analysis procedures were followed to produce data from the participants' thought verbalizations made during the orientation learning session for addressing study research questions four and five relating to orientation learning cognitive and SRL events and patterns. Lastly, the critical incident content analysis addressed research question six regarding identification of major issues or difficulties encountered by the participant during the orientation learning session. The three procedures are summarized below.

Participant movement content analysis. The participant movement analysis consisted of two major steps, data transformation and content analysis. Data transformation procedures converted the video recordings to a time-ordered database of the heading positions viewed by the participant moving through the virtual scene. The time series database served as the source text for content analysis procedure. The content analysis procedures produced graphical plots and diagrams from the time series that were analyzed to infer the participants' movement patterns. Information regarding both analysis steps is presented below.

Data transformation. The ScreenFlow program produces a video recording of computer screen activity by essentially taking a snapshot, called a *frame*, of the screen's image every thirtieth of a second, for a recording rate of 30 frames per second (FPS). Individual recorded frames of the video recording can be programmatically extracted from the video recording as Portable Network Graphic (PNG) images. As described in the Instrumentation section of this chapter, the VR system displayed a graphical radar widget that graphically depicted the heading and field of view of the displayed VR scene in real time. The researcher wrote computer programs in the AppleScript and Java programming languages that analyzed the visual features of the radar widget to produce a time series of data that contained the heading and FOV each participant used to view the VR scene during every second of the orientation learning session. Additional details regarding the programs that analyzed the radar widget image are contained in Appendix G.

Content analysis. To address research question one, the researcher generated time series plots of heading positions for each participant to facilitate the detection of movement patterns. These plots were then examined to determine movement patterns both from an overall participant session perspective, as well as from the spatial and temporal perspectives. To address research question two, the researcher generated histograms from the participant movement data to show how often participants used different FOV levels to view the VR scene. Finally, to address research question three, the researcher generated scatter plots of the FOV vs. heading observations to visualize the relationship between those variables. These scatter plots were fitted with LOESS (locally weighted regression) smoothing curves (Cleveland & Devlin, 1988; Wickham, 2009), which showed the local trends in the the relationship, such as the tendency of a participant to use a particular FOV with a certain range of heading intervals. All of the time series, histograms, and scatter plots were generated from programs written by the researcher in the R statistical programming language (Chambers, 2008) using the ggplot2 graphics package (Wickham, 2009). Participant identifiers and associated frequency counters were linked to each of the detected patterns.

Orientation learning event content analysis. The orientation learning event content analysis procedure involved four major steps: (1) transcription, (2) segmentation, (3) coding, and (4) frequency analysis. Transcription converted audio recordings of the participant think-alouds to a textual format that was used as the source text for the content analysis procedure that encompassed the segmentation, coding, and frequency analysis processes. As the first step in content analysis, the segmentation processes partitioned the textual record of think-alouds into logical units. The coding process assigned codes to segments of the transcript that indicated the participant had engaged in an orientation learning event and classified the codes into subcategories and categories. Finally, the frequency analysis process produced individual participant profiles by counting the occurrence of codes classified at the category and subcategory levels and calculating relative frequency distributions.

Transcription. The researcher submitted a protocol modification request to the OSU IRB requesting permission for two additional personnel to assist in the transcription of the audio recordings made during the study's data collection phase. To maintain participant privacy, the modified protocol specified that the additional personnel were to sign confidentiality agreements and destroy the audio recordings after completing the transcription. Approval of the requested modification to the protocol was received on February 23, 2015, as documented in Appendix B. After signing a confidentiality agreement, one of the researcher's colleagues used the HyperTRANSCRIBE program (Researchware Inc., 2013) to transcribe each participant's audio recording from the orientation learning session into Microsoft Word files. Using guidance from generally accepted think-aloud transcription practices (Ericsson & Simon, 1999; van Someren, Barnard, & Sandberg, 1994), the researcher instructed the transcriber to produce a transcription that was as literal as possible, including pauses, stammering, and filled pauses, but omitting intonations and indicators of utterance stress and duration. After the transcription were completed, the researcher checked each against the original audio recordings and found them to be accurately transcribed. Although the IRB approved the researcher's request to have two additional personnel transcribe the transcripts, only one person was used to complete the transcription process due to scheduling conflicts with the second person. The researcher solely transcribed the critical incident interviews using the HyperTRANSCRIBE program.

Segmentation. Transcripts may be parsed in analyzable segments according to a number of factors, including verbal pauses, sentences, phrases, and clauses; time intervals, ideas, and even thoughts (Eveland & Dunwoody, 2000). Due to the exploratory nature of orientation learning, the think-aloud verbal transcripts from the orientation learning sessions in this study were generally unstructured and unevenly delivered, often resembling a stream of consciousness rather than a precise and orderly thought process expressed in orderly sentence constructions. Segmentation of these transcripts, therefore, was done by partitioning the transcripts according to "referential units, which are defined by the particular objects, events, or ideas to which an expression refers" (Kirakowski & Corbett, 1990, p. 264) For this study, the referential units corresponded to the objects in the scene as well as the cognitive and regulatory events related to orientation learning (i.e. identifying, locating, and regulating).

Coding. Completed transcripts were loaded into the HyperRESEARCH (Researchware Inc., 2014) qualitative data analysis system. The transcripts were coded with a hybrid approach that used both inductively and deductively generated codes. Top level code categories (identifying, locating, and regulating) were identified prior to the start of coding and deductively derived from the major orientation learning and SRL components of the study's conceptual framework. The coding process was conducted in two phases, as recommended by Saldaña (2009). In the first phase, process codes (Bogdan & Biklin, 1992) that described the events undertaken by the participants in learning the virtual scene were used to inductively code segments. During this phase, codes were iteratively refined by merging similar codes and deleting redundant codes, which required review and recoding of previously processed participant transcripts (Silver & Lewins, 2014). The second coding phase classified the initial process codes into pattern codes (Miles & Huberman, 1994), which served as intermediate subcategories that mapped the process codes to the top level categories. The subcategories were inductively generated from the process codes except for subcategories of the locating category (allocentric and egocentric) and the regulating category (planning, monitoring, controlling), which were deductively generated from the types of reference systems used in orientation and major categories of SRL events (Pintrich, 2000), respectively. Some participant verbalizations recorded in the transcripts were not consistent with the predetermined top level categories; these segments were deductively coded in the first phase, and then classified with pattern codes in the second phase into appropriate additional categories and subcategories.

Content analysis. This process used the frequency reporting tool of the HyperRESEARCH program to determine the number of occurrences of codes that belonged to the coded subcategories and categories and calculated corresponding relative frequency distributions. These relative frequencies were presented in a table for each participant and used as inputs to a program written in the R programming language that constructed a star chart (Yau,

2011) for each participant. The length of a segment of the star corresponds to the calculated relative frequency of a category. An example of a star char for a participant and the associated key that maps the four categories of regulating, locating, identifying, and contextualizing to the star's segments, is shown in Figure 6. Grouping the individual star diagrams in an arrayed graphical presentation facilitated the comparison of the star diagram shapes and detection of patterns of category use amongst the participants. Programs were also written in R to plot stacked bar charts showing the subcategory frequency data for each category by participant.

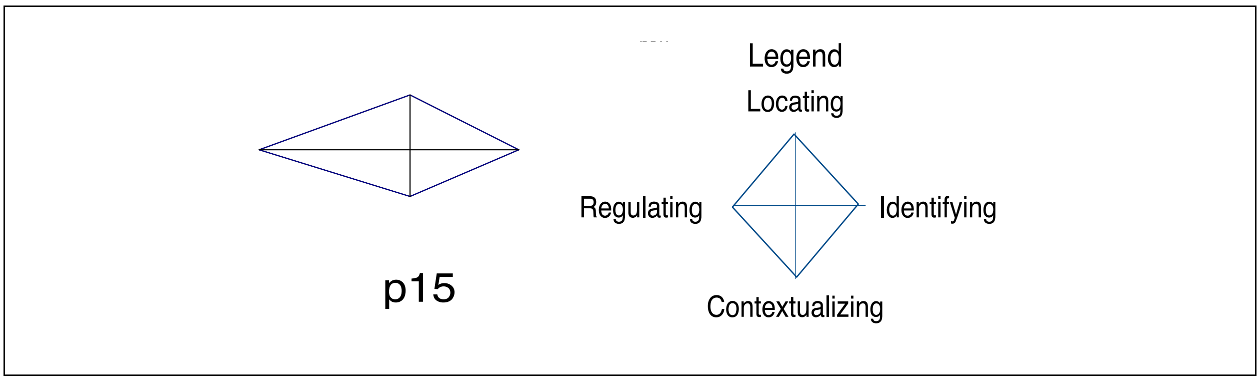

Figure 6. Typical star chart for participant shown with dimensions legend.

Critical incident content analysis. Responses to the critical incident interview questions were transcribed into textual format by the researcher from the ScreenFlow audio recordings to form the text for the subsequent content analysis. Incident descriptions and associated impacts described by the participants were first coded with descriptive codes, followed by second round of coding that used pattern codes to categorize the problems and the associated severities (Miles & Huberman, 1994). Counts of problem types and severity categories were determined and the results of the analysis were summarized in tabular format.

CHAPTER IV

FINDINGS: MOVEMENT PATTERNS

The present chapter describes the findings relating to the study's research questions one, two, and three, which concern how participants used the VR system to move through the virtual scene. The first major section of the chapter addresses research question one regarding the participants' patterns of movements. The second major section of the chapter addresses research question two regarding the field of view (FOV) levels used by the participants. Lastly, the third major section of the chapter addresses research question three regarding the relationship between observed participant movement headings and FOV levels. Findings regarding the cognitive patterns used by the participants during the VR orientation learning sessions are separately discussed in Chapter 5.

Research Question 1

What patterns of movement were used by the participants to rotate through the VR scene during the orientation learning session?

Discussion regarding the findings of the first research question are organized into two subsections, titled *Participant Session Movement Synopses* and *Movement Patterns*. The first section consists of twelve narratives that describe the major movement actions each participant executed during the orientation learning session. Accompanying each narrative is a time series plot that graphically illustrates the participant's rotational movement during the scene by plotting the heading position observed at each second spent in the VR session. The second section describes the patterns of movement that were observed amongst the participants during the orientation learning sessions. Patterns are classified according to the major dimensions of a taxonomy of movement patterns proposed by Dodge, Weibel, and Lautenschütz (2008): spatial, temporal, and spatio-temporal. Within the context of this study, spatial patterns were used to classify movements that tended to occur at a particular location within the virtual surround, temporal patterns were used to classify movements that tended to occur during a particular time relative to the start of the orientation learning session, and spatio-temporal patterns were used to classify movements of a global nature that tended to occur throughout the virtual surround over the full course of the session.

Participant Session Movement Synopses

The purpose of each participant session movement synopsis is to provide a brief description of the participant's major rotational movements and associated transitions in direction that were executed over the course of the VR orientation learning session. Descriptions emphasize the general trend of a rotational direction used by the participant and do not address occurrences of the minor local direction reversals that occurred along the time series path for most of the participants' sessions. Prior to the individual participant synopses, background information regarding the conventions used for heading positions, interpretation of the time series plots, and session durations are presented in following sections.

Participant identifiers for the study (P1, P3, P4, P6, P10, P12, P15, P16, P17, P18, P19, and P20) were constructed from a random number sequence and do not convey any supplemental information such as their order of participation in the study or any type of ranking or rating. Narratives are presented in identifier sequence order.

Heading position conventions. Heading locations that are described in the participant narratives are expressed in units of degrees in the same manner as a conventional navigation compass, ranging from 0º to 360º around the full circumference of the virtual scene. Figure 7 presents a map that fixes the location of the major heading quadrants relative to the virtual scene. The red circle at the center of the map represents the position of the observer in the virtual scene and the shaded sector represents the angular segment of the scene's circumference, or field of view (FOV), seen by the observer in the VR initial scene.

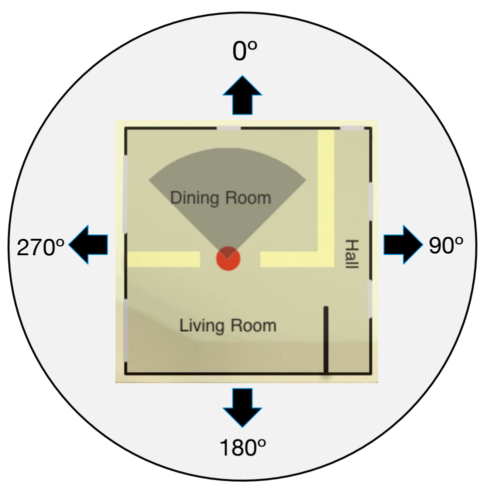

Figure 7. Map of study scene with headings.

Time series interpretation. A time series plot included in each participant's synopsis records the observed directional heading of the participant for each second of the orientation learning session. The elapsed time of an observation is plotted in the x-axis of the diagram, which ranges from zero to the session end time as indicated by a dashed vertical line, and the corresponding heading position is plotted on the y-axis, which ranges from 0º to 360º. Clockwise (CW) rotations through the VR scene are represented in the time series by positive (upward) sloping lines, whereas counter-clockwise (CCW) rotations are represented by negative (downward) sloping lines. The slopes of the time series plot indicate the speed of rotation, with faster speeds having the larger (steeper) slopes. Rotational pauses are indicated in the time series by horizontal lines that show zero change of heading over time. Each time series will show that the initial starting heading is located near the top of the time series heading axes at 358º.

Orientation learning session durations. Participants were instructed to end a session voluntarily when they believed they had learned enough of the virtual scene to answer questions about it. Orientation sessions durations varied widely, as shown in Figure 8, lasting from 1 minute (min) 5 seconds (s) to 15 min 20 s. The median session length was 7 min 40 s.

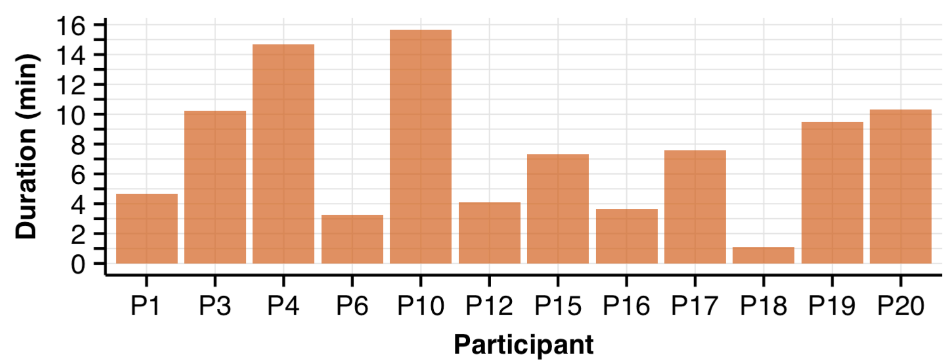

Figure 8. Session duration times by participant.

Participant P1. As shown in the P1 time series in Figure 9, participant P1 rotated steadily though the scene in the CW direction after a short initial pause, completing a full rotation of the scene at elapsed time (ET) 135 s. P1 continued in the CW direction after ET 135 s to complete another full rotation at ET 245 s. After completing the second full rotation, P1 continued in the CW direction to end the session near heading position 160º.

Participant P3 . As shown in the P3 time series in Figure 9, participant P3 started the session with a CCW rotation to 300º after a short initial pause, but changed direction to a CW rotation near ET 30 s, returning to the starting heading at ET 130 s. After ET 130 s, P3 continued the general CW rotation trend, considerably slowing the rotation rate between ET 270 s and ET 450 s. P3 covered a heading distance of only about 65º during that three-minute interval. After ET 480 s, P3 continued with CW rotation at an increased rate, completing a full rotation at ET 530 s. Finally, P3 continued for approximately another 100º in the CW direction after completing the full rotation.

Participant P4. As shown in the P4 time series of Figure 9, participant P4 moved through the scene in a generally CCW rotation direction through ET 220 s. During this interval, P6 complete almost a full rotation, but stopped the CCW rotation near a heading of 10º. After ET 220 s, P4 reversed direction and started a general CW rotation, albeit with some larger local direction reversals that continued to ET 760, noticeably slowing the rate of rotation from ET 360 s to ET 660 s through less than 120º of heading. After ET 760 s, P4 rotated through the scene quickly, reversing to a general CCW rotation shortly thereafter at ET 765 s, followed by another general direction reversal to CW near ET 790 s that rotated 360º to complete another full rotation at session’s end.

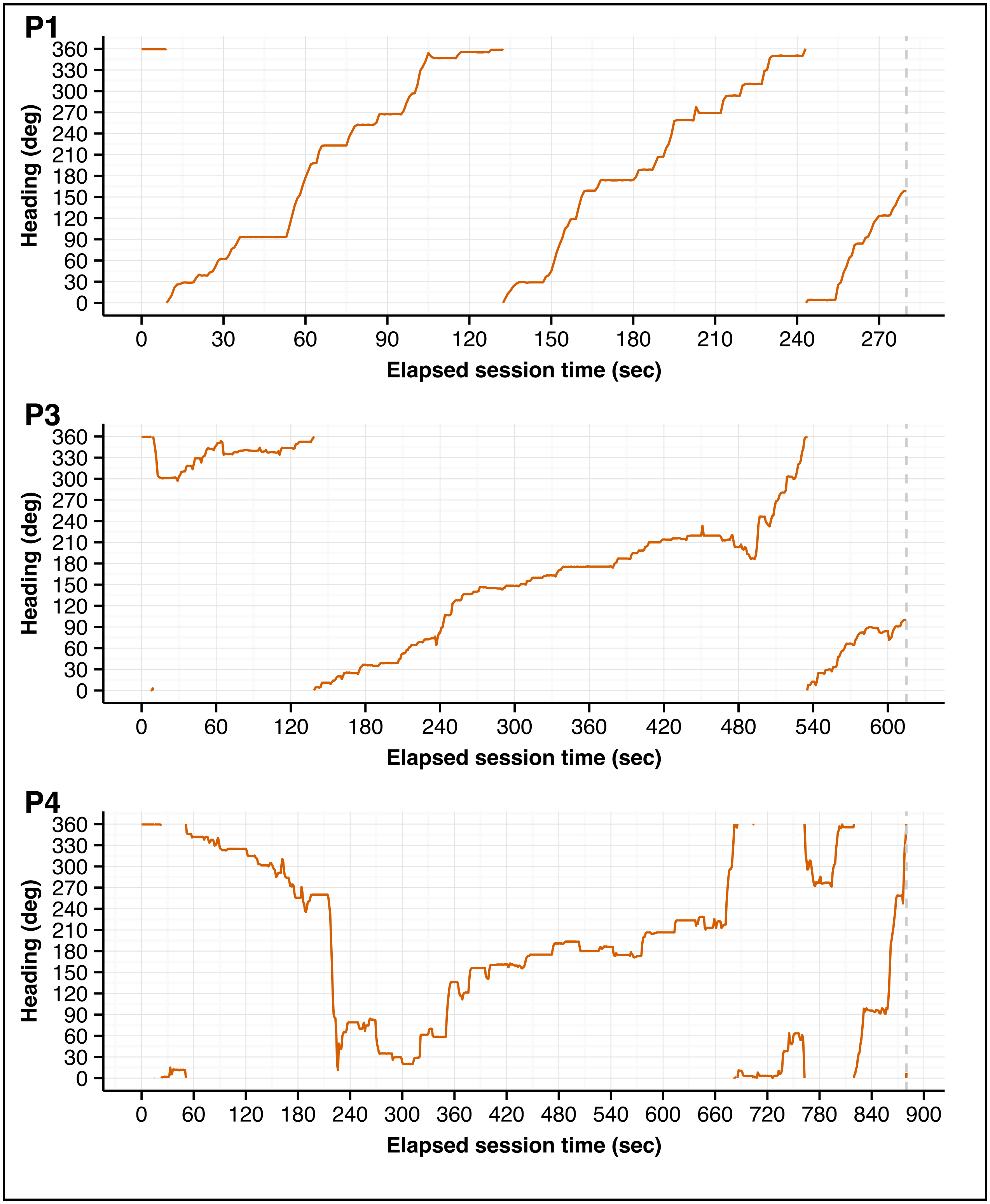

Figure 9. Heading times series for participants P1, P3, and P4.

Participant P6. As shown in the P6 time series of Figure 10, participant P6 executed a small CW rotation at ET 8 after an initial pause, followed by a series of small alternating directional changes of no more than 30º between heading interval 330º to 360º that continued through ET 90 s. After ET 90 s, P6 started rotation in a general CW direction with just a few very minor reversals for the remainder of the session, slowing the rate considerably between ET 110 s and 150 s, to finish at heading 315º. P6’s path through the scene fell short of full rotation by 15º, as shown by the absence of any part of the time series path between headings 315º and 330º.

Participant P10. As shown in the P10 time series of Figure 10, participant P10 started the session with a CCW rotation, but shortly changed direction to a CW rotation near ET 5 s, returning to the starting heading at about ET 30 s. P10 continued to rotate through the scene in a general CW direction after ET 30, albeit with some local sharp direction reversals of about 45º similar to the one occurring at ET 250 s. At ET 345 s, P10 completed a full rotation of the scene and continued in a general CW direction in the same manner as earlier in the session. After ET 420 s, P10 considerably slowed the overall rate of rotation through the end of the session, covering only about 90º of heading in through the end of the session near heading 260º.

Participant P12. As shown in the P12 time series of Figure 10, P12 rotated in the CCW direction through ET 28 s, but only after a lengthy initial pause of 20 s. After ET 28, P12 reversed direction to CW through ET 92 s, then finished the session with a general CCW rotation that resembled the general stepped shape of the movement pattern used near ET 30 s.

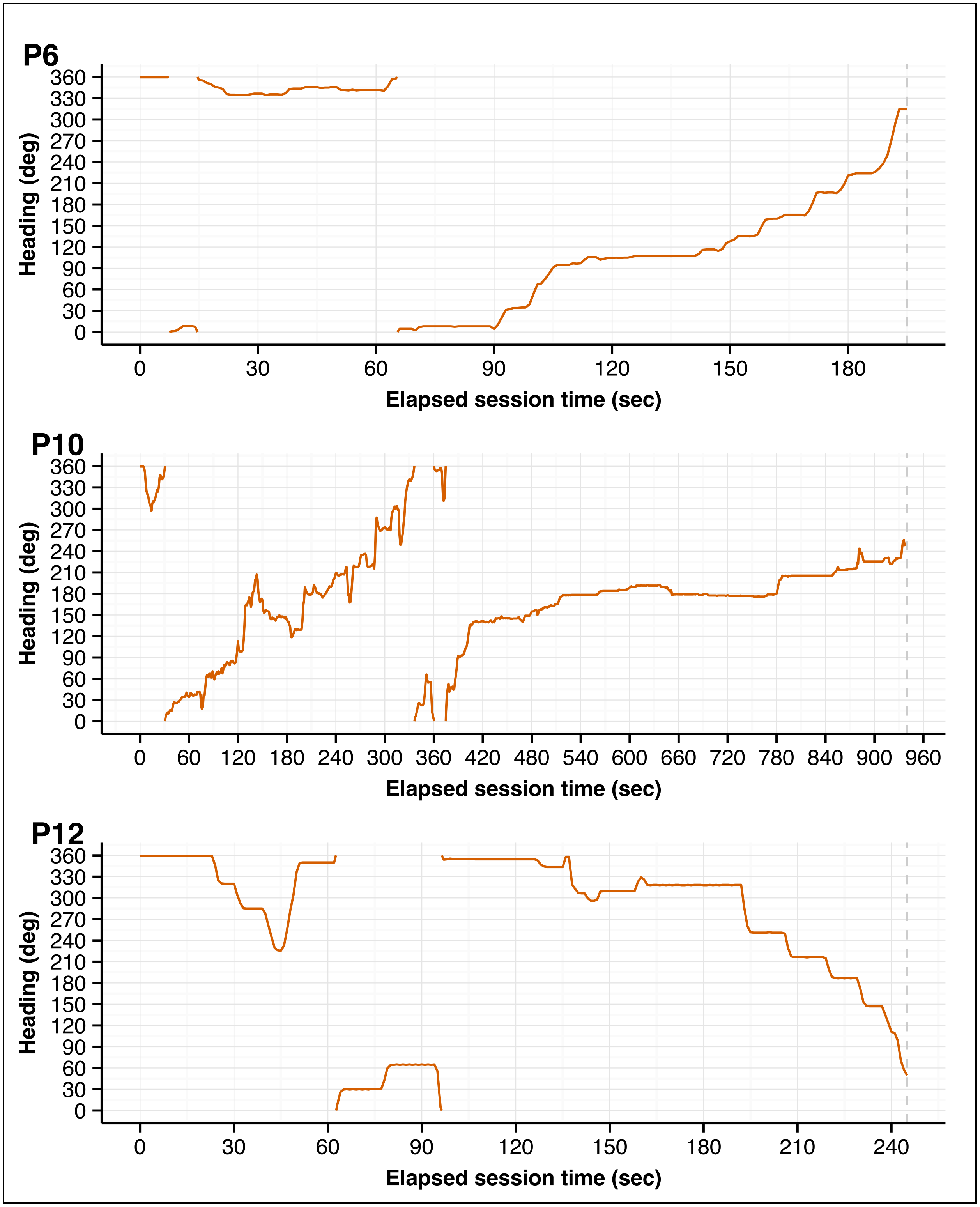

Figure 10. Heading times series for participants P6, P10, and P12.

Participant P15. As shown in the P15 time series of Figure 11, P15 rotated through the scene in a CCW direction through ET 390 s, completing a full rotation of the scene at ET 350 s. After ET 390 s, P15 reversed direction to CW for the remainder of the session with one interspersed local direction reversal near ET 400 s.

Participant P16. As shown in the P16 time series of Figure 11, P16 rotated in the general CW rotation after a short initial pause through ET 45 s. After ET 45 s, P16 reversed direction to CCW through ET 175 s with a notably large local direction reversal at ET 120 s of about 60º. After ET 175 s, P10 rotated through the scene in a similar pattern to the earlier part of session, rotating first in a general CW direction and then reversing direction at ET 200 s, to complete the session at a heading of 90º.

Participant P17. As shown in the P17 time series of Figure 11, P17 started a general CW rotation almost immediately after the session started that continued through ET 250 s. At ET 250 s, P17 reversed the direction to CCW for a short interval through ET 270 s, and then quickly reversed direction to CW for another short interval through ET 275 s. For the remainder of the session, P17 rotated in the general CCW rotation, nearly symmetrical to the CW rotation pattern exhibited in the first part of the session between ET 120 s and ET 270 s.

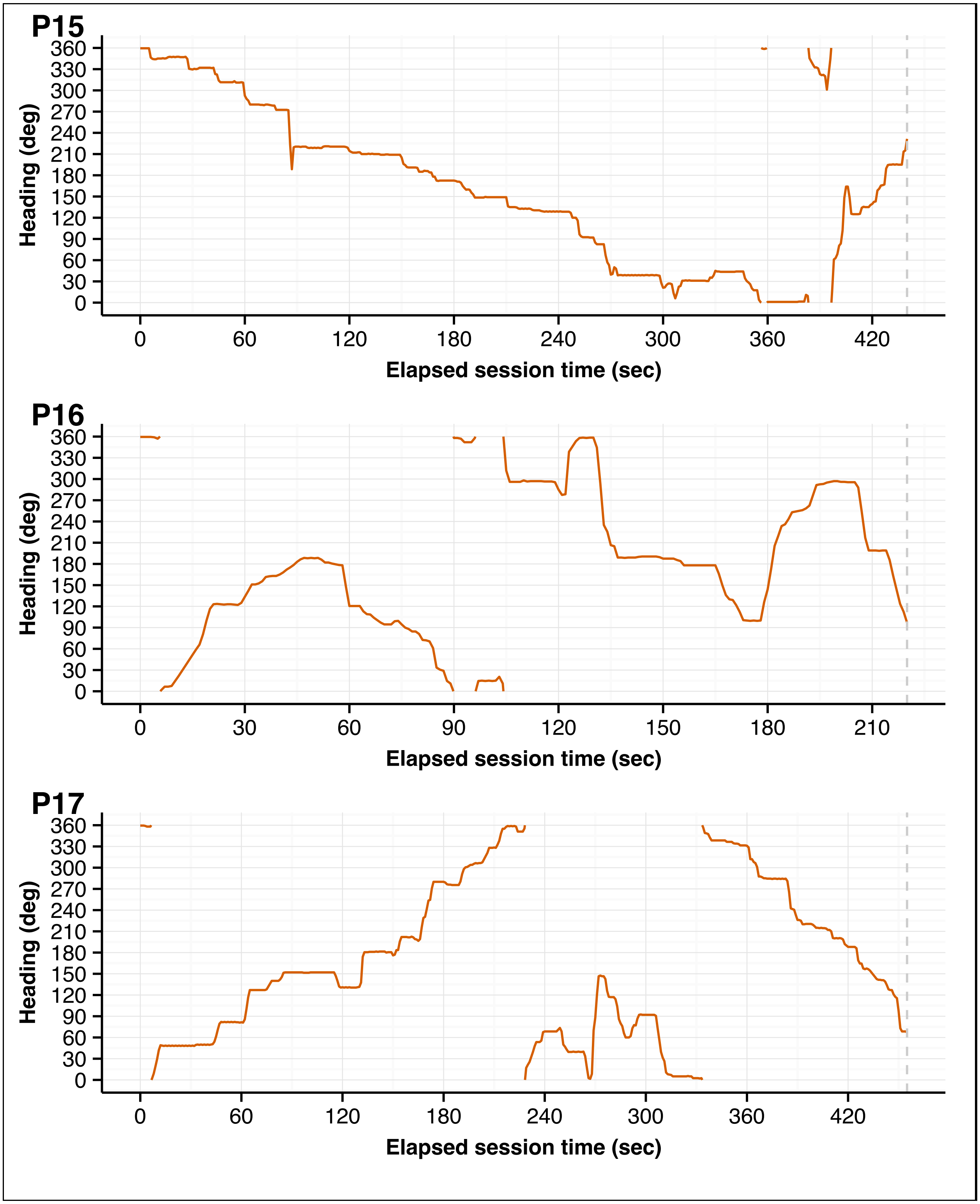

Figure 11. Heading times series for participants P15, P16, and P17.

Participant P18. As see in the P18 time series of Figure 12, participant P18 started the session after a short initial pause with a CW rotation that continued for the entire session. P18 but slowed the rotation rate after ET 70 s, completing a full rotation at ET 112 s before ending the session a few seconds later.

Participant P19. As shown in the P19 time series in Figure 12, P20 started a rotation in the general CCW direction to complete a full rotation at ET 400 s. The movement pattern of the session changed considerably at this time. After ET 400 s, P19 continued in the CCW direction, but at a noticeably increased rotation rate. At ET 420 s, P19 sharply reversed direction to CW with an interspersed local direction reversal at ET 425 s, changing heading from 165º to 360º to 120º. P19 reversed direction of rotation to CCW at ET 490 s, and to CW at ET 515 s. At ET 530 s, P10 executed a final general reversal for the session to CCW, but ended with a local hook-shaped reversal to CW to end the session.

Participant P20. As shown in the P20 time series of Figure 12, P20 started a general CCW rotation after a short initial pause that continued through ET 45. After ET 45, P20 moved in a general CW direction, completing a full rotation of the scene at ET 210 s. P20 followed the first complete rotation with similar CW rotation patterns to complete full rotations at ET 270 s, ET 370 s, and ET 500 s. P20 executed the last full rotation at a noticeably slower rate than the first three instances due to several consecutive pauses between ET 440 s and ET 490 s. At ET 530, P20 reversed the general direction of CW rotation that had been used throughout most of the session to the CCW direction A few seconds prior to end of the session, P20 returned the rotation to the dominant CW direction.

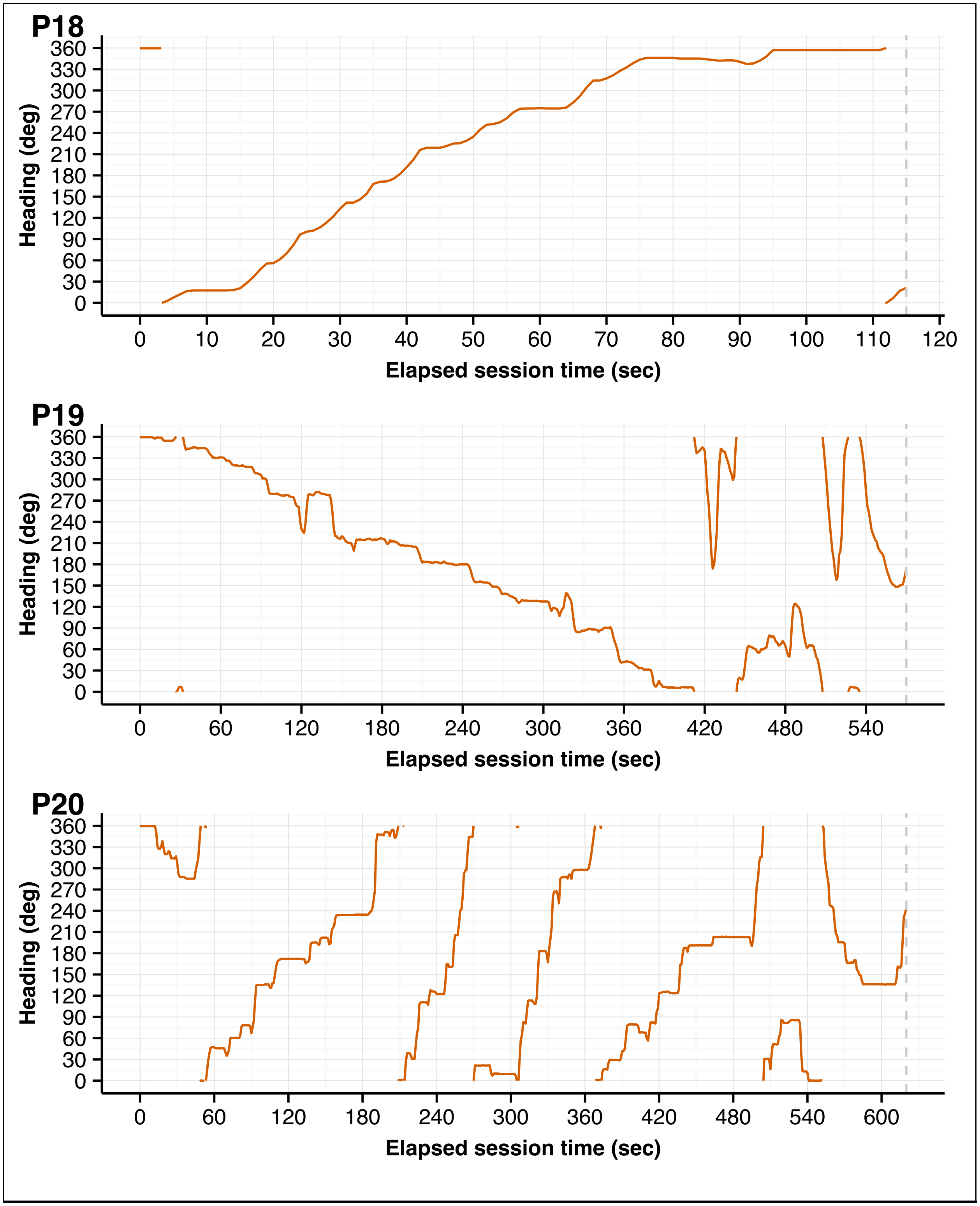

Figure 12. Heading times series for participants P18, P19, and P20.

Movement Patterns

In order to reveal the participants' orientation learning movement patterns, the researcher compared participants' time series from three perspectives: spatio-temporal, temporal, and spatial. The purpose of examining the time series from a spatio-temporal perspective was to recognize *global* trends in the participant's heading position that occurred over the course of the *entire* session, as expressed by the overall shape of the plotted time series path. In contrast, the purpose of examining the time series from the temporal perspective was to recognize *local* trends in the heading position path that occurred along particular *segments* of the time axis. Likewise, the purpose of examining time series from a spatial perspective was to recognize local trends in the heading position path that occur along along segments of heading axis.

Spatio-temporal perspective. Analysis of the time series data from the spatio-temporal perspective indicated that participants used one of two general movement patterns that the researcher has designated as the *lap* movement pattern and the *backtrack* movement pattern. Of the study's twelve participants, eight (P1, P3, P6, P10, P15, P18, P19, and P20) used the lap pattern, and four (P4, P12, P16, and P17) used the backtrack pattern.

Lap pattern. Participants who use the lap pattern tended to rotate through the scene in a single direction, much like a race car might traverse an oval track. A lap pattern is recognized on a time series chart by a path that (1) slopes predominantly in one direction, (2) covers the full heading range, and (3) maintains the pattern's shape for most of the session. These criteria are not absolute, but are based on judging the general trend of the time series path over the entire session, as indicated by the dashed lines superimposed on the participant time series in Figure 13 and Figure 14. Some lap pattern time series, such as the series for participant P20, present a fairly consistent path slope that indicates exclusive use of a single direction over the entire session. Other lap pattern time series, such as the series for participant P16, present a less consistent path slope that contains local reversals of direction, even though the general trend of the time series path is unidirectional. Movement parameters such as the rotation direction and the number of full rotations completed contribute to a variety of lap pattern time series shapes. For the rotation direction movement parameter, the lap pattern time series for participants P1, P3, P6, P10, P18, P19, and P20 indicate a CW direction of rotation, whereas the time series for participants P15 and P19 indicate a CCW direction of rotation. For the full rotation count parameter, the lap pattern time series for participants P1 and P20 indicate two and four full rotations of the scene were completed during the session, respectively, whereas the lap pattern time series for participants P3, P6, P10, P18, P15, and P19 indicate only a single full rotation of the scene. Upon first inspection, the time series of participants using the lap pattern appear to be quite diverse, however, they share the specified pattern inclusion criteria.

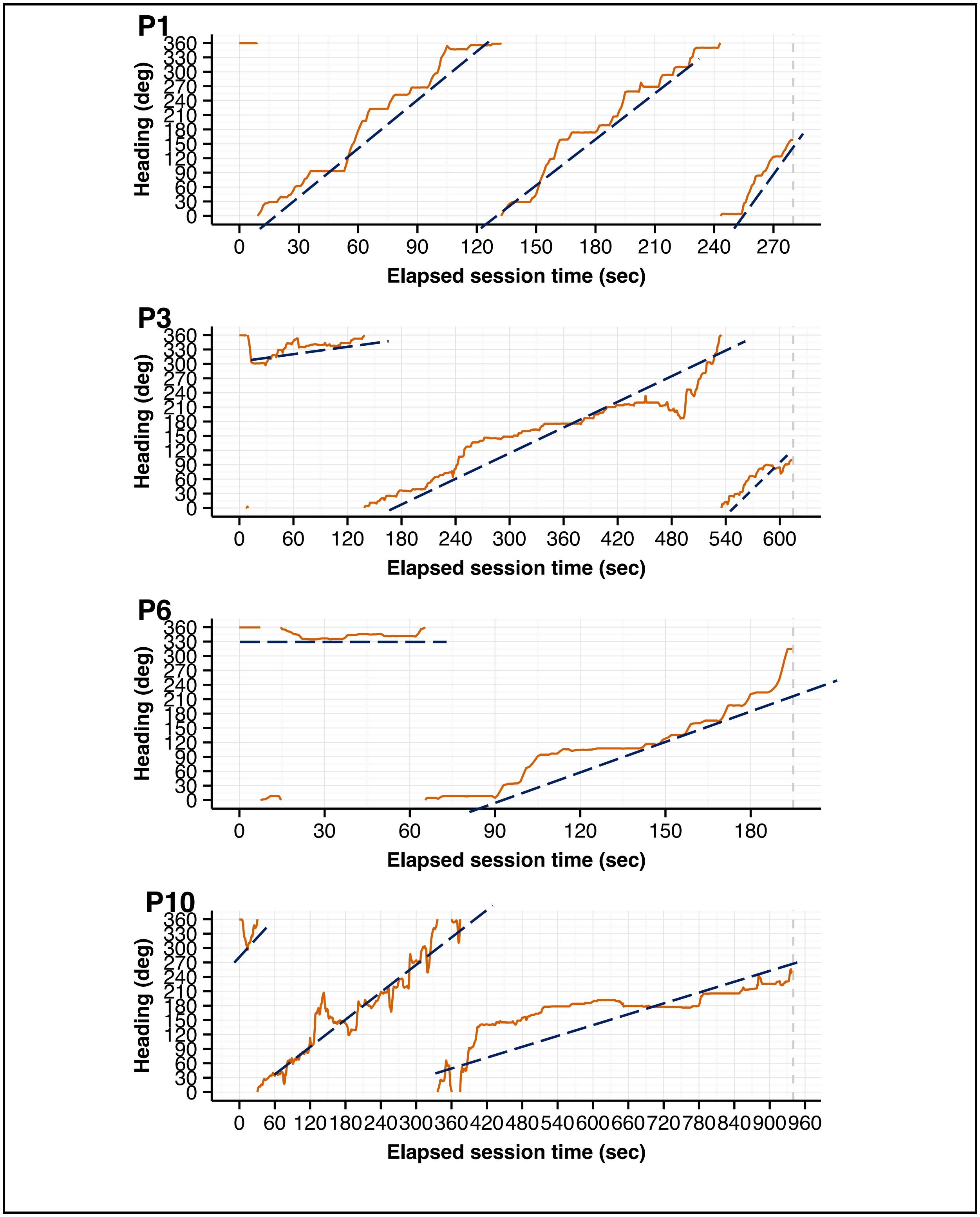

Figure 13. Lap pattern for participants P1, P3, P6, and P10.

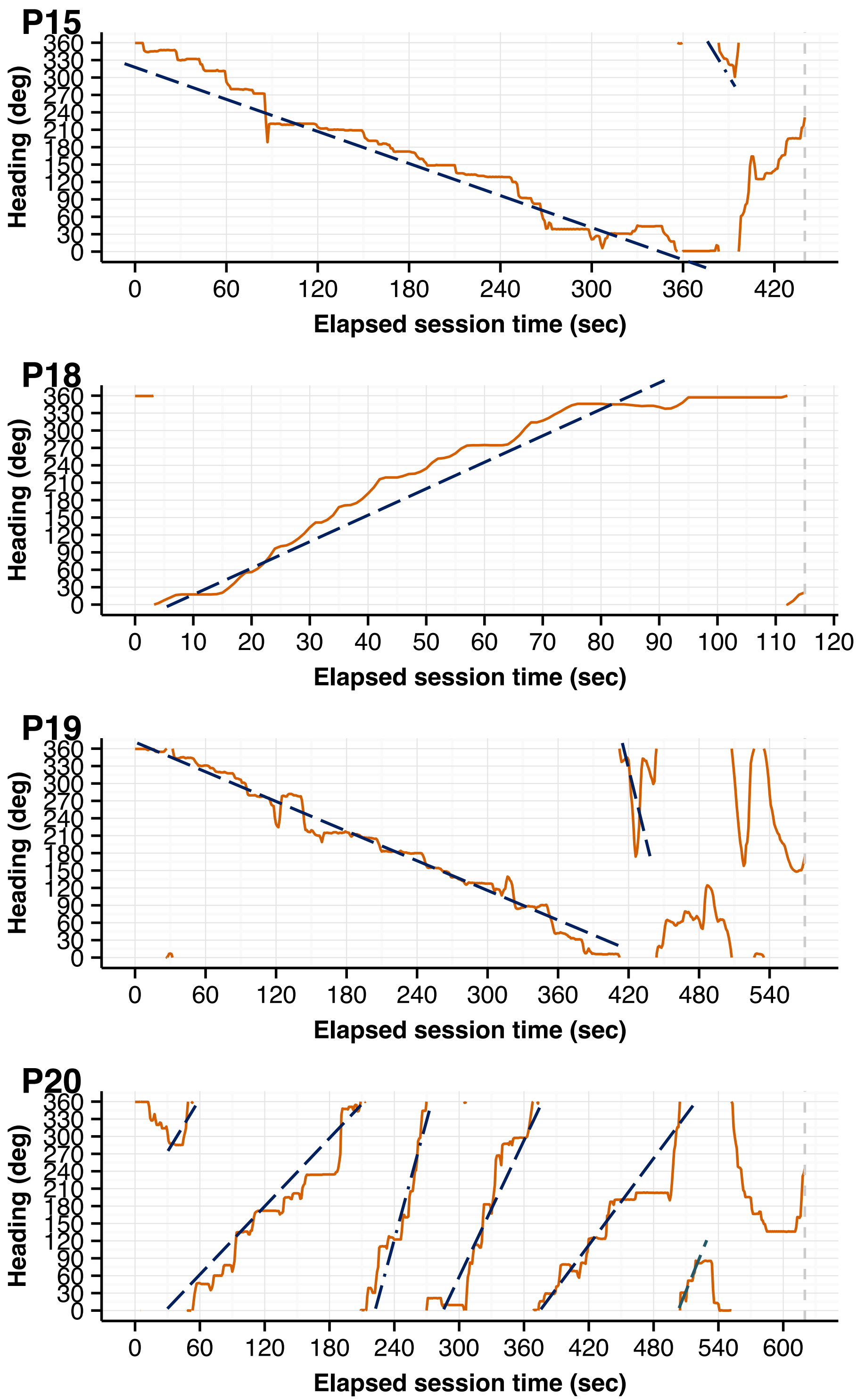

Figure 14. Lap pattern for participants P15, P18, P19, and P20.

Backtrack pattern. Participants who used the backtrack pattern tended to rotate through the scene in alternating directions, visiting a range of headings and then reversing direction to revisit the range or a portion thereof. A backtrack pattern is recognized on a time series chart by a path that is sloped in one direction, followed by a change in path slope to the opposite direction, as shown in Figure 15. In simplest form, the shape of the pattern resembles the letter "V" or its turned variant "Λ." The reversal pattern, however, can take more complex forms when one or more direction reversals are added to the two required for the minimal case. Like the lap pattern, this pattern is judged by examining the trending patterns of the time series path. Movement parameters such as initial rotation direction, the number of session direction reversals, the amount of heading angle traversed in a visit–revisit series, and the time duration of the visit-revisit cycle contribute to a variety of backtrack pattern time series shapes that are generally more complex than lap pattern time series. The backtrack pattern time series for participant P4, for example, had an initial CCW direction, and revisited the entire full heading 360 range over the course 660 seconds in one visit-revisit cycle. In contrast, the backtrack time series for participant p16 had an initial CW rotation, and had multiple reversals that revisited over smaller ranges between 90º and 180º with visit-revisit cycle times of 15 s, 60 s, and 90 s. As with the lap patterns, upon first inspection the time series of participants using the lap pattern appear to be quite diverse, but they all share the specified pattern inclusion criteria.

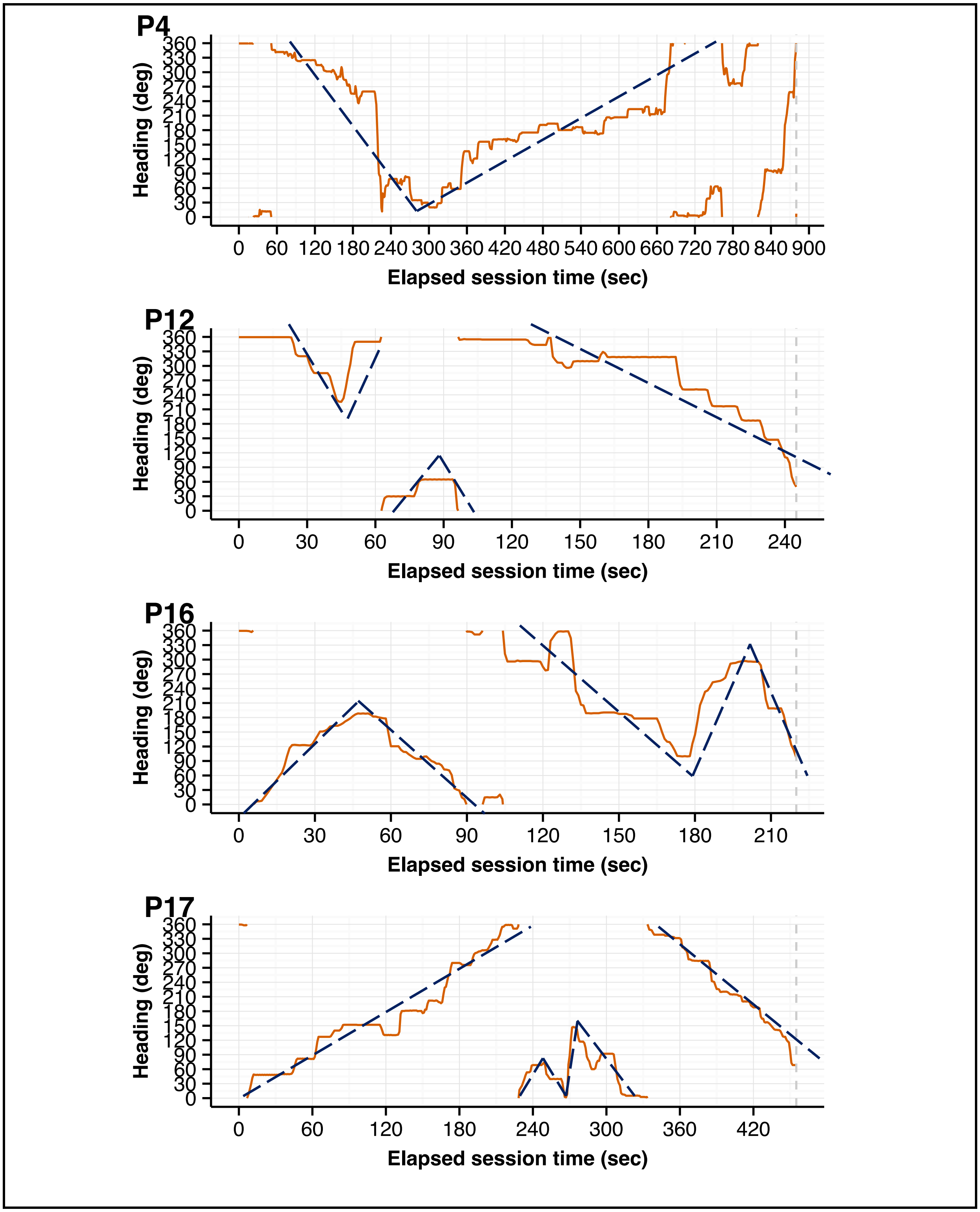

Figure 15. Backtrack pattern for participants P4, P12, P16, and P17.

Temporal perspective. Analysis of the time series data from the temporal perspective indicated that some participants used two temporal movement patterns either singularly or in combination. One pattern, designated by the researcher as the *tentative start* pattern, occurred at the start of session. The second pattern, designated by the researcher as the *last chance* pattern, occurred at the end of sessions. Time series of participants P3, P6, and P10 exhibited the tentative start pattern, and time series of P4, P15, and P19 exhibited the last chance pattern. Participant P20's time series exhibited both patterns.

Tentative start pattern. Participants who used the tentative start pattern (P3, P6, P10, P20) executed the first rotation in the session in a direction that is opposite to the predominant direction of rotation for the session. For the case of participant P6, the pattern was executed several consecutive times, resulting in a slow start to the session. Locations of the tentative start pattern are marked on participants' time series in Figure 16.

Last chance pattern. Participants who used the last chance pattern (P4, P15, P19, and P20) executed at least one reversal of direction at the end of the session that traversed more than 180º to nearly 360 º of heading over a short period of time. Locations of the last chance pattern are marked on participants' time series in Figure 17.

Spatial perspective. Analysis of the time series from the spatial perspective reveals that some participants tended to concentrate on a particular section of the scene. The time series signature for this *spatial concentration* pattern is a horizontal or nearly horizontal line that spans a small range of headings over a long period time, as shown in Figure 18. Although time series plots can be directly used to identify spatial concentration patterns, the pattern can also be revealed with histograms of heading intervals.

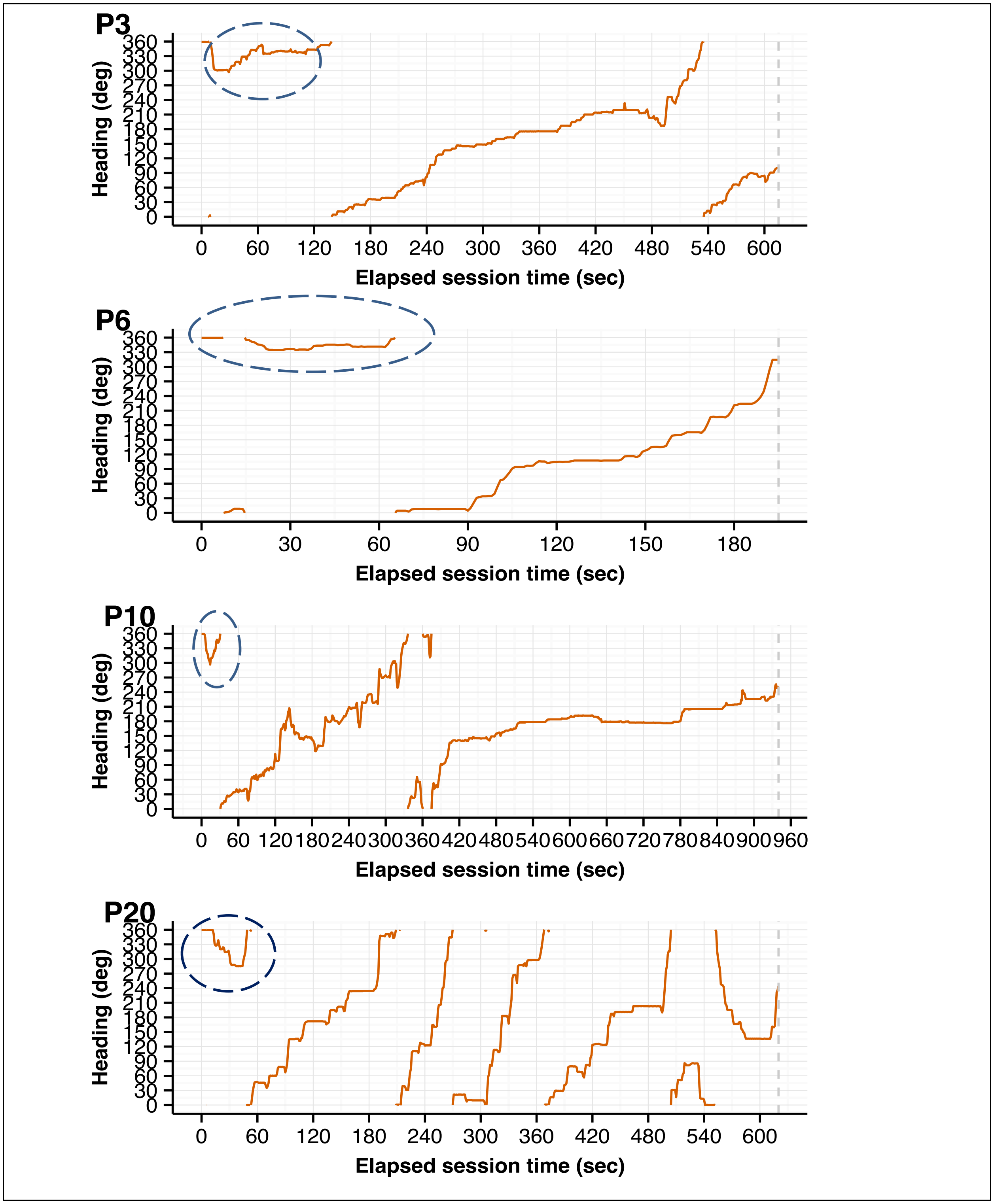

Figure 16. Tentative start pattern for participants P3, P6, P10, and P20.

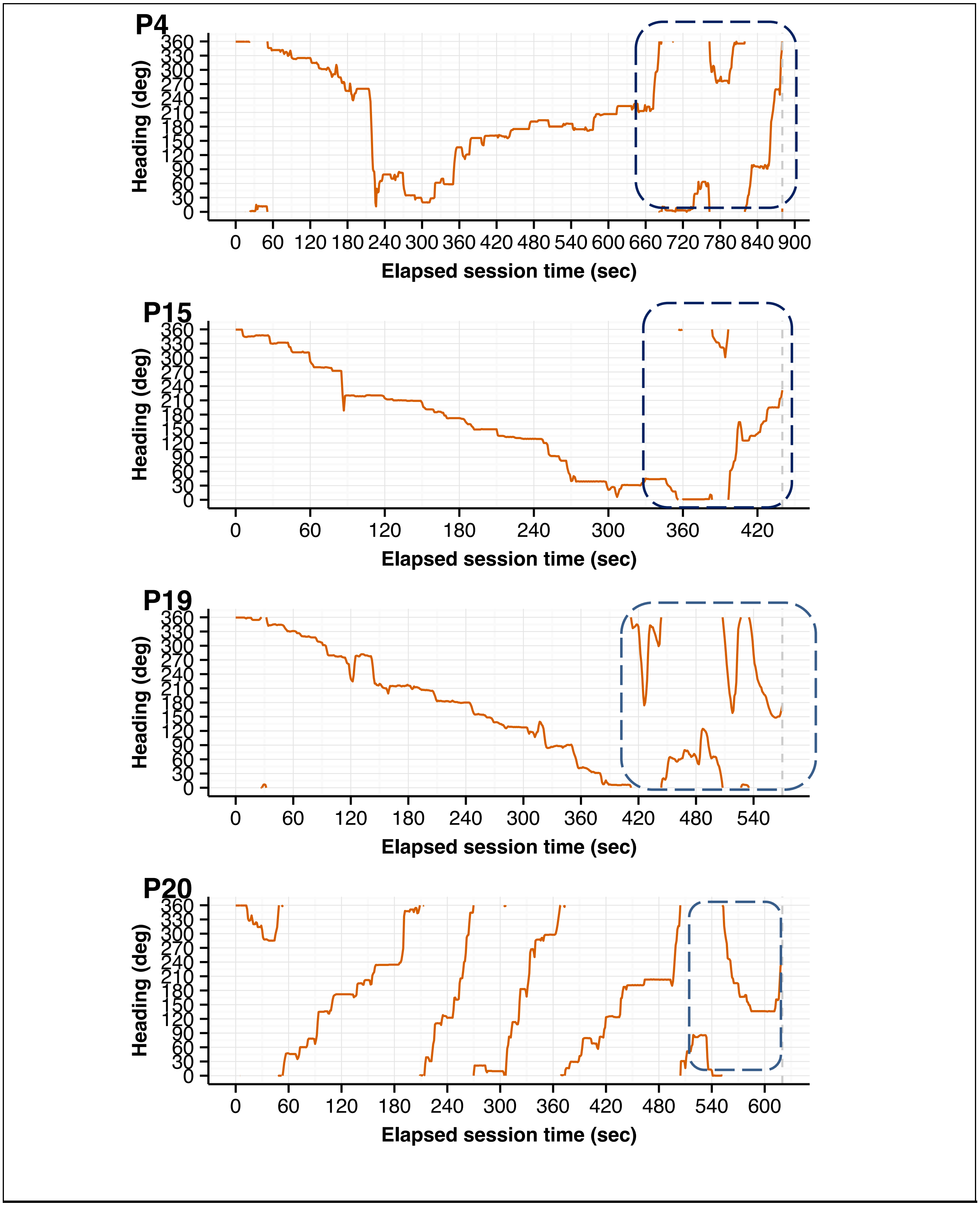

Figure 17. Last chance pattern for participants P3, P6, P10, and P20.

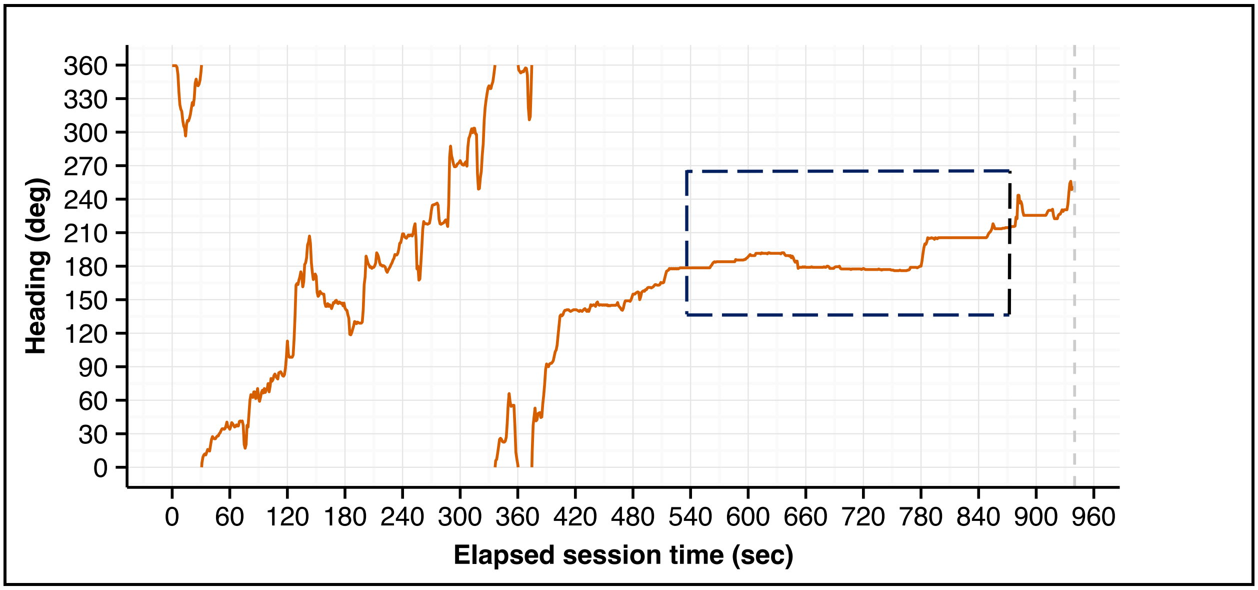

Figure 18. Spatial concentration pattern for participant P10. Dashed lines indicate heading interval of 150º to 180º as spatially concentrated.

Spatial concentration. As shown in the arrayed histograms of Figure 19, participants P6, P10, P12, and P18 had the least uniform distribution of relative heading observations amongst the study participants. In this pattern of spatial concentration, each of the four participants visited at least one heading interval that was measured to have a frequency density of at least 0.008, which corresponds to a relative frequency of 24% of the session observations. The most frequently visited interval for three of the four participants, P6, P12, and P18, was the interval from 330º to 360º. The fourth participant of the group, P10, spent the most time at interval 150º to 180º. In the cases of participants P10, P12, and P18, the second most frequently observed heading intervals, 150º to 180º, 300º to 330º, and 0º to 30º, respectively, were adjacent to their most frequently occurring interval. In contrast, an examination of the arrayed histogram indicates that two adjacent intervals between 240º and 300º degrees were amongst the least frequently visited session intervals. Frequency tables for these histograms are presented in Appendix H.

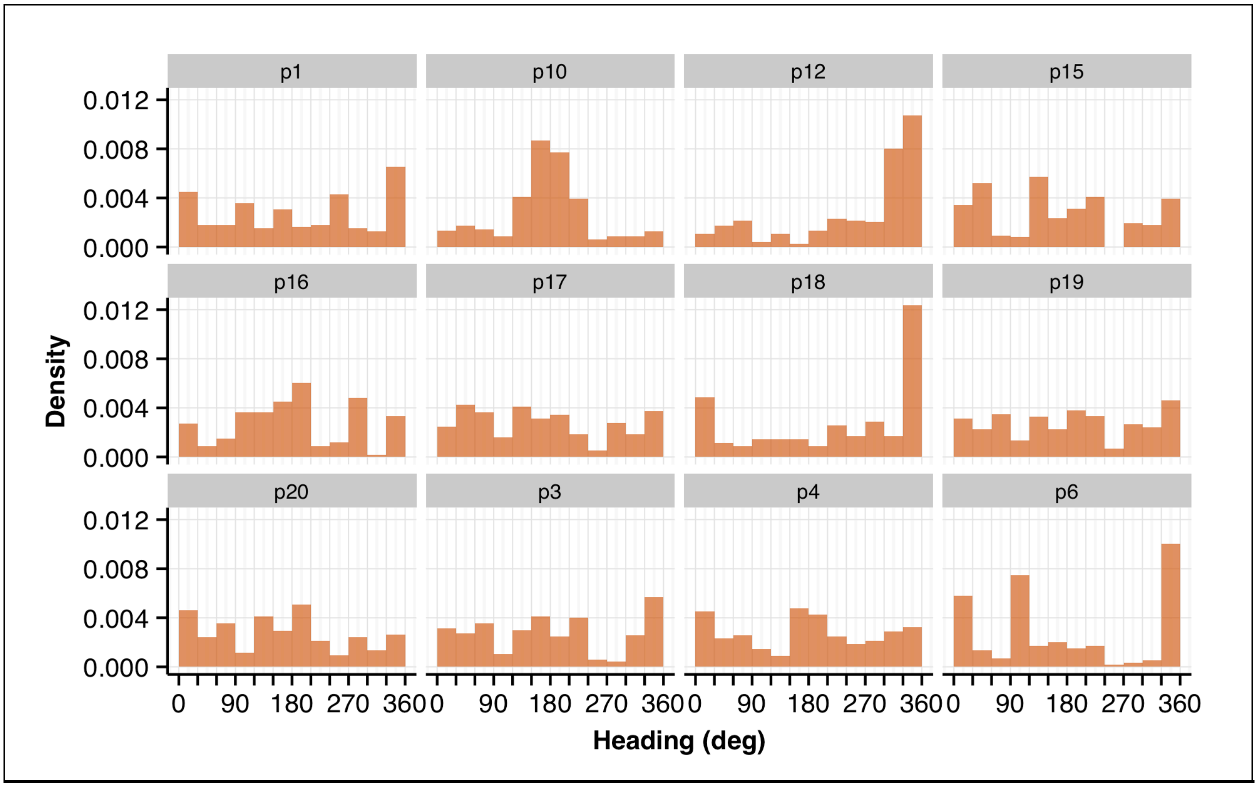

Figure 19. Concentration of heading intervals by participant.

Summary. Participant time series revealed a large variety of movement paths that were used during orientation learning. Despite the apparent dissimilarity amongst the time series, five movement patterns were discovered to be in use among the participants, as shown in Table 5. Spatio-temporal lap and backtrack patterns revealed that some participants rotate through the VR scene in a single direction, whereas others rotate through the scene in alternating directions with series of visit-revisit cycles. Temporal tentative start and last chance patterns revealed that final and initial movement patterns could significantly vary from those used in the main session. Finally, the spatial concentration pattern revealed that some participants tended to visit a small area of the scene much more frequently than other areas.

Table 5

Summary Matrix of Movement Patterns by Participant

Participant	Spatio-temporal Patterns		Temporal Patterns		Spatial Patterns
	Lap	Backtrack	Tentative Start	Last Chance	Spatial Concentration
P1	X				
P3	X		X		
P4		X		X	
P6	X		X		X
P10	X		X		
P12		X			
P15	X			X	
P16		X			
P17		X			
P18	X				X
P19	X				
P20	X		X	X	X

Research Question 2

What FOV levels were used by the participants to view the VR scene?

As shown in the arrayed histograms of FOV levels presented in Figure 20, the majority of participants (n = 8; P3, P4, P10, P15, P17, P18, P19, P20) were observed to use narrow FOV level in the range of 30º to 90º more often than a wider FOV level of greater than 90º. In the group of participants who more frequently used a narrow FOV, P15 and P19 were observed using the narrowest FOV level interval, 30º to 60º, at a frequency density greater than 0.02, which corresponds to a relative frequency of 60%, and participant P12 never used a wide FOV level. Three participants, P1, P16 and P20, used a wide FOV level for a majority of the time with P20 using the widest FOV interval level of 120º to 150º at a frequency density of .02. Participant P3 was observed to use approximately the same proportion of wide and narrow FOV levels. Participant P4 did not change the FOV level from its initial default of 88º.

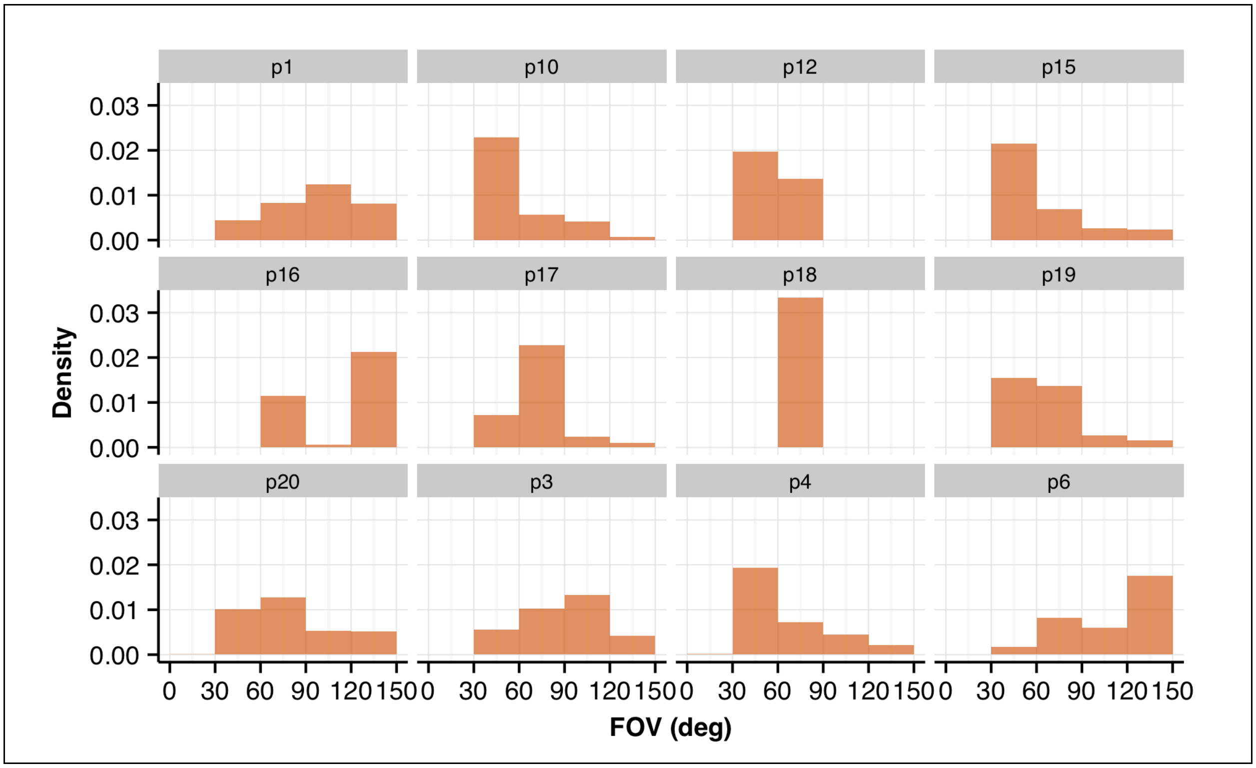

Figure 20. Concentration of FOV intervals by participant.

Research Question 3

*What is the relationship between the heading and FOV levels used by the participants in the VR scene***?**

As shown in Figure 21, LOESS regression paths, shown by dark blue lines, on the participants' FOV vs heading scatter plot varied considerably. Three groups of participants shared similar patterns. For the first group of participants, P15, P18, and P20, heading and FOV level were independent. For the second group of participants, P10, P18, and P20, FOV level narrows near heading 180º. Finally, for the third group of participants, P1 and P16, FOV level widened for headings greater than 180º, peaking near 270º. No shared relationship patterns appear beyond these three groups of participants.

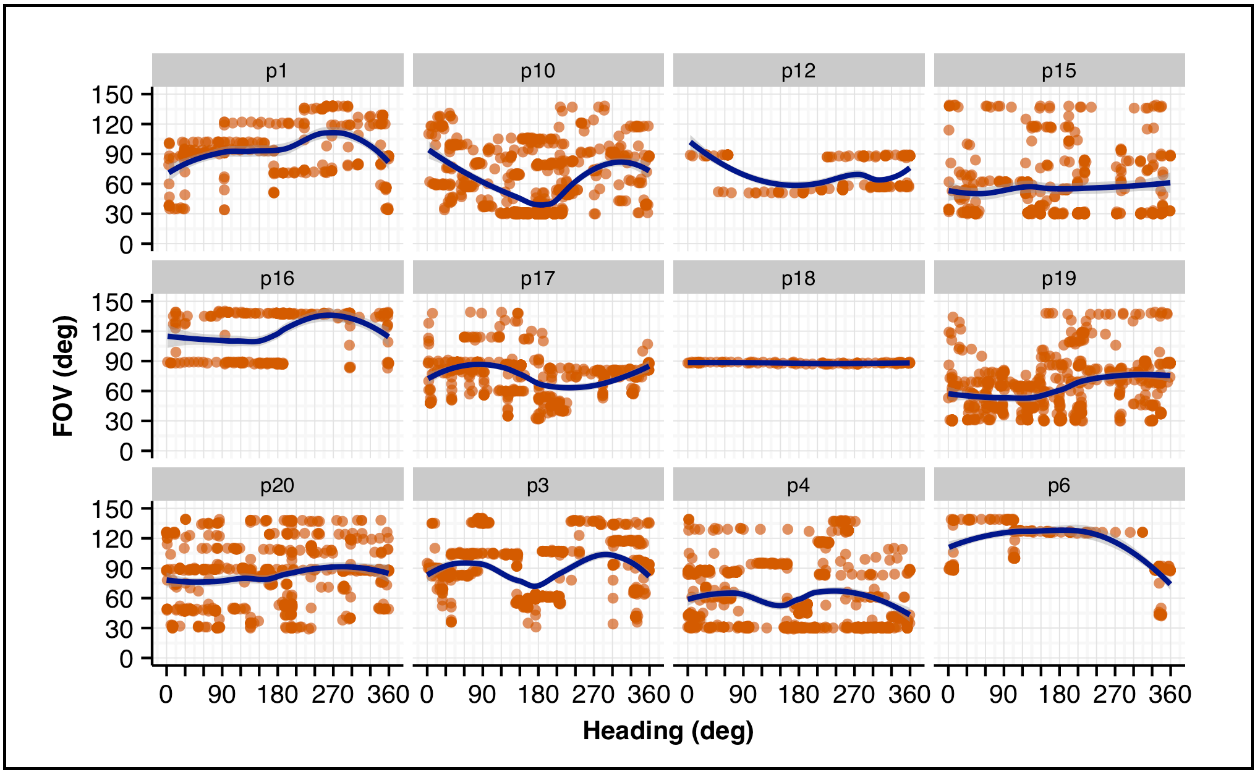

*Figure 21.*Scatter plot of FOV vs heading intervals by participant with overlaid LOESS regression paths.

CHAPTER V

FINDINGS: LEARNING EVENT PATTERNS

This chapter, which is organized by research question, addresses the study findings regarding learning event patterns. The first section of the chapter addresses research question four regarding the events that participants used during the orientation learning sessions. The second section of the chapter addresses research question five regarding the individual patterns of events that were used by each participant during the orientation learning sessions. The third section addresses research question six regarding the problems that participants encountered during the orientation learning sessions. A final section presents an additional finding regarding the sense of presence participants may have experienced using VR. Although the study did not plan to directly investigate the presence phenomena, it is a core characteristic of the VR experience (Ausburn & Ausburn, 2010) that is relevant to educational applications of the technology, including the orientation learning that is the focus of the study.

Research Question 4

What events did the participants use during the orientation learning sessions?

The types of events that the participants used during the orientation learning sessions were derived by coding the think-aloud transcripts as part of a content analysis. Descriptive codes assigned to segments of the transcripts indicated a particular type of action the participant completed at that point in the transcript. As coding proceeded, the codes were gathered into categories and sub-categories that represented classes of events. These categories and sub-categories were organized and presented graphically as a learning events model.

Learning Events Model

Results of the learning event content analysis are presented as a hierarchical model of learning events, as seen in Figure 22. Four main learning event categories, *identifying*, *locating*, *regulating*, and *contextualizing*, represented by rectangles in the figure, define the model's highest level of categorization. The identifying, locating, and regulating categories were derived from the study's conceptual framework prior to the commencement of coding, whereas the contextualizing category emerged during coding of the transcripts as a component of orientation learning that was not included in the the framework. Each of the categories was further classified into two or three finer-grained sub-categories, represented by ovals that are connected to the associated parent category in the model. The identifying category contains subcategories of *naming*, *describing*, and *associating*; the locating category contains subcategories *allocentric* and *egocentric*; the regulating category contains subcategories of *controlling*, *monitoring*, and *planning*; and the contextualizing category contains subcategories of *reacting* and *interpreting*. Subcategories for the identifying, and regulating subcategories were defined prior to coding, whereas subcategories for the identifying and contextualizing categories were dynamically constructed during the content analysis process. Further descriptions of the categories and subcategories are presented in following sections.

All of the descriptive codes that were used in analysis of the think-aloud transcripts are presented in tables in Appendix I, organized by category and subcategory. Each table includes the name of the code and associated sample excerpts from the think-aloud transcripts. Similar tables included in Appendix J document the number of times each code was applied to a participant's think-aloud transcript during the coding process.

As the orientation learning process involves learning the spatial relationships amongst objects and the learner, the descriptive codes associated with both the identifying and locating categories, as well as some of the contextualizing subcategories, were necessarily linked with a

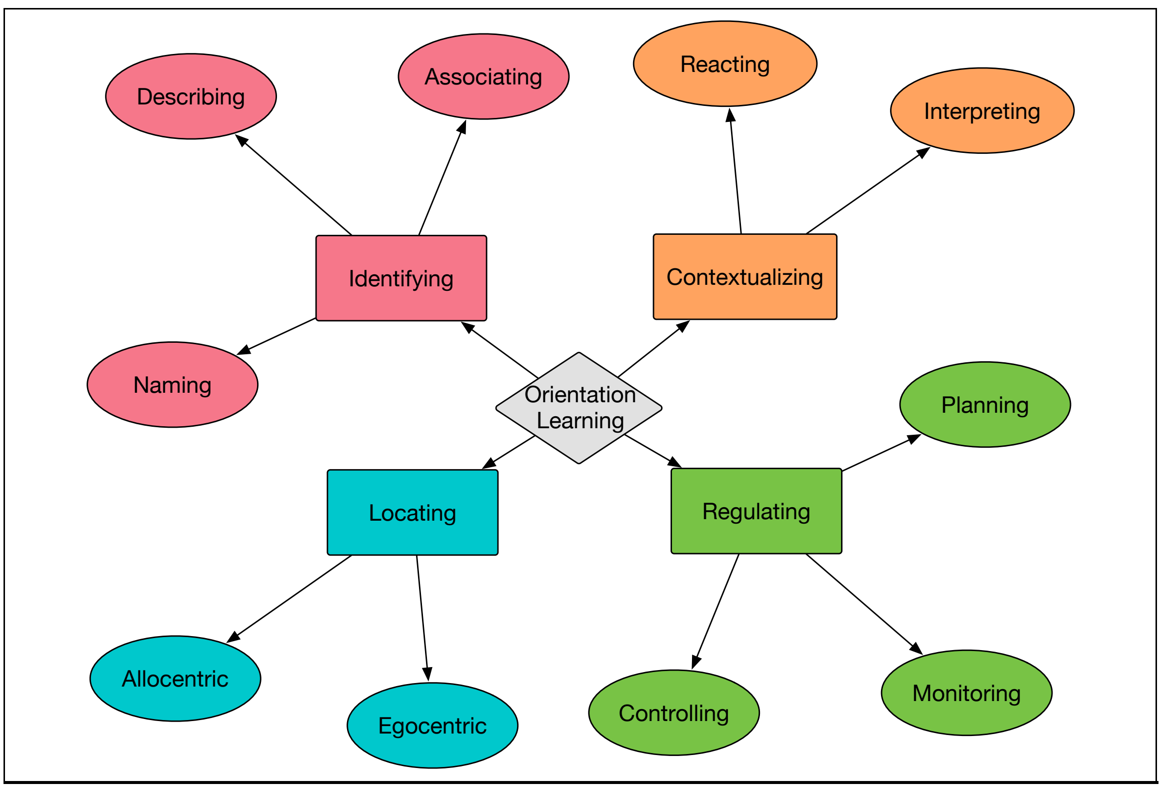

Figure 22. Learning event categories of orientation learning.

referenced object. For example, a participant might identify a piece of furniture by describing its color (e.g. the white sofa) or might allocentrically locate it (e.g. in front of a window) or perhaps even react to it (e.g. like its style). The orientation learning scene contained many different types of objects, so including the specific name of each object in a code quickly grows the number of code variants. To manage this situation, the researcher developed a taxonomy of objects to reduce the types of referenced objects to a manageable number of categories. Instead of including the name of a specific object in a descriptive code's identifier, the category of the object is included. The resulting object taxonomy, as seen in Table 6, was developed according to an object's size and commonly accepted function and purpose. Taxonomies of this type are useful in reducing coding variants that involve object references, but are specific to the type of virtual scene.

Table 6

Taxonomy of Objects Used in Coding Identifying and Locating Categories

Category	Definition	Examples
Boundary	A planar object that bounds the VR scene.	Floor, ceiling, window, door
Room	An area within a household scene primarily used for a single function.	Dining room, living room, porch, hallway
Fixture	A permanent, generally architectural, feature that is not a boundary and is usually not moved during a household relocation.	Fireplace, ceiling beam, partition, curtain, carpet, shelf, electrical outlet, wall switch, chandelier
Furniture	Moveable household equipment used for common living functions and needs.	Table, sofa, chair, cabinet, piano, rug
Item	A small object used for decorative or functional purposes.	Dish, book, glass, vase, figurine, teapot
Picture	A graphical representation of scenery or object primarily used for decoration	Photograph, painting, certificate, mounted butterfly
Outdoor	An area outside the interior of the house	Porch

Identifying. The identifying category included codes that indicated how a participant constructed a representation of an object's identity. Three major subcategories of identifying events emerged from the coding of the think-aloud transcripts: *naming*, *describing*, and *associating*. Naming subcategory codes, as listed in Table I1, indicated that the participant had only uttered the name of an observed object. (See Appendix I to examine all tables that are numbered as I*x*). Describing subcategory codes, listed in Table I3 and Table I4, identified that the participant assigned an attribute (e.g. color) and associated value (e.g. red) to an object to further detail its characteristics. For most of the describing subcategory codes, the object description was in the form of an adjective modifying a noun within the transcript segment; however, some of these codes indicated that the participant identified an unfamiliar object by verbalizing its function. Associating subcategory codes, as listed in Table I5, were used to identify events where the participant had linked the object in the scene to another familiar object. In most cases the object was recalled from the participant's prior experience, although some references were made to objects described in earlier parts of the participant's orientation learning session.

Locating. The locating category included codes that indicated how a participant represented the spatial positioning of an object. The locating category was further classified into two subcategories according to whether an object was located *allocentrically*, relative to another object, or whether an object was located *egocentrically*, relative to the participant's position in the virtual scene. Allocentric subcategory codes, listed in Table I6 and Table I7, contained the category of the located object and the category of referenced object, both determined by the object taxonomy developed for the study. For example, the descriptive code of *locating item allocentric to furniture* indicated that an item was located relative to a reference piece of furniture, corresponding to an utterance such as the "the statue was on the table." Egocentric codes, listed in Table I8, contain only the object type of the located object as the observer is the implied reference object. In some cases, participants located an object relative to a location that was specified as "here" or "there" in the transcript, referring to an area of the scene pointed to with the mouse cursor. Although the area that was referenced could be potentially interpreted as a reference to an object pointed at by the cursor, the researcher coded these event as egocentric locating subcategory since “here” or “there” only has meaning within the context of a particular portion of the viewed scene.

Regulating. The regulating category codes indicated how the participant managed the orientation learning session. The regulating category was further classified into three subcategories according to Pintrich (2000) general framework of SRL events as *controlling*, *monitoring*, and *planning*. Controlling subcategory codes, listed in Table I11, indicated that the participant selected a particular strategy for moving within or viewing a section of the virtual scene (e.g. *moving to a room*) or memorizing the virtual scene. Monitoring subcategory codes, listed in Table I10, indicated that the participant compared some existing condition, position or state with a desired condition or state. The single planning event subcategory code in the study identified an event where the participant indicated an intention to survey a portion of virtual scene before moving to a particularly interesting area (Table I9). No observations were made of any events that would be classified according to the *reflecting* task of the SRL framework (Pintrich, 2000).

Contextualizing The contextualizing category included event codes that indicated how the participant viewed individual objects within the scene, collections of objects within the scene, or the scene itself, from a perspective that differed from the core definition of orientation learning, i.e., acquiring knowledge regarding spatial relationships amongst objects and the participant observer. Two subcategories of contextualizing events emerged from the analysis of the think-aloud transcripts: *interpreting* and *reacting*. Interpreting subcategory codes, listed in Table I12, indicated that the participant reasoned about the possible origin of an object or the interests and demographic profiles of the object's owner (e.g. "this person likes to collect something about the ocean"). Reacting subcategory codes, listed in Table I13, were used to indicate that the participant made a affective valence (positive or negative) judgment regarding an object (e.g. "that's a neat little lamp with an elephant on it").

Research Question 5

What patterns of learning events did the participants use during the orientation learning sessions?

To address research question five, frequency distributions of the assigned codes are presented from three perspectives. First, the frequency of the assigned codes aggregated at the subcategory and category level are presented in tables with an accompanying description for each participant. Next, frequency distributions of the subcategory codes within each of the four categories across all the participants are presented. Lastly, the relative frequencies of assigned codes at the category level are graphically depicted for each participant in the form of a star chart and the participants are grouped according to similar category level distributions.

Participant P1

As seen in Table 7, participant P1 used events in each of the four categories of identifying, locating, regulating, and contextualizing, with the identifying and locating categories accounting for approximately 66% of the coded events. P1 most commonly used events in the the naming subcategory, followed closely by the describing, and associating subcategories within the identifying category and located objects primarily with allocentric relationships. Events coded in the monitoring subcategory dominated the regulating category, and events coded in reacting subcategory dominated the contextualizing category, although absolute frequencies for both categories were small.

Table 7

Code Distribution by Category and Subcategory for Participant P1

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	4	22.2	51.4
	Describing	6	33.3	
	Naming	8	44.4	
Locating	Allocentric	4	80.0	14.3
	Egocentric	1	20.0	
Regulating	Controlling	1	14.3	20.0
	Monitoring	6	85.7	
	Planning	0	0.0	
Context	Interpreting	1	20.0	14.3
	Reacting	4	80.0	

Participant P3

As seen in Table 8, participant P3 used events in each of the four event categories of identifying, locating, regulating, and context, with the identifying and locating categories accounting for approximately 88% of the coded events. P3 used nearly twice as many describing subcategory events in comparison to naming subcategory events to identify objects and located objects primarily with allocentric relationships by an order of magnitude over the use of egocentric relationships. Monitoring subcategory events dominated the regulating category, and reacting events category was the sole subcategory used in the contextualizing category.

Table 8

Code Distribution by Category and Subcategory for Participant P3

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	60.0
	Describing	44	63.8	
	Naming	25	46.2	
Locating	Allocentric	30	90.9	28.7
	Egocentric	3	9.1	
Regulating	Controlling	3	60.0	4.3
	Monitoring	20	40.0	
	Planning	0	0.0	
Contextualizing	Interpreting	0	0.0	7.0
	Reacting	8	100.0	

Participant P4

As seen in Table 9, participant P4 used each of the four event categories of identifying, locating, regulating, and context, with the identifying and locating categories accounting for 92% of the coded events. P5 used nearly six times as many describing subcategory events as naming subcategory events to identify objects and located objects almost exclusively with allocentric relationships. Monitoring subcategory events were the sole event type used in regulating category, which comprised less than 8% of the observed events, and a single reacting subcategory event comprised the entire contextualizing category.

Table 9

Code Distribution by Category and Subcategory for Participant P4

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	38.0
	Describing	53	85.5	
	Naming	9	14.5	
Locating	Allocentric	85	96.6	54.0
	Egocentric	3	3.4	
Regulating	Controlling	0	0.0	7.4
	Monitoring	12	100.0	
	Planning	0	0.0	
Context	Interpreting	0	0.0	0.6
	Reacting	1	100.0	

Participant P6

As seen in Table 10, participant P6 used three of the four event categories of identifying, locating, and regulating, with the identifying and locating categories accounting for approximately 72% of the coded events. P6 primarily used describing subcategory events to identify objects and located objects with allocentric relationships four times as often as egocentric relationships. Controlling subcategory events dominated the regulating category, occurring more than four times as often as the monitoring subcategory events.

Table 10

Code Distribution by Category and Subcategory for Participant P6

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	20.5
	Describing	7	87.5	
	Naming	1	12.5	
Locating	Allocentric	16	80.0	51.3
	Egocentric	4	20.0	
Regulating	Controlling	9	81.8	28.2
	Monitoring	2	18.2	
	Planning	0	0.0	
Context	Interpreting	0	0.0	0.0
	Reacting	0	0.0	

Participant P10

As seen in Table 11, participant P10 used three of the four event categories of identifying, locating and, regulating, with the identifying and locating categories accounting for approximately 88% of the coded events. P10 used approximately an order of magnitude more describing subcategory events than naming subcategory events and just a few associating subcategory events to identify objects, and located objects primarily with allocentric relationships by an order of magnitude in comparison to egocentric relationships. Monitoring subcategory events dominated controlling subcategory events in the regulating category by an order of magnitude margin.

Table 11

Code Distribution by Category and Subcategory for Participant P10

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	3	2.3	52.2
	Describing	116	88.5	
	Naming	12	9.2	
Locating	Allocentric	82	91.1	35.9
	Egocentric	8	8.9	
Regulating	Controlling	2	6.7	12.0
	Monitoring	28	93.3	
	Planning	0	0.0	
Contextualizing	Interpreting	0	0.0	0.0
	Reacting	0	0.0	

Participant P12

As seen in Table 12, participant P12 used each of the four event categories of identifying, locating, regulating, and context, with the identifying and locating categories accounting for approximately 53% of the coded events. P12 primarily used describing subcategory events in preference to a single naming subcategory event to identify objects, and located objects exclusively with several egocentric relationships. Only a few of the monitoring and controlling subcategory events were used in the regulating category. Reacting subcategory events were exclusively used in the contextualizing category, the second most commonly used category.

Table 12

Code Distribution by Category and Subcategory for Participant P12

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	48.8
	Describing	19	95.0	
	Naming	1	5.0	
Locating	Allocentric	0	.0	4.9
	Egocentric	2	100.0	
Regulating	Controlling	1	33.3	7.3
	Monitoring	2	66.7	
	Planning	0	0.0	
Context	Interpreting	0	0.0	39.0
	Reacting	16	100.0	

Participant P15

As seen in Table 13, participant P15 used each of the four event categories of identifying, locating, regulating, and context with the identifying and locating categories accounting for approximately 69% of the coded events. P15 used approximately the same amount of describing subcategory events and naming subcategory events and just a few associating subcategory events to identify objects and located objects primarily with allocentric relationships. Monitoring subcategory events dominated the regulating category, the second most commonly occurring, with nearly seven times as many events as the combined controlling subcategory events and the single observed planning subcategory event in the study. Within the contextualizing category, P15 used about twice as many reacting subcategory events, as compared to interpreting subcategory events, but the contextualizing category comprised less than 10% of the coded observations.

Table 13

Code Distribution by Category and Subcategory for Participant P15

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	4	8.9	52.3
	Describing	20	44.4	
	Naming	21	46.7	
Locating	Allocentric	12	80.0	17.4
	Egocentric	3	20.0	
Regulating	Controlling	2	11.1	20.9
	Monitoring	15	83.3	
	Planning	1	5.6	
Context	Interpreting	3	37.5	9.3
	Reacting	5	62.5	

Participant P16

As seen in Table 14, participant P16 used three of the four event categories of identifying, locating and, regulating, with the identifying and locating categories accounting for approximately 83% of the coded events. P16 used equal amounts of describing subcategory events and naming subcategory events to identify objects and located objects exclusively with allocentric relationships. A single controlling subcategory event comprised the regulating category, and several interpreting and reacting subcategory events each were used in the contextualizing category.

Table 14

Code Distribution by Category and Subcategory for Participant P16

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	66.7
	Describing	12	50.0	
	Naming	12	50.0	
Locating	Allocentric	6	100.0	16.7
	Egocentric	0	0.0	
Regulating	Controlling	0	0.0	2.8
	Monitoring	1	100.0	
	Planning	0	0.0	
Context	Interpreting	2	40.0	13.9
	Reacting	3	60.0	

Participant P17

As seen in Table 15, participant P17 used each of the four event categories of identifying, locating, regulating, and context, with the identifying and locating categories accounting for approximately 84% of the coded events. P17 used approximately twice as many describing subcategory events than naming subcategory events to identify objects with only a few associating subcategory events, and located objects primarily with allocentric relationships. About twice as many monitoring subcategory events were used in comparison to controlling subcategory events in the regulating category and several interpreting and reacting subcategory events were used in the contextualizing category.

Table 15

Code Distribution by Category and Subcategory for Participant P17

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	2	5.1	57.4
	Describing	25	64.1	
	Naming	12	30.8	
Locating	Allocentric	17	94.4	26.5
	Egocentric	1	5.6	
Regulating	Controlling	2	28.6	10.3
	Monitoring	5	71.4	
	Planning	0	0.0	
Context	Interpreting	2	50.0	5.9
	Reacting	2	50.0	

Participant P18

As seen in Table 16, participant P18 used three of the four event categories of identifying, regulating, and context, with the identifying category accounting for approximately 83% of the coded events. P17 used approximately twice as many naming subcategory events than describing subcategory events to identify objects. Several monitoring subcategory events were used in the regulating category, and a single reacting subcategory event was used in the contextualizing category.

Table 16

Code Distribution by Category and Subcategory for Participant P18

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	82.4
	Describing	4	28.6	
	Naming	10	71.4	
Locating	Allocentric	0	0.0	0.0
	Egocentric	0	0.0	
Regulating	Controlling	0	0.0	11.8
	Monitoring	2	100.0	
	Planning	0	0.0	
Context	Interpreting	0	0.0	5.9
	Reacting	1	100.0	

Participant P19

As seen in Table 17, participant P19 used three of the four event categories of identifying, locating, and regulating, with the identifying and locating categories accounting for approximately 87% of the coded events. P19 used approximately twice as many describing subcategory events than naming subcategory events to identify objects with no associating subcategory events, and located objects exclusively with allocentric relationships, except for one egocentric instance. Half again as many monitoring subcategory events were used in comparison to controlling subcategory events in the regulating category.

Table 17

Code Distribution by Category and Subcategory for Participant P19

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	0.0	25.0
	Describing	19	65.5	
	Naming	10	34.5	
Locating	Allocentric	71	98.6	62.1
	Egocentric	1	1.4	
Regulating	Controlling	6	40.0	12.9
	Monitoring	9	60.0	
	Planning	0	0.0	
Context	Interpreting	0	0.0	0.0
	Reacting	0	0.0	

Participant P20

As seen in Table 18, participant P20 used three of the four event categories of identifying, locating, and regulating, with the identifying and locating categories accounting for approximately 82% of the coded events. P19 used approximately twice as many naming subcategory events than describing subcategory events to identify objects with no associating subcategory events, and located objects with allocentric relationships five time as often as with egocentric relationships. The monitoring subcategory events were exclusively used by P20 within the regulating category.

Table 18

Code Distribution by Category and Subcategory for Participant P20

Category	Subcategory	*f*	Subcategory %	Category %
Identifying	Associating	0	.0	46.4
	Describing	14	35.9	
	Naming	25	64.1	
Locating	Allocentric	25	83.3	35.7
	Egocentric	5	16.7	
Regulating	Controlling	0	0.0	17.9
	Monitoring	15	100.0	
	Planning	0	0.0	
Contextualizing	Interpreting	0	0.0	0.0
	Reacting	0	0.0	

Cross Participant

Learning event patterns for the entire group of participants were revealed by comparing the distributions of the participants' code frequencies at the subcategory level for each of the four categories. Descriptions of these patterns follow.

Identifying category distribution. The describing subcategory was the most commonly used event type within the identifying category. As seen in Figure 23, the describing subcategory events comprised between 50% and 75% of the identifying category codes for four of the twelve participants (P3, P6, P17, and P19) and more than 75% for three participants (P4, P6, and P10). For the remaining five participants, the distribution between the describing subcategory event and naming subcategory event were approximately equal for two of the participants (P15 and P16), whereas the frequency for naming subcategory events exceeded the frequency of the describing subcategory events for three participants (P1, P18, and P20). The associating subcategory event was the least frequently occurring subcategory in the identifying category, used only by four participants (P1, P10, P15, and P17) at a low rate of occurrence.

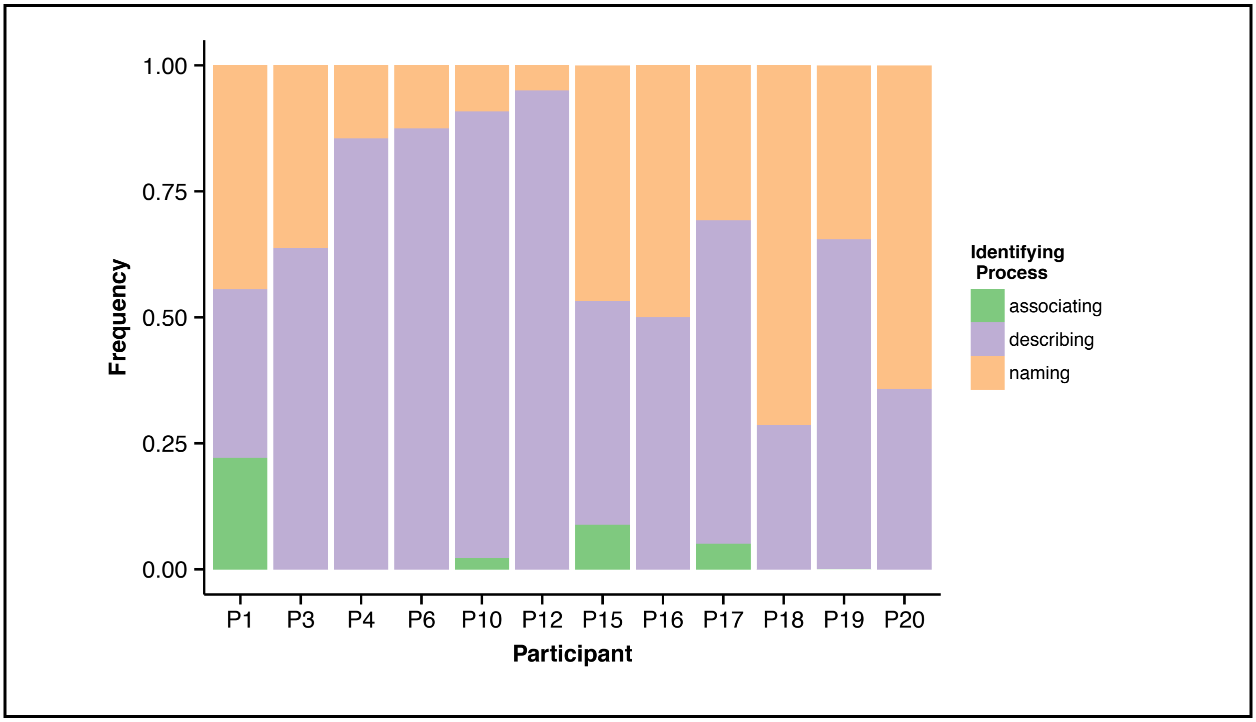

Figure 23. Distribution of identifying subcategories by participant.

Locating category distribution. Allocentric relationships were the dominant way in which the participants located objects. As seen in Figure 24, allocentric spatial relationships comprised at least 75% of the events that were used to locate objects in ten of the twelve participants (P1, P3, P4, P6, P10, P15, P16, P17, P19, and P20), Participant P12 exclusively used egocentric relationships for all of the locating events, and participant P18 did not use any locating category events.

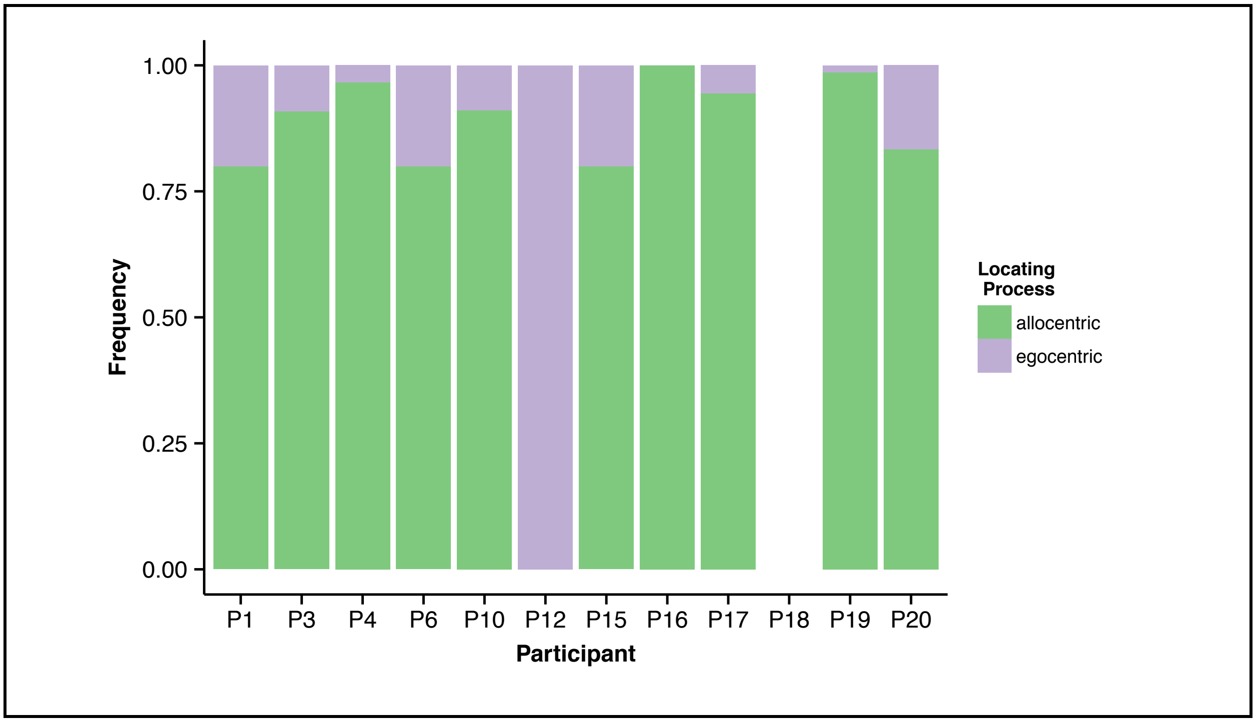

Figure 24. Distribution of locating subcategories by participant.

Regulating category distribution. The monitoring subcategory was dominant within the regulating category. As seen in Figure 25, monitoring subcategory events comprised between 50% to 75% of the regulating category codes for three of the twelve participants (P12, P17, and P19) and more than 75% for seven participants (P1, P10, P15, P16, P18, and P20). For the remaining two participants (P3 and P6), the relationship was reversed. The frequency for controlling subcategory events exceeded 50% of the regulating category codes for P3 and and 75% for P6. The single instance of the planning subcategory event in the study was used by participant P15.

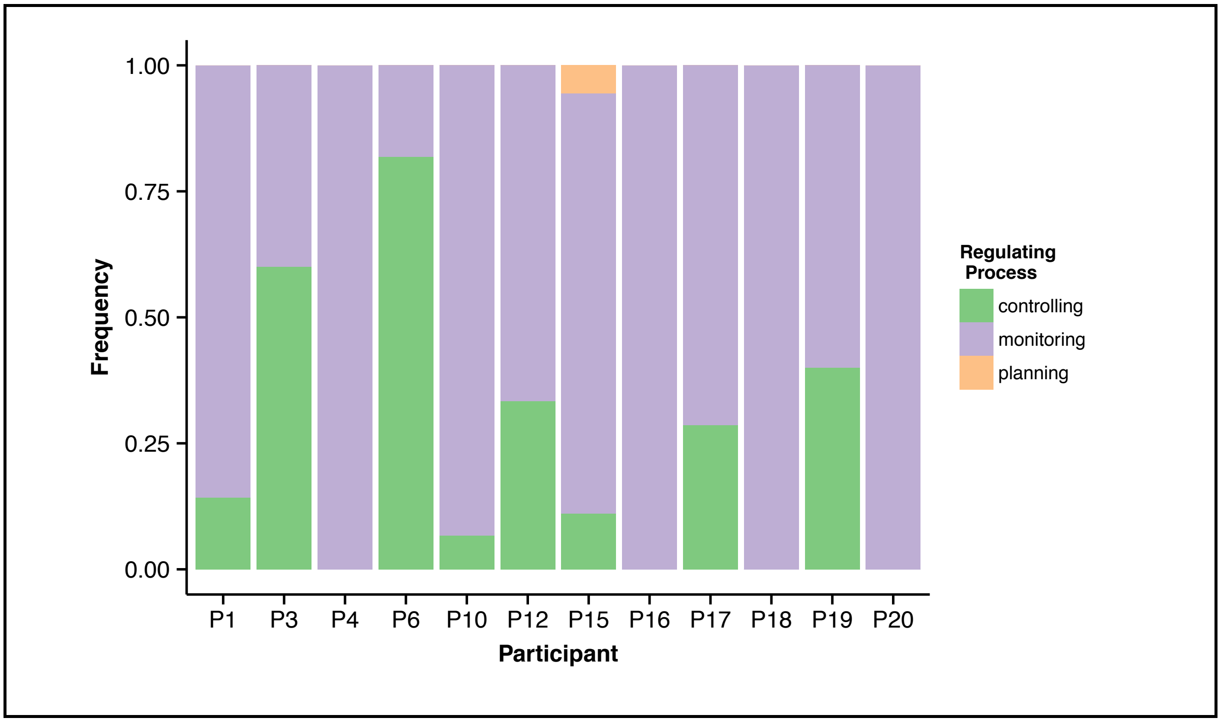

Figure 25. Distribution of regulating subcategories by participant.

Contextualizing category distribution. The reacting subcategory was dominant within the contextualizing category. As seen in Figure 26, reacting subcategory events comprised between 60% and 80% of the contextualizing category codes for three of the twelve participants (P1, P15, and P16), and four participants (P3, P4, P12, P18) used the reacting event subcategory exclusively within the contextualizing category. Participant P15 used equal proportions (50%) of the reacting and interpreting event subcategory codes. Two participants (P6 and P10) did not use any events of the contextualizing category.

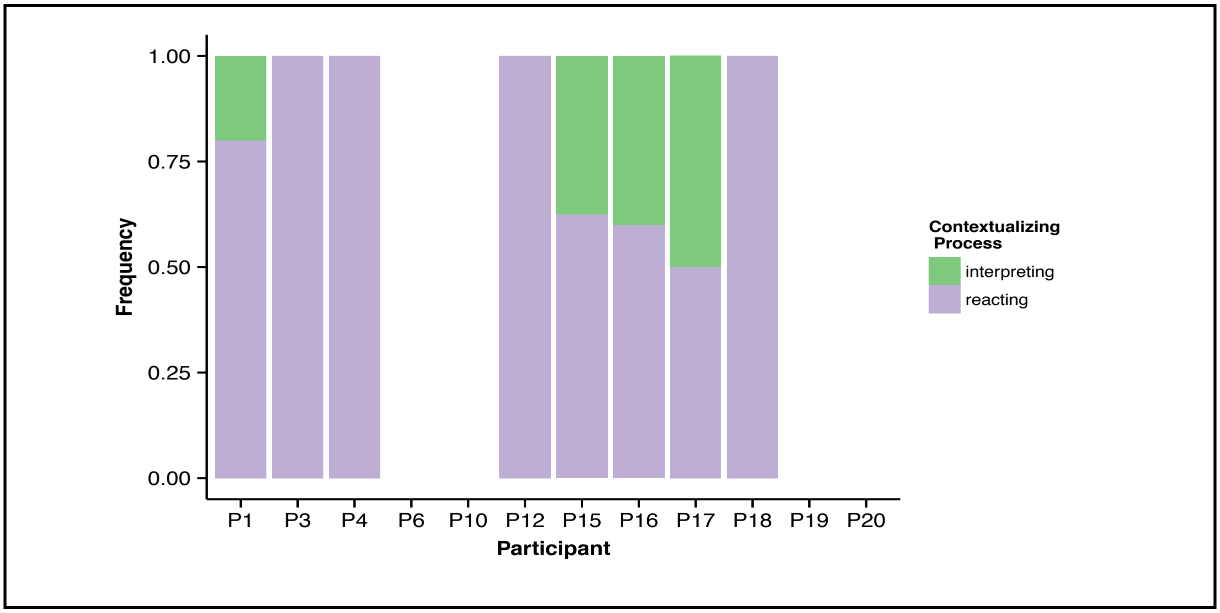

Figure 26. Distribution of contextualizing subcategories by participant.

Participant Profile Patterns

Participant learning event patterns were visualized by representing the relative frequency distributions of the categories identified in the orientation learning event model, as seen in Figure 22, as star charts for each participant. While the model identified the four major event categories that were used by the entire participant group during the orientation learning session, each of the star charts presents an individual profile of the relative extent the events represented by the categories were utilized by a participant during the session.

The star charts for each participant are shown in Figure 27. Each axis of the star chart maps to one of the four categories of identifying, locating, regulation, and contextualizing, as shown on the key at the bottom of Figure 27. The relative occurrence frequency of each of the categories was used to scale the length of the axes for each participant's star chart. Lines connect the end point of each scaled axis to construct a shape that facilitates visual comparison and

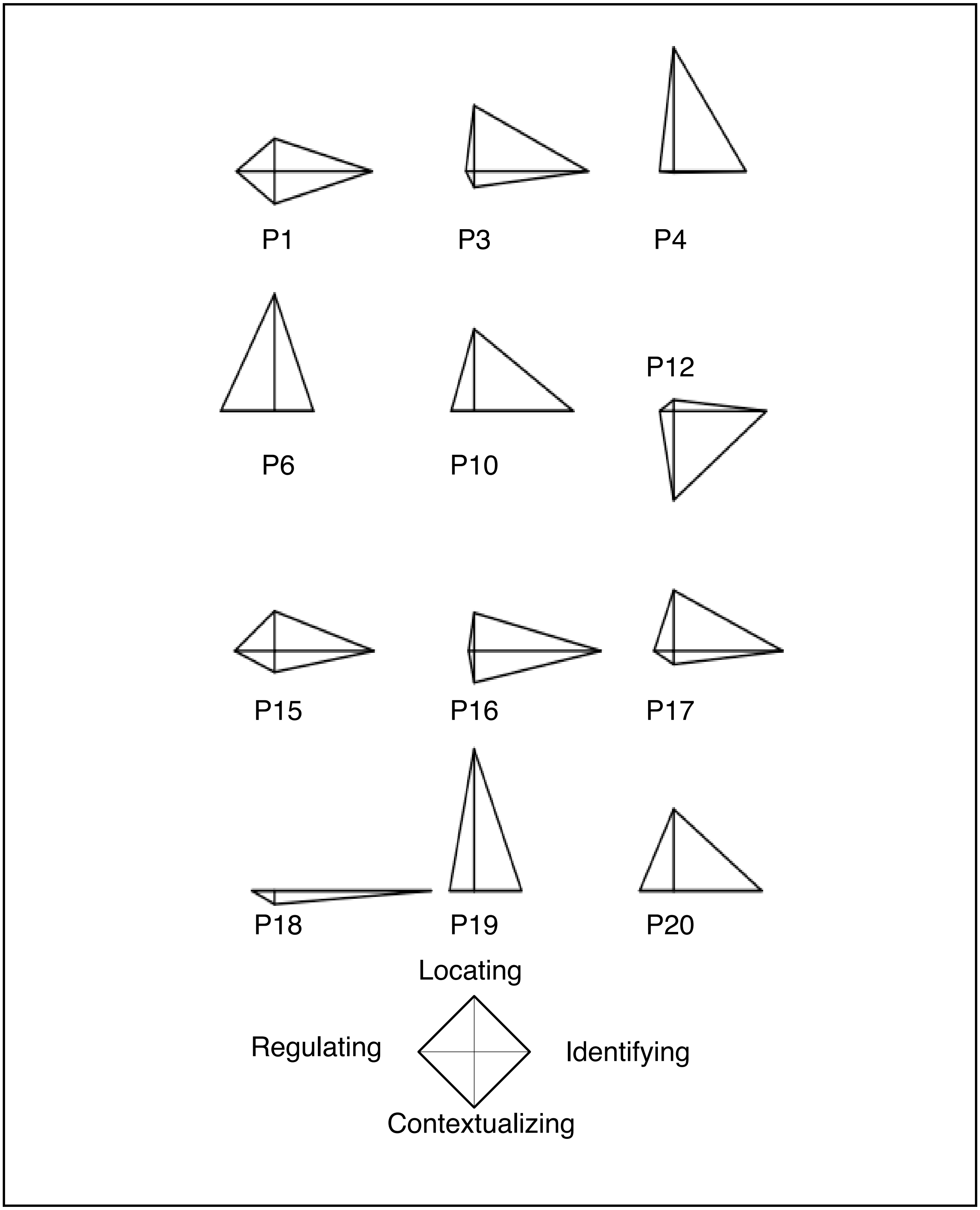

Figure 27. Star charts of participant category distributions.

grouping of the participant profiles into similar groups. Participant identification labels (e.g. P1) are located adjacent to each shape.

Initial visual inspection of the figure indicated a general skewing of most shapes to the right of the vertical axis and above the horizontal axis, reflecting the larger relative frequencies of those categories for most of the participants, as previously discussed. Exceptions to the general distribution of the identifying and locating categories are readily apparent in the star charts for participants P12 and P18 which have distinctly different shapes than the reminder of the participant group.

Comparison of the participant star charts revealed four groups of similar shapes. A first group included participants P1 and P15. The general shape of the star charts for participants in this group were formed with the identifying category as the longest of the four axes and approximately equal lengths for the locating, regulating and contextualizing categories. Participants in this group used events from the identifying and locating categories for learning spatial relationships amongst objects, but also engaged in regulating category and contextualizing category events in approximately the same proportion as the identifying and location categories.

A second group included participants P3, P16, and P17. Like the first group, the identifying category axis was the longest of the four axes. The length of the locating category axis was the second longest in these shapes, but the regulating and context category axes were no longer than the locating category axis and generally much shorter. Like the first group, participants in this second group used the fundamental identifying and locating category events for learning spatial relationships amongst object. The second group, however, engaged in a lesser proportion of regulating category events and a lesser (P3 and P17) or approximately equal (P16) proportion of contextualizing category events as the first group.

A third, and largest, group included participants P4, P6, P10, P19, and P20. The general shape of the star charts for this group of participants was formed from the three axes of identifying, locating, and regulating categories. Analysis of the think-aloud transcripts for this set of participants revealed that they did not engage in any contextualizing category events. The lengths of the identifying and locating axes were approximately equal in these groups, and the length of the regulating axis was generally shorter than either the identifying or locating axis. A minor exception existed for the case of participant P6. The star chart for participant P6 shared the general overall shape profile with other members of the group, but the regulating axis was slightly longer than the identifying axis. Like the first and second group, participants in this third group used the fundamental identifying and locating category events for learning spatial relationships amongst object, and engaged in regulating category events to manage the orientation learning session.

A final fourth group included participants P12 and P18. The identifying axis was the longest (P18) or as long as the next longest axis, but the locating axis was either very small or non-existent. For both participants, the regulating axis was quite short; however, the contextualizing axis was the shortest for P18, but the longest for P12. Members of this group did not actively engage in the locating category events that are fundamental to the learning of spatial relationships among objects. Participant P12's star chart indicated a focus on contextualizing category events, but participant P18's star chart indicated little activity in that area.

Research Question 6

What problems did the participants experience during the orientation learning sessions?

Participants' responses to the critical incident interview questions are summarized in Appendix K. Three general types of problems were identified by the participants: the large amount of scenic details to remember, VR system interface problems, and lack of detail or access to portions of the visual scene. Participants reported that the problems were generally minor, that none of the problems impacted the learning session in a major way, and they were able to solve or work-around the problem. Two of the participants (P12 and P17) reported encountering no problems during the orientation learning session.

Large Amounts of Scenic Details

Three of the participants reported problems regarding the amount of details contained in the scene and the associated difficulty in remembering those details. P1 reported problems answering the questions on paper and trying to learn everything. Similarly, P16 reported there was a lot to memorize such as details regarding the location of specific pieces of furniture. P18 echoed these concerns, reporting it was hard to remember the details of the scene, particularly with only a single prior exposure to using a VR system.

VR System Problems

Six of the participants reported problems with the VR system. Participants P3 and P20 reported that pan actions performed with the mouse moved the scene in the opposite direction to what they expected, and P19 experienced a similar problem when using the shift and command modifier keys as zoom controls. P14 reported another issue with the zoom control, stating that the control tended to coast past the desired zoom level. Participant P15 found the system to be slow to respond to pan movements initiated from the mouse.

Virtual Scene Problems

Participant P10 reported a lack of detail when zooming-in on some of the objects. Another participant (P6) reported that he was unable to determine if a sliding glass door was a door or window because he could not see around another object that blocked the view.

Additional Finding Regarding Presence

Results from the content analysis of the participants' think-aloud verbalizations made during the orientation learning session indicated that some participants constructed personal interpretations of the virtual surround and its objects in the same way that one might with a real physical space and associated objects, thus supporting an inference that participants may have experienced a sense of presence in the desktop VR environment. These interpretations were revealed in learning event codes that were categorized in the reacting and interpreting subcategories of the contextualizing and the associating subcategory of the identifying category. The associated codes and example text for each of these subcategories are contained in Table I12 (interpreting), Table I13 (reacting), and Table I5 (associating). As can be seen from the arrayed star charts in that depict the relative weights of the four major categories (REF and the stacked bar chart the shows the relative distribution of associating events within the naming category, these indicator categories vary considerably across participants, which indicated that sense of presence likely varies considerably across participants.

CHAPTER VI

CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

Summary of the Study

The purpose of the study was to provide a baseline description of how learners use desktop VR systems for orientation learning. This description led to a better understanding of how learners navigate within the virtual surround, how they perceive objects and spatial relationships among the scene's objects, how they regulate the orientation learning process, and the nature of the major problems they encounter when using a desktop VR system for orientation learning. The base line description of user behavior provides valuable input for instructional designers to improve VR-based orientation learning.

The study used a mixed methods content analysis approach. Twelve participants were trained on the operation of a desktop VR system and the use of a concurrent think-aloud protocol. After completing the training, the participants individually used a desktop VR system to explore the virtual surround of a residential living and dining space. A screen-recording program captured each participant's on-screen navigation movements and thought verbalizations. The video screen recordings were processed by computer programs to create a time ordered database of heading and field of view positions that served as a source text for a context analysis of movement patterns. Time series plots of the participants' heading positions in the virtual surround were produced from the database and visually analyzed to detect any movement patterns. The database was also used to detect patterns and relationships between participants' FOV and heading positions. Audio recordings of participants' think-aloud transcripts were transcribed and used as the source text for a content analysis that identified the cognitive and SRL orientation learning events participants used during the VR-based orientation learning sessions.

The median orientation session length was approximately seven minutes in duration, but several sessions were less than two minutes long and two were more than 15 minutes long. Analysis of the heading data revealed that eight of the participants generally moved in a single direction through the surround, whereas the remaining four moved in a direction and then reversed that direction. Movement patterns of some of the participants were also found to be different at the beginning and end of the sessions, and some participants tended to navigate through certain areas of the surround more slowly. Some participants tended to view the surround scene with wide or narrow fields of view during most of the session, whereas other varied the field of view. In addition, some participants tended to view a particular area of the scene with narrower or wider fields of view, but others varied the field of view across the positions of the scene.

A model of orientation learning events was derived from analysis of the orientation learning event content analysis showed that participants engaged in four categories of learning events: identifying, locating, regulating, and contextualizing. Participant profiles indicated that events associated with the identifying and locating categories occurred most often. Four groups of profile patterns were identified among the participants: the first group of two participants use approximately equal proportions of events assigned from all four categories, the second group of three participants used fewer regulating category events than the first, the third group of five participants used approximately equal proportions of the identifying, locating, and regulating category events with no contextualizing category events, and the fourth group of two participants used very few locating category events.

Five major conclusions were derived from the study's findings, as follows.

Conclusion #1

With the exception of a few learners, learners used SRL events sparingly during orientation event learning.

The proportion of regulation event codes used by the participants was relatively small compared to other learning event categories, as can be seen by the star charts shown in Figure 27. Only one third of the participants (P1, P6, P15, and P20) used SRL events for more than 15% of their total observed event occurrences, with P6 using the maximum of 28%. The observed low and highly variable use of SRL events, however, is consistent with one of the basic assumptions of SRL expressed by Pintrich (2000) that stated all learners were capable of self-regulation, but the level of practice varied. Supporting empirical results from the *MetaTutor* project showed that only 15% events recorded for hypermedia learning systems without supporting scaffolds were metacognitive, which corresponded to a rate of a single event every four minutes (Azevedo et al., 2009). These relatively low observed usage rates of SRL events indicate that the design of supporting scaffolds or instructional methods to increase SRL awareness would be a worthwhile area of instructional design to pursue for desktop VR, as was the case for hypermedia studies reviewed in Chapter 2.

The monitoring and controlling events that were observed, however, were relevant to and useful in managing orientation learning, as assumed in the study's conceptual framework. For example, several controlling events expressed the need to reexamine a particular area of the VR surround or revise one's description of an object on second look. The majority of the monitoring events expressed a lack of available detail in the scene to be able to precisely identify an object, thus expressing an evaluated condition that orientation of at least part of the surround could not be obtained.

The design of the study may have partially contributed to the observed low level of SRL planning and reflection events. Only one planning event was observed in the regulation and no reflection events were observed. SRL planning events generally involve recall and organization of previous knowledge, as was noted in several of the SRL hypermedia studies conducted by Azevedo and colleagues (e.g. Azevedo & Cromley, 2004; Azevedo, Guthrie, et al., 2004). In this study, however, the participants had no prior knowledge of the residential surround in this study because the study was their first exposure to it, so the opportunities to plan activities are minimal. Similarly, the orientation learning session ended when the participants stated they had learned the orientation of the virtual surround and the protocol did not provide opportunities for the participants for self-reflection.

The low awareness of SRL events observed in the study could possibly be related to the type of think-aloud techniques that was used in the study to collect participants' verbalizations of thought. The concurrent protocol was chosen over the retrospective variant because it had been successfully used in studies of SRL use in hypermedia and because its concurrent approach minimizes inclusion of information about the event that may have been inferred or generated after the event (Gilhooly & Green, 1996). Some studies of VR education applications in virtual worlds such as *Second Life*, however, have asserted that the concurrent protocol is difficult for participants to perform without extensive periods of practice and unduly burdens task performance (Henderson et al., 2010). One approach that might be useful in future studies of VR that use think-aloud protocols would be to use both variants of the protocol in the same study, as Hill and Hannafin (1996) did in their study of learning strategies and metacognition in open-ended hypermedia environments and compare findings observed with the two variants of the protocol.

Conclusion #2

As in the real world, learners combine movement patterns, including the lap, backtrack, tentative start, last chance, and spatial concentration patterns, and learning event categories, including identifying, locating, regulating, and contextualizing, in numerous and diverse combinations during orientation learning in a virtual world.

Analysis of the participants' movements revealed some general patterns when the data were viewed from spatio-temporal, spatial, and temporal perspective, but there was considerable difference even among these same types of patterns and only two of the participants used the same set of general patterns. Likewise, the duration of the sessions varied considerably. Although desktop VR offers only three movement controls (pan, zoom, and tilt) and a single central or egocentric point-of-view perspective, the learner has complete freedom on how and when to to use them when moving about the surround. The study's findings certainly indicate that the participants had multiple approaches on the best way to move around the surround in order to learn the orientation. Similarly, the participants' profiles of the four major identified categories of learning events varied considerably, indicating a large amount of diversity regarding how to process the visual data the learners saw as they moved about the surround.

When the identifying and locating categories were generally dominant, participants strictly focused on learning spatial relationships amongst the object. In other cases, the contextualizing category played a larger role in profile and the session focus turned more towards the participant’s perceptions of the object in the surround and less on learning spatial relationships.

The observed diversity of movement patterns and learning event categories is consistent with other studies that have examined strategies used in open-ended learning. For example, although hypermedia users have a limited (although possibly large) number of choices to make during navigation in comparison to VR systems, the early study of hypermedia learning by Hill and Hannafin (1996) showed that a large number of strategies were used by participants.

The findings of this study in a VR environment and its similarities to results in hypermedia environments suggest that variety and individuality in learning approaches and patterns is common in media-based open-ended environments just as it is the real world. When learners are free to choose their own learning patterns in either technology-mediated or real-world situations, they apparently choose their own strategies and demonstrate individuality.

Conclusion #3

Scene objects possess meaning for orientation learning in virtual environments.

Results of this study, showed that participants were aware of object context within the association category of the identifying category, as well as both of the subcategories of the contextualizing category, interpreting and reacting.

Associations ranged from simple (“I have curtains just like that”, participant P1) to full and description, as illustrated by a participant’s portrayal of a set of decorative horse statues:

> And the wonderful horse statues which from the designs on them they actually look more of the American horse styles, not the ah Japanese war horses which when I first saw them in the uh, picture when I first came up that's kind of what they looked like, those giant horses in front of P.F. Chang's. (participant P15)

The researcher admittedly did not know what was meant by "P.F. Chang's," as it was outside his direct realm of dining experience. Both examples from participants P1 and P15, however, demonstrate that the personal experience of the participants play an important part in interpreting the object in the scene and placing it in a context that has meaning for the participant. Indeed, experience has been an essential component of adult learning and Knowles (1984) placed the role of the learners' experience as one of the six factors that differentiate the andragogical model of learning from its pedagogical counterpart.

There were only a few verbalizations in the interpreting category of the contextualizing category, but they demonstrate how humans cannot resist imbuing objects with meaning beyond their apparent appearance.

> I think this person likes to collect something about ocean because it has ship, some fish, and that's some ocean view. He has collection here, too. (participant P16)

Within the reacting subcategory of the contextualizing category, there were eight types of codes for positive comments and six for negative comments with a total of 34 instances of object attributions classified as having either a negative or positive rating. Recent research in the field of psychology on "micro-valences" (Lebrecht, 2012; Lebrecht, Bar, Barrett, & Tarr, 2012) asserts that everyday objects such as those in the study's virtual surround have an inherent weak valence, either positive or negative, that is a property of the object much like its material or color. Micro-valences are not results of intentional cognitive judgment, but are calculated by the visual system during perception of the object. According to the paradigm offered by micro-valences, the classifications of objects in the reacting subcategory of the contextualizing category might be more appropriately placed in the identifying category indicating that the object's micro-valance was identified by the participant during orientation learning.

The concepts of experience and meaning have not been absent in wayfinding models, but may have been relegated to secondary consideration. Lynch (1960) included meaning, along with identify and structure, as one of the primary components of an environmental feature, but rationalized its deletion from his conceptualization of imageability by stating “Since the emphasis here will be on physical environment as the independent variable, this study will look for *physical qualities* [emphasis added] which relate to the attributes of identity and structure in the mental image” (p. 9). The Arthur and Passini (1992) concept of building memorability also incorporates concepts of meaning by including a building’s historical and cultural context as one of the four constituent factors. Perhaps most obvious of all, the Chen and Stanney (1999) model clearly indicated experience as an “other factor” that provided input to both the cognitive mapping and decision making process. Experience and meaning, therefore, are not new concepts in the domain of wayfinding, and future theoretical conceptualizations of a broader model of orientation learning should consider their roles to be as important as cognitive mapping, movement decision, and SRL. It is also perhaps significant that the role of experience and attaching of meaning to objects in the environment may be as likely in virtual environments as in the real world. This may be another demonstration of similarity of human behavior in the two worlds.

This study supported two additional conclusions regarding the concept of presence (i.e., actually being in a virtual environment) in VR. While examination of the presence concept was not part of the planned research questions for this study, the data was so supportive of presence that it warranted drawing conclusions regarding both its existence and its assessment. As summarized by Ausburn and Ausburn (2010), presence has long been considered critical in VR technology, and has been assessed via quantitative instruments, largely without great success. As reported in Chapter 5of the present study, the data indicated that the participants felt a sense of presence in the VR orientation learning program. Further, this evidence came largely from qualitative data and procedures. The importance of the presence concept in VR and the evidence offered in this study led to two conclusions of importance to VR research. These two conclusions are presented below.

Conclusion #4

Learner thought verbalization during orientation learning indicate attainment of a sense of presence in the virtual environment.

Learner verbalizations that were classified in the associating subcategory of the identifying category as well as the interpreting and reacting subcategories of the contextualizing category, as discussed in the previous section, primarily consisted of cognitive thoughts and affective reactions towards virtual objects. The nature of the verbalizations indicates a degree of learner interaction and involvement with these virtual objects that goes beyond simple identification of objects and determination of the spatial relationships amongst them explicitly identified in the definition of orientation learning. Rather, learners interacted with these virtual objects much like they would have interacted with real objects in a physical room. This type and degree of learner-object interaction indicates that some of the study's participants felt a sense of presence (i.e., a sense of actually being in the place) while using the desktop VR system.

The study had no plan to specifically measure presence in any way, but the evidence of participant presence with the study's desktop VR system, as encapsulated in the think-aloud verbalizations, is clearly evident. This evidence and conclusion are significant, given the importance of the presence concept in VR as a defining characteristic of the technology and its potential as a medium for learning.

Conclusion #5

This study may open the door to advancement of presence research in VR through a qualitative paradigm.

Current practice for measuring presence generally involves asking the learner about the VR experience after exposure through the system through a variety of survey instruments and even physiological evaluations (Ijsselsteijn et al., 2001; Sadowski & Stanney, 2002). This approach has had mixed results, but has to date failed to produce a generally accepted strategy for operationally defining or measuring presence in virtual environments. However, this study may take a step forward in changing the paradigm for VR presence research. The study offers evidence that interpretation of concurrent think-aloud verbalizations may be a simple and effective *qualitative technique* towards identifying sense of presence in desktop VR systems. Although post-session interviews with participants in past studies of orientation learning with desktop VR systems such as the one by Ausburn, Martens, Washington, and colleagues (2009), provided qualitative clues that participants may have felt a sense of presence, they primarily used quasi-experimental, quantitative methodologies that were designed to provide insight into learner performance rather than the process-oriented perspective of the current study. This study demonstrates, as suggested by Ausburn and Ausburn (2010), that qualitative approaches may be the key towards measuring and consequently better understanding the degree of presence inherent in the desktop VR technologies. This change in basic paradigm may represent a turning point in VR research and the documentation and analysis of presence that is critical for the technology but has long puzzled researchers.

Recommendations

Theory

A more complete model of orientation learning would include components that describe the interaction between objects and learner in addition to components of SRL and wayfinding. There are a variety of traditional theory bases, such as adult learning and some wayfinding models, as well as newer ones, such as perceptions of micro-valences in common objects, that may provide a base for further development of this theory. (Conclusion 3).

Research

Increasing metacognitive and SRL awareness in hypermedia has been extensively studied and could serve as a model for further research towards investigating how to increase the awareness in orientation learning. Several participants reported in the study's critical incident interview that they had a difficult time dealing with the complexity of the scene. Helping learners to manage complexity is an area where greater awareness of SRL events may contribute to better outcomes, and further research in this area could identify techniques for increasing this awareness and possibly reduce subsequent cognitive load in participants. A reasonable starting point for this research is to incorporate SRL awareness in presession training. A VR presession training model (Ausburn & Ausburn, 2010) that could be amended to included SRL awareness components that are based on the subcategories found in the regulation category of this study. Research conducted by Burkett (2014) on using this VR training model could serve as a template for such a study and the tutorial software that was developed as part of that study might possibly be modified to incorporate modules for SRL awareness in orientation learning. Following the full path of the hypermedia SRL awareness research past presession training into automated scaffold based prompting such as *MetaTutor* (Azevedo et al., 2009) should be evaluated carefully, however, as this type of development may be expensive and could potentially offset the advantages that desktop VR current possesses in relatively low cost of entry and development. An additional difficulty that might be encountered in developing software scaffolds for desktop VR is the proprietary nature of most of desktop VR systems. (Conclusion 2).

Future process-oriented studies of orientation learning should consider using both concurrent and retrospective think-aloud protocols to reduce the possibility that the low metacognitive awareness level observed in this study is not a measurement effect. (Conclusion 2).

Future studies of VR-based learning that examine aspects of presence should consider concurrent thought verbalizations as possible alternative or supplement to current measurement techniques for identifying participants' sense of presence. (Conclusions 4 and 5).

Practice

Based on the wide variety and movement patterns observed in the study, instructors and facilitators who choose to use desktop-based VR should assume that learners are likely to have a wide variety of ideas and associated techniques on how to best go about orientation learning. Similarly, instructors and facilitators should be aware that learners use a wide variety of techniques, some of which may introduce a degree of contextualization and interpretation, that would not be expected given the literal definition of orientation learning. To the extent possible, instructors and facilitators should creatively exploit this contextualization to create learning opportunities that would not otherwise exist. (Conclusion 1).

Development of software tools for desktop VR systems that could track learner movements would facilitate future research in studying learner behavior in virtual environments. Reports produced from such a tools would be especially useful as stimuli in post-session interviews with participant learners. Although the researcher developed several computer programs that analyzed screen recording video images to extract these types of data and produce associated time series plots, the process required manual processing of intermediate files and did not capture data concerning the learners' operations of the tilt commands. Systems such as the *krpano* VR player supply widgets that can display these data on the system monitor, but this display method distracts from the screen presentation and is so processor intensive that the software developers recommend that it not be used for production situations. An ideal logging tool would record movement data to a file without noticeably increasing response latency. The log data file could then be read by standard plotting software or statistical packages to produce analysis products such as time series plots and summary session reports. (Conclusions 1 and 2).

Concluding Thoughts

Prior to starting this study, the researcher imagined orientation learning in VR as a simplistic and orderly process. Each movement of the mouse and the zoom key would fulfill a specific subgoal in the service of the master goal to produce a near-perfect representation of the physical scene in each learner's memory. Learners' monitoring processes would watch over the situation closely and gently nudge the learner back on process-perfect track when they would detect a wavering commitment to the plan. The reality of virtual reality revealed itself to be totally different than imagined, more hectic and chaotic than the researcher ever thought possible; virtual life is, indeed, a reflection of the disorder of the real world. This context of real-world messiness, however, served as an insightful backdrop for the observation of problem solving, which is exactly how Romedi Passini captured the essence of wayfinding. Some learners were brilliant wayfinders and problem solvers, others struggled. There is much more to learn about what navigators of VR surrounds are thinking about as they solve the problems requisite to learning virtual worlds. This study provides some preliminary hints that the process and environment can be improved to help those who stumble and need guidance, but hopefully this won't impact that authentic messiness, that sense of presence, that provides the setting for learners to develop their problem solving skills.

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APPENDICES

APPENDIX A: SUBJECT RECRUITMENT

Appendix A contains letters from the OSU Institute of Technology and the Tri-County Technology Centers administrators granting the researcher approval to recruit study participants from their institutions, as well as the subject recruitment script that was approved by the OSU Institutional Research Board.

Recruitment Approval: OSU Institute of Technology

OKLAHOMA STATE UNIVERSITY
INSTITUTE OF TECHNOLOGY

Academic Affairs

1801 East 4th Street
Okmulgee, OK 74447-3901

918 293 5260 | 800 722 4471
Fax 918 293 5255
www.osuit.edu

July 11, 2013

Jon Martens
1525 Whiteway Court
Bartlesville, OK 74006

Dear Mr. Martens,

I have reviewed your request to conduct a research study at OSU Institute of Technology, and have approved your request. I look forward to assisting you in any way I can in this study for your dissertation study entitled, "Foraging for Spatial Information in Virtual Environments: A Self-Regulated Learning Perspective."

Per your request, you will be allowed to recruit eight to ten adult students to utilize a virtual reality computer program, which will be provided by you. I understand the protocols and procedures for the human subjects' research will be reviewed and approved by the Oklahoma State University Institutional Review Board to ensure compliance with the established guidelines.

I wish you success in your research and trust you will contact me with any questions or concerns you may have.

Sincerely,

Greg Mosier

Greg A. Mosier, Ed.D
Vice-President
Academic Affairs

create / innovate / educate / Go STATE

Recruitment Approval: Tri County Technology Center

From: **Tammie Strobel** tstrobel@tctc.org
Subject: Permission for Research
Date: September 24, 2013 at 1:51 PM
To: Jon Martens jonmartens@mac.com

Dear Mr. Martens,

The intent of this email is to provide documentation indicating that we have discussed your study "Foraging for Spatial Information: A Self-Regulated Learning Perspective on Orientation Learning". As the principal investigator, you have my permission to recruit adult participants and conduct your research at Tri County Technology Center. I understand the nature of the study and the risks that are involved to the participants.

I wish you all the best in your endeavors and I look forward to reading your results.

Regards,
Tammie Strobel

Tammie Strobel, Ed.D.
Assistant Superintendent for Instruction
918.331.3238
www.tctc.org

Tri County Technology Center
6101 SE Nowata Road
Bartlesville OK 74006

Approved Subject Recruitment Script

Foraging for Spatial Information: A Self-Regulated Learning Perspective on Orientation Learning

Recruitment Script

Jon Martens

Good morning. My name is Jon Martens and I am a doctoral student in occupational education studies at Oklahoma State University. Today I would like to tell you about the research I am conducting for my dissertation and would also like to invite you to consider participating in that research.

I am studying how career and technical education students explore and learn the layout of physical spaces through the use of virtual reality (VR) software. To do this, I ask participants to use virtual reality software to learn the layout of several residential rooms and continuously tell me what they are a thinking while they are using the VR software to perform this learning task. Prior to this session, participants are trained on how to verbalize their thoughts and how to operate the VR software program, including time for practice of the think-aloud technique and the VR software. After the learning session, participants complete a written exercise that evaluates their knowledge of the space the learned by using the VR program. In addition, I ask participants to identify one time during the session where they had a difficult time and ask them several questions about that. Finally, I ask the participants some general demographic information, which I only report in aggregate.

Your participation should take about one hour and is strictly on a voluntary basis. You may freely choose to discontinue your participation at any time. You will not be penalized if you decide not to participate or discontinue participation, nor will you receive any type of award or compensation if you decide to participate. I am looking for about 8 people to participate over the next few days. You must be 18 years of age or older to participate.

By participating in the study, you will provide information that will help researchers and teachers identify areas where VR programs and techniques for using them could be improved. You may also find participation in a computer research study to be an interesting experience.

Do you have any questions about the study or any of the activities that participants are asked to perform during the study?

Thank you for your attention and I hope you will consider participating in the study.

APPENDIX B: IRB APPROVALS

Institutional Research Board Approval

Oklahoma State University Institutional Review Board

Date:	Wednesday, October 09, 2013
IRB Application No	ED13160
Proposal Title:	Foraging for Spacial Information in Virtual Environments: A Self-Regulated Learning Perspective on Orientation Learning
Reviewed and Processed as:	Exempt

Status Recommended by Reviewer(s): Approved Protocol Expires: 10/8/2016

Principal Investigator(s):

Jon Martens	Lynna Ausburn
1525 Whiteway Ct	257 Willard
Bartlesville, OK 74006	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI, advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Cordell North (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Shelia M. Kennison

Shelia Kennison, Chair
Institutional Review Board

Foraging for Spatial Information: A Self-Regulated Learning Perspective on Orientation Learning

Verbal Informed Consent Script and Information Sheet

Jon Martens

Before we begin the study, I would like to explain why I am conducting the research and what I will be doing with the information you provide to me. After you hear the details about the study, you can decide whether or not you would like to participate.

I am doing this research as part of my studies at Oklahoma State University and will be using the data I collect in my Doctoral dissertation. I will be observing how you and about 8 other career and technical education students use virtual reality (VR) software to lean the layout of physical spaces. It is possible that I might use the information from this study as the basis for journal articles or academic conference presentations in the future. The data that I collect from you will be retained for 3 years.

Your participation should take about one hour and is strictly on a voluntary basis. You may freely choose to discontinue your participation at any time. You will not be penalized if you decide not to participate or discontinue participation, nor will you receive any type of award or compensation if you decide to participate. You must be 18 years of age or older to participate.

During this study, you will first be trained on a technique you will use to verbalize your thoughts while you are operating a VR computer program. Next, you will be trained in the operation of the VR program and given some time to practice with the program. You will then use the program to learn the layout of several rooms and the location of objects in the room while telling me what you are thinking. After using the program, you will complete several written exercises that will evaluate you knowledge of the rooms you learned with the VR program. You will also identify a time when you were using the program that seemed especially difficult, and answer several questions about the problems you had at that time. Finally, you will complete a short survey that will ask your gender, VR experience level, birth year, and education level.

You will be exposed to minimal risks during this study, no more than you would expect to encounter in routine daily activities. There are some small risks regarding confidentiality of data that will be controlled, as will be shortly explained. To further protect confidentiality of your data, I will not ask you to sign this agreement, but only provide me with verbal consent.

By participating in the study, you will provide information that will help researchers and teachers identify areas where VR programs and techniques for using them to learn the layout of physical space could be improved.

Your voice will be audio recorded with computer software when you are performing the learning activity with the VR program and telling me what you are thinking. Your voice will also be recorded when you tell me what part of the program caused you difficulty, and answer some questions about that difficulty.

It is possible that someone could use the audio recordings to identify your voice. To minimize this risk, only I (the researcher) will transcribe the recordings into text format. Anything in the recordings that might identify you will not be transcribed. The recordings will be encrypted and the USB flash drives that contain the recording files will be securely stored in a locked cabinet. In addition, the audio recording files will be securely erased after transcripts have been produced.

The actions that you perform with the VR program as displayed on the computer screen will be video recorded with computer software. No identifying information such as an image of your face will be present in this recording because the recording software directly access the data displayed on the screen from the computer's memory rather than using a video camera. I will transcribe the actions you perform into a textual and graphical format, but will retain these video screen capture recordings and may use portions of them in reports of this research.

Other researchers may examine the transcripts and view the video recording to evaluate how accurately and consistently I interpreted the data, but they will not have access to the audio recordings.

A description of the actions that you performed during the learning session, results from written exercises, and portions of what you said during the learning session with the VR program may be included in reports of the research, but will only be associated with an alias such as "P5" that cannot be linked to your identity.

You will answer questions about your VR experience, gender, birth date, and education level. These data, however, will be collected on a form without any identifying information and will only be aggregated with the same data from the other participants to describe the study's sample, such as the number of males and females participating.

Do you have any questions about the study or how the data will be used?

You may contact me, my faculty advisor, or staff at the Oklahoma State University Institutional Research Board (IRB) if you have questions at any time. The contact information is listed below.

If you agree to participate in the study you should retain this information sheet. If you do not agree to participate, please return this sheet to me.

Do you consent to participate in the study?

Contact Information:

Researcher:

Jon Martens
1525 Whiteway Court
Bartlesville, OK 74006
Email: jon.martens@okstate.edu
Phone: (918) 671-1857

Faculty Advisor:

Dr. Lynna Ausburn
257 Willard Hall
Stillwater, OK 74078
Phone (405) 744-8322
Email: lynna.ausburn@okstate.edu

Oklahoma State University Institutional Research Board:

Dr. Shelia Kennison
IRB Chair
219 Cordell North
Stillwater, OK 74078
Email: irb@okstate.eud
Phone: (405) 744-3377

Institutional Research Board Protocol Modification Approval

Oklahoma State University Institutional Review Board

Date:	Monday, February 23, 2015	Protocol Expires:	10/8/2016
IRB Application No:	ED13160		
Proposal Title:	Foraging for Spacial Information in Virtual Environments: A Self-Regulated Learning Perspective on Orientation Learning		
Reviewed and Processed as:	Exempt **Modification**		

Status Recommended by Reviewer(s) **Approved**

Principal Investigator(s):

Jon Martens 1525 Whiteway Ct Bartlesville, OK 74006	Lynna Ausburn 257 Willard Stillwater, OK 74078

The requested modification to this IRB protocol has been approved. Please note that the original expiration date of the protocol has not changed. The IRB office MUST be notified in writing when a project is complete. All approved projects are subject to monitoring by the IRB.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

The reviewer(s) had these comments:

Modification to add two additional personnel to assist in transcribing the recordings and four graduate students to assist in coding the de-identified transcripts. All will sign a confidentiality agreement.

Signature :

Hugh Crethar, Chair, Institutional Review Board

Monday, February 23, 2015
Date

APPENDIX C: ORIENTATION LEARNING EXERCISE

Foraging for Spatial Information: A Self-Regulated Learning Perspective on Orientation Learning

Orientation Learning Exercise

This exercise is designed to see how much you learned about the house scene you studied in the computer-based activity you have just completed. Please answer EVERY question, even if you are not sure of the answer.

Subject Alias:

Part I

Instructions

For this part of the exercise, you will be asked about the position of objects in the house scene. Please choose your answer and draw a circle around its letter.

1. The fireplace in the living room is located on the same wall as the:
   A. Entryway from the hall
   B. Large window
   C. Piano
   D. Sofa

2. You are standing facing the large window in the living room. The dining room is located:
   A. Behind you
   B. Out of your sight
   C. To your left
   D. To your right

3. You are standing in the center of the living room facing the dining room. The fireplace is located:
   A. Behind you
   B. In front of you
   C. To your left
   D. To your right

4. You are sitting on the sofa in the living room with the large window directly behind you. The entryway from the hall is located:
   A. Behind you
   B. In front of you
   C. To your left
   D. To your right

5. You are playing the piano. The dining room is located:
   A. Behind you
   B. In front of you
   C. To your left
   D. To your right

6. You are standing in the living room. A small table and 2 matching green chairs are located between the:
   A. Entry hallway and the fireplace
   B. Fireplace and the sofa
   C. Grandfather clock and the piano
   D. Piano and the entry to the dining room

7. In the dining room, the 2 china cabinets are located:
   A. On adjoining walls, immediately next to each other
   B. On opposite walls, across the room from each other
   C. On the same wall, immediately next to each other
   D. On the same wall, but not immediately next to each other

8. You are sitting at the head of the dining room table facing a half-wall with spindles. The living room is located:
   A. Behind you
   B. In front of you
   C. To your left
   D. To your right

9. You have entered the front door, walked across the entry hall, and are stepping into the living room. What do you see ahead of you at the far end of the room?
   A. Entry to dining room
   B. Fireplace
   C. Large window
   D. Piano

10. You are standing in front of the large window in the dining room, looking out. The dining table is located:
   A. Behind you
   B. In front of you
   C. To your left
   D. To your right

11. You are looking at the grandfather clock. It is located next to the:
   A. Entry to the dining room
   B. Larger china cabinet
   C. Piano
   D. Sofa

12. You are in the living room looking up a word in the large open dictionary on a stand. You are standing next to the:
    A. Fireplace
    B. Grandfather clock
    C. Piano
    D. Sofa

13. You are looking at a matched pair of green statues of horses. They are located on the
    A. Dining table
    B. Fireplace step
    C. Living room coffee table
    D. Table in front of the dining room window

14. You are looking at the 2 carved giraffe figures. They are located next to
    A. The piano
    B. A world globe
    C. The fireplace
    D. A china cabinet

15. You are looking at a large silver candelabrum. It is located on the
    A. China cabinet top
    B. Fireplace mantle
    C. Piano
    D. Small table next to the sofa

STOP!

STOP when you have completed this part of the exercise! Tell the researcher you have finished and put down your pen or pencil.

For this part of the exercise, you will be timed. When you are told to begin, pick up your pen/pencil and list on the next page as many items as you can remember being in the rooms you have studied.

List a single item per line.

Do NOT list large items of furniture.

You have 1 minute and will be told when to stop

LIST ITEMS BELOW:

STOP!

STOP when you have completed this part of the exercise! Tell the researcher you have finished and put down your pen or pencil.

Part III

1. Please choose the answer below that best describes how confident you feel that you have a clear understanding of the details of the scene you have studied and have accurately answered the questions in this exercise. Circle your answer.

   A. I have absolutely no confidence in my understanding of the scene's details and the accuracy of my answers
   B. I have a little confidence in my understanding of the scene's details and the accuracy of my answers.
   C. I have moderate confidence in my understanding of the scene's details and the accuracy of my answers.
   D. I have good confidence in my understanding of the scene's details and the accuracy of my answers.
   E. I have absolute certainty in my understanding of the scene's details and the accuracy of my answers.

2. Please choose the answer below that best describes how difficult you feel learning about the orientation of the rooms and answering the questions on this exercise have been. Circle your answer.

   A. This experience has been extremely easy for me.
   B. This experience has been easy for me.
   C. This experience has been a little difficult for me.
   D. This experience has been difficult for me.
   E. This experience has been very difficult for me.

APPENDIX D: DEMOGRAPHIC QUESTIONNAIRE

Foraging for Spatial Information: A Self-Regulated Learning Perspective on Orientation Learning

Demographic Questionnaire

1. What year were you born?

For each of the following questions, please circle the appropriate answer.

2. What is your gender?
   A. Female
   B. Male

3. What is the highest education level you have attained?
   A. Did not complete high school
   B. High school diploma
   C. Associate's degree
   D. Bachelor's degree
   E. Graduate degree

4. How often have you used VR applications before today?
   A. Never
   B. Between 1 and 5 times
   C. Between 5 and 10 time
   D. More than 10 times

APPENDIX E: VR SCENES

Figure E1. VR training scene.

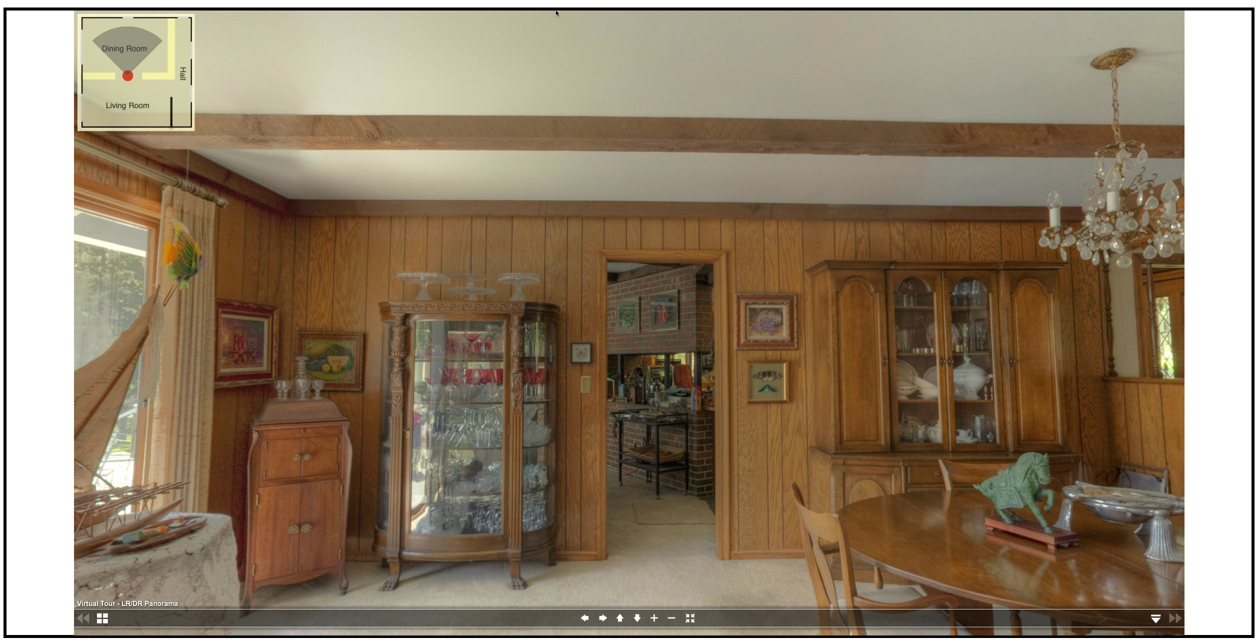

Figure E2. VR orientation learning scene.

APPENDIX F: PROTOCOL FOR DATA COLLECTION

Foraging for Spatial Information: A Self-Regulated Learning Perspective on Orientation Learning

Protocol for Data Collection

Jon Martens

Setup

Assumptions

- ✓ The participant has provided consent to participate in the research.
- ✓ Hardware and software are setup and configured
- ✓ Instruments and supplies are available

Hardware

- ✓ MacBook Pro laptop computer
- ✓ Bluetooth wireless keyboard
- ✓ Bluetooth wireless mouse
- ✓ AC power adapter
- ✓ Microphone
- ✓ Dell 27” LCD computer monitor
- ✓ Thunderbolt cable and adapter (monitor to MacBook Pro)
- ✓ USB 2.0 type A/B cable (microphone to MacBook Pro)
- ✓ USB 8-GB (or larger) flash drive(s) formatted for encryption
- ✓ Stopwatch

Software

- ✓ krpano Tools and Viewer (version 1.16.6 or later)
- ✓ Telestream ScreenFlow (version 4.0 or later)
- ✓ Mac OS X operating system (10.8.4 or later)

System Configuration

- ✓ VR userid available and logged on
- ✓ No network cabling attached

- ✓ WiFi disabled
- ✓ Bluetooth enabled for wireless mouse and keyboard
- ✓ 2560 x 1440 monitor resolution.

Instruments

- ✓ Subject Alias Sheet (for researcher use only)
- ✓ Orientation Learning Exercise booklet (one per subject)
- ✓ Demographic Questionnaire (one per subject)

Supplies

- ✓ Blank paper for optional subject notes (See Critical Incident Identification Section)
- ✓ Pencils

Research Protocol Scripts

Script Notation Key
Researcher directions to participant
[Researcher note, action, or instruction]
{Participant reply or action}

Introduction

Thank you for participating in the study. Before we start, let me review the major activities that I'd like you to perform during the study.

Basically, the study will examine how students learn to orient themselves to an environment - such as a physical space consisting of several rooms - by learning the layout and the location of objects though the use of a virtual reality, or VR, computer program.

In order for me to know how you learn, you will let me know what you are thinking as you are going about exploring and learning an environment. Our first activity, therefore, will be practice a technique you'll use for telling me what you are thinking when you are performing an activity.

In the second activity I'll show you how to operate the VR system you will be using. You will then be able to practice using the system.

The third activity is the heart of the study. You will use the VR system to learn an environment - a residential living and dining room - while you are telling me what you are thinking throughout the process.

For the fourth activity, you will complete a brief written exercise that will ask you questions about the layout of the environment and its objects.

During the fifth activity I'll ask you to identify a time during the session where you may have had some difficulties and ask you a few questions about those difficulties

And finally, for the sixth and final questions, I'll ask you a few demographic questions such as your gender, education level, and year of birth.

I will provide full instructions for each activity as we proceed through the study. Before we start, do you have any questions?

{Replies Yes or No}

[If subject replies "Yes," probe if necessary to answer question and resolve issue.]

Okay, if you have no further questions, let's get started.

Think-Aloud Protocol Training

During the study, I will ask you to use a VR computer program to learn the layout of the room, including the location of objects in the rooms. You may do this in whatever way makes most sense for you. While you are doing this, I want you to continuously tell me what is going through your mind. I may remind you to "keep talking" from time-to-time during this process if you stop talking for more than about 5 seconds. You will get a chance to practice this shortly.

This process is probably new and unfamiliar to you, but please know there are no wrong answers. I am only interested in knowing what is going through your mind in the present moment. Do you understand the general idea of what I will ask you to do?

{Replies Yes or No}

[If subject replies "No", researcher clarifies technique].

Okay, very good. Now, let's practice this technique now with a warm-up exercise. This isn't really part of the study, but is just to help you become familiar and comfortable with the technique.

Try to visualize the place where you live and think about how many windows there are in that place. As you count the windows, tell me what you are seeing and thinking about.

{Subject replies with think-aloud exercise}

[If subject stops talking for more than 5 seconds]: Keep talking

[Researcher evaluates subject response to ensure that the response is concurrent and not reflective in nature, and may provide additional guidance in that area and request the exercise be repeated.]

Now, let’s move on to the next activity to show you how the VR system works and let you practice the program.

VR Interface Training

As I previously mentioned, you will be using a VR computer program to explore and learn the layout of some rooms. Now, I'll introduce you to the interface controls of the VR program and demonstrate how to use them, and then let you practice what I've shown you.

Before we start taking about the mechanics of the programs, let's briefly discuss the concepts behind the controls. They should be very familiar to you.

Imagine that you are in the center of a room looking at a particular object, say a picture hanging on a wall. If you wanted to look at the picture to see the details, you would move closer it. To see the entire picture, and perhaps other objects next to it, you might move away from the picture.

[Lean body back and forth in chair to demonstrate.]

The action of moving closer to an object is called a zoom-in and the action of move away from an object is called a zoom-out.

To see other objects in the room you could rotate your head and body to the right or left.

[Move head right and left to demonstrate.]

These actions are called pan right and pan left.

You could also move you head up or down to get a better look at objects that are not in your direct line of sight.

[Move head up and down to demonstrate.]

The actions of moving you head up and down are called a tilt up and tilt down.

Of course, you can also combine these movements of zoom, pan, and tilt, and you probably do so quite unconsciously and naturally when viewing a room. The VR interface controls essentially allow you to simulate these actions on the computer display.

Let's see how these actions are controlled in the program. I'll demonstrate the controls and then you can have as much time to practice as you need.

[Launch VR training scene by double clicking on the TrainingSession icon. Place the scene in full screen mode by right clicking on scene and selecting “Fullscreen.”]

Here we see a scene that has a picture hanging on a wall. Notice these icons at the bottom of the screen - they are the controls for the VR program that allow you to perform the actions I just told you about.

[Point to controls on screen with cursor.]

The control to zoom-in is the plus sign, and the control to zoom-out is the minus sign. Clicking on the plus sign zooms-in the image...

[Click on plus sign to demonstrate zoom-in.]

... and clicking on the minus-sign zooms out the image.

[Click on minus sign to demonstrate zoom-out].

You can also hold down the mouse button over the plus or minus signs to continuously zoom-in or out. Release the button to stop the action.

[Hold down mouse button on plus and minus signs in turn to demonstrate continuous zoom-in and zoom-out.]

The controls to pan are the right and left arrows. To pan to the right, click on the right arrow...

[Click on right arrow to demonstrate pan right.]

…and to pan to the right click on the left arrow.

[Click on left arrow to demonstrate pan left.]

Just like the zoom controls, you can also hold down the mouse button over the right or left arrow to continuously pan right or left. Release the button to stop the action.

[Hold down the mouse button on right and left arrow buttons in turn to demonstrate continuous pan right and pan left.]

The controls to tilt, as you might expect, are the up and down arrows. To tilt up, click on the up arrow...

[Click on up arrow to demonstrate tilt up.]

…and to tilt down, click on the down arrow.

[Click on down arrow to demonstrate tilt down].

As with the other controls, you can hold down the mouse button over the up or down arrow to continuously tilt up or down. Release the button to stop the action.

[Hold down the mouse button on the up and down arrow buttons in turn to demonstrate continuous tilt up and tilt down.]

There is one more very useful control that returns you to the view that is displayed when the VR program starts. First you click on the "window pane" icon on the left portion of the menu. This action brings up a thumbnail image of the starting VR scene. You can then click on the thumbnail to reset the scene to where it was when the VR program was started.

[Click on window pane and then click on thumbnail to demonstrate returning to the start scene state.]

Finally, you can also make the palette of control icons disappear totally from the scene by clicking on the down-facing triangle at the far right end of the palette.

[Click on the down-facing triangle.]

Notice how the down arrow has change to an up arrow. To restore the palette, click on the up-facing triangle.

[Clicking up-facing arrow]

There is another way to use the mouse and keyboard to control your actions in the VR scene. Let's go over the operations with the mouse only mode.

You zoom-in with the shift button on the keyboard …

[Press shift key to demonstrate zoom-in.]

… and zoom-out with the command key.

[Press command key to demonstrate zoom-out.]

You can hold those keys down to perform a continuous zoom-in or zoom out.

To pan with the mouse, hold down the mouse button and move it in the right or left.

[Hold down mouse button and move mouse right and left to demonstrate pan right and pan left]

To tilt with the mouse, hold down the mouse button and move it towards you to tilt down or away from you to tilt up, like this.

[Hold down mouse button and move mouse back and forth to demonstrate tilt.]

So far, the mouse actions mimic those of the icon controls. The advantage of the mouse is that you can combine pan and tilt by holding down the mouse button and moving the mouse on the diagonal. By moving the mouse at different angles you can control the degree of pan and tilt.

Movements towards the back and forth direction have more of an effect on tilt than pan...

[Hold down mouse button and demonstrate movement with mostly tilt.]

…while movements right to left have more pan than tilt...

[Hold down mouse button and demonstrate movement with mostly pan]

… and a diagonal movement has about the same degree of pan and tilt.

[Hold down mouse button and demonstrate movement with approximate same degree of pan and tilt]

Sounds complicated, but it's actually quite a natural movement after just a little practice.

I'd like to explain one more thing before you practice using the program. You may have noticed a graphic in the top-left corner of the display. The graphic represents a "birds-eye" view or map of the room. A red circle in the middle of the map marks your position in the room. The cone that originates from the red circle indicates the part of the room scene that is currently displayed on the computer monitor, essentially marking the areas that you are looking at.

As you pan around the scene, you can see the cone moves to track where you are currently looking in the room, like this…

[Pan right to left and back to show how cone move.]

As you use controls to zoom in and out, you will also notice that the shape of the cone changes. When you zoom in the angle of the cone narrows to show a decreased field of view…

[Click on up arrow to reveal icon menu and zoom in with the plus icon to demonstrate how cone shape changes.]

… and when you zoom out the angle of the cone widens to show an increased field of view.

[Click on the minus icon to demonstrate how cone shape changes.]

You can also so use the radar device to pan around the room. If you click on the cone, you can drag it and rotate it around the red circle. As you drag the cone, the displayed room scene changes to match the location of the cone.

[Click and drag radar cone clockwise and counter-clockwise to demonstrate how room scene changes].

That's all the ways you can navigate around the room with the VR interface controls. You can use them in any combination you want. It's up to you to decide what you feel most comfortable with.

Now it's your turn to try out the system. Go ahead now and try out the controls so you feel comfortable operating the program. Let me know if you have questions. Take as much time as you need up to 15 minutes. Let me know when you think you've had enough practice to feel comfortable operating the program and are ready to start the orientation learning session.

I'll set the VR program to its starting point and then let you try it out.

[Return VR scene to start position and hand over system to subject]

[Starts stopwatch]

{Practices using VR controls and possibly asks questions}

[Answer questions regarding the use of interface controls]

{Tells researcher practice is complete}

[If the subject is still practicing at 15 minutes]: Your 15-minute practice time is up; we need to move on to complete the study in the scheduled time.

[Stop and reset stopwatch]

You have completed all the training you need for the study, so now we are ready to start the actual study.

Orientation Learning Session

In this activity, you will use the VR system to learn the layout of two adjacent rooms – a living room and dining room and the location of objects in that room. There is no single right way to accomplish this. Navigate around the rooms with the VR system at whatever pace and in whatever way you feel is best for you to learn the rooms.

As you are using the system I want you to verbalize your thought, just like in the practice session you completed earlier. If you are stop talking for more than about 5 seconds, I will remind you to "keep talking. I will be recording what you are saying, so please speak clearly. I will also be making video recording the computer desktop to see how you navigate within the VR program. I will not be making any video recordings of your face or body.

You will have a maximum of 30 minutes for the session. If needed, I'll warn you when there are 2 minutes left in the maximum time limit. Let me know when you think you have learned the layout of the room well enough to answer questions about the orientation of the room and the location of objects within the room.

Do you have any further questions before you start the learning session?

{Replies Yes or No}

[If participant replies "Yes," probe if necessary to answer question and resolve issue.]

First I will setup the system for recording.

[Click on the ScreenFlow icon and select check boxes to record audio and desktop. Do NOT check video.]

As you can see, I will be recording audio and desktop capture only, and not any video of you.

[Point to ScreenFlow recording options panel with mouse pointer to illustrate]

Now, I'll start the VR program for you, so you will be ready to go.

[Start the VR scene by clicking on the LearningSession icon. Place the scene in full screen mode by right clicking on scene and selecting "Fullscreen."]

Okay, I am going to start the recording now and then hand the system over to you. You will see a 5-4-3-2-1 second countdown displayed on the screen. At the end of the countdown you can start the learning session. Remember to tell me when you are done and remember to keep verbalizing your thoughts. Take as long as you need up to the maximum time limit of 30 minutes.

[Start ScreenFlow recording session (command-shift-2)]

[Start stopwatch]

{Conducts orientation learning and tells researcher when done}

[If the subject has not finished the orientation learning session after 30 minutes]: Your 30-minute session time is up; we need to move on to complete the study in the scheduled time.

[Stop ScreenFlow recording session (command-shift-2). Identify the next available alias in the Subject Alias Sheet list and write a check mark to indicate it is being used. Save the recording file for this activity to USB flash drive as "<subject alias> ls".]

[Stop and reset stopwatch. (Time for session will be available from recording files).]

Orientation Learning Exercise

Next, you will complete a written exercise based upon the VR orientation session you just finished. I'll give you a booklet that you will use during this exercise to record your answers. Do not turn the first page until I tell you.

[Write subject alias on front of the Orientation Learning Exercise and place the booklet and pencil on the table for the participant.]

There are three parts to the exercise. You will complete one section at a time. I will explain each section to you and review the instruction before you begin each section. You will have the opportunity to ask questions prior to starting each section if you are unclear regarding instructions.

Okay, you can turn the front cover page of the exercise and review the instructions along with me.

{Turns cover page}

In the first part of the exercise, you will answer 15 multiple choice questions about the position objects in the VR living and dining room scene. Be sure to answer all 15 of the questions. Select only one answer for each question and circle the answer in your booklet.

At the end of the questions there are instructions to STOP, written in large, bold letters. Do not proceed to the second part of the exercise. Let me know when you have completed the questions.

You have up to 15 minutes to complete the section. I will notify you when there are 2 more minutes left if you are still working on the section at that time.

Do you have any questions about the exercise instructions?

{Replies Yes or No}

[If participant replies "Yes," probe if necessary to answer question and resolve issue. Answer only questions about protocol procedures.]

Are you ready to start?

{Replies Yes or No}

[If participant replies "No," probe if necessary to answer question and resolve issue. Answer only questions about protocol procedures. Verify the participant's readiness to continue after answering questions.]

Okay, you can now turn the page and start answering the questions. Be sure to answer all the questions and let me know when you are done.

{Turns page and start exercise}

[Start stopwatch]

{Completes Part I questions and notifies researcher}

[If the subject is still answering questions at 15 minutes]: Your 15-minute time to answer questions is up, we need to move on to complete the study in the scheduled time. Please place your pencil down.

[Stop and reset stopwatch.]

Okay, we are now ready to complete the second part of the exercise. You can now turn the page of the booklet to read the instructions for Part II along with me.

{Turns page}

This is a timed exercised. In one minute, you will write down the names of as many objects from the VR living and dining room scene as you can remember. Do not list large pieces of furniture such as sofas, tables, chairs, or cabinets. Write one object per line on the page.

At the end of the list there are instructions to STOP, written in large, bold letters. Do not proceed to the next part of the exercise.

Do you have any questions about the exercise instructions?

{Replies Yes or No}

[If participant replies "Yes," probe if necessary to answer question and resolve issue. Answer only questions about protocol procedures.]

Are you ready to start?

{Replies Yes or No}

[If participant replies "No", probe to answer question and resolve issue. Answer only questions about protocol procedures. Verify the participant's readiness to continue after answering questions.]

Remember that you have just one minute to complete the list. Time starts when you turn the page upon my instructions. Okay, you can now turn the page and start writing down the objects on the next page.

{Turns page}

[Start stopwatch]

{Lists objects for one minute in booklet}

[Stop stopwatch after 1 minute]

Time is up. Please stop writing and place your pencil down.

Okay, we are now ready to complete the last part of the exercise. You can now turn the page of the booklet to read the instructions for Part III along with me.

In this section, you will answer two multiple-choice questions about how confident you felt during the learning session and this exercise and how difficult you found the learning session and exercise.

Answer both questions and select only one answer per question. Circle the answer you feel best describes your perceptions of confidence and difficulty.

Do you have any questions about the exercise instructions?

{Replies Yes or No}

[If participant replies "Yes," probe if necessary to answer question and resolve issue. Answer only questions about protocol procedures.]

Okay, you can turn the page and answer the two questions. This should only take you a few minutes to complete. When you are done, return the exercise booklet to me.

{Completes question and returns booklet to researcher}

Critical Incident Identification

In this next activity, I would like to ask about some of your experiences with the VR learning session. In particular, I would like to focus on where you might have encountered difficulties or problems using the VR program to learn about the living and dining room scene.

Please think back on the VR orientation earning session and try to identify a time or event that you found particularly difficult or confusing. Once you've identified that event, I'll be asking you to describe and briefly discuss that event with me.

You can use the recording that was made during the learning session to help you play back the session recording and identify the area where you may have had difficulty. Let me show you how to do that.

[Start ScreenFlow and open the session screen recording made in the Orientation Learning Session activity.]

It's really quite easy, just like playing a video. You use the forward, backward, and stop playback control icons to review the recording to help you identify where you may have encountered the most difficulty. Let me just quickly show you how this works.

[Demonstrate the forward, backward, and stop buttons]

You can also drag the time line control to move through the recording, like this.

[Demonstrate the time line control]

Now I'd like you to review the recording so you can identify that one point where you think you had the most difficulty. Let me know when you have found that point.

There's some paper and pencil here if you want to take notes. It's up to you. Any notes you take are for your own use – I won't be looking at them or collecting them.

[Show participant paper and pencil.]

Do you have any questions about viewing the recording or what I am asking you to identify?

{Replies Yes or No}

[If participant replies “Yes”, probe if necessary to resolve situation. Answer only questions about protocol procedures. Avoid prompting or suggestions regarding what events to identify as critical incidents.]

Go ahead and review the recording and let me know when you have found the incident that caused you the most difficulty.

{Uses computer ScreenFlow program to review recording and informs researcher that incident has been identified.}

Now I’d like to ask you a few questions about the incident. I will turn on the recording software to ensure I accurately capture your answers. If needed, you can continue to use the playback controls to refresh your memory of the session to help you answer the questions. You could also refer to notes you made earlier.

[Select ScreenFlow recording icon and set parameters for desktop & audio recording. Do NOT set for video recording.]

As you can see on the display, I will record our conversation and capture any actions you make on the computer desktop, such as playback of the learning session recording.

[Point to ScreenFlow recording options panel with mouse pointer to illustrate]

Are you ready?

{Replies Yes or No}

[If participant replies “No”, probe if necessary to answer question and resolve issue. Answer only questions about protocol procedures. Verify the participant’s readiness to continue after answering questions.]

Okay, I am going to start the recording now and ask you questions about the incident that I would like you to answer.

[Start ScreenFlow recording session (command-shift-2)]

What was the time of the incident on the elapsed video timer?

{Reply}

How would you describe the incident?

{Reply}

Why was this a difficult situation for you?

{Reply}

What were you trying to do at the time?

{Reply}

What was the severity of the problem?

{Reply}

How did this event impact or change the remainder of your learning session?

{Reply}

Were you able to solve or work around the problem?

{Reply}

Okay, thanks for your insights into the orientation learning activity. We are almost done; there is just one more short activity to complete.

[Stop the ScreenFlow recording session (command-shift-2) and save the recording file for this activity to USB flash drive as “<subject alias> ci”.]

Demographic Survey

I would like to collect some demographic data from you that I can use to characterize the entire sample of study participants. This data will only be aggregated with the same type of data from the other study participants and will never be reported on an individual basis. You will not be able to be identified by anyone through these data.

[Give Demographic Questionnaire to participant. Do NOT write subject alias on the sheet.]

Please complete each question in the survey. Write in your birth year and select one answer from each of the remaining question about gender, education level, and VR experience. Circle your answers.

{Completes survey and returns it to researcher}

Wrap Up

Okay, that completes all the research activities. Thank you for participating in this study. Do you have any additional questions for me?

{Replies Yes or No}

[If subject replies "Yes", answer any questions as accurately as possible].

If you think of other questions about this research study, you have contact information on the consent information sheet that I gave you at the start of the session.

APPENDIX G: COMPUTER PROGRAM DESCRIPTIONS

This appendix describes the researcher-developed programs that were used to collect participant movement data from the ScreenFlow recordings of the study's orientation learning sessions. The programs are designed to be executed in order of Program1, Program 2, and Program 3 to process the recording of each participant in the study. Output from Program 1 is used for input to Program 2, and output from Program 2 is used as input for Program 3. Program 4 is not executed directly, but provides computational services to Program 3. Program 1 was written in AppleScript language, whereas the remaining three programs were written in the Java programming language. All programs were executed on the Mac OS X operating system.

Program 1: Extract Frame by Seconds

Purpose

The purpose of this program was to extract every 30th frame (corresponding to one second intervals) from the session recording file that was created by the ScreenFlow program during a participant's orientation learning session.

Assumptions

The program assumed that ScreenFlow was configured to record at the default rate of 30 frames per second.

Input

The input for the program was the ScreenFlow recording of the orientation learning session for a participant. The recording files had been saved with names such as *P1_ls.scc*, indicating that this file contains the recording for participant P1's learning session.

Processing

ScreenFlow does not have a set of built-in Apple Events that an AppleScript program can use to directly invoke ScreenFlow functions, but an AppleScript program can use the AppleScript System Event suite to simulate mouse selection actions and keystrokes directed to the ScreenFlow GUI interface. First, the AppleScript program prompted for the participant id from the keyboard, and then requested ScreenFlow to open the file that was recorded for the specified participant during an orientation learning session. Next, the program read the displayed duration of the recording from the ScreenFlow GUI display, converting the minutes and seconds format (e.g. 3:46) to total seconds. The program next started the main loop, which incremented a time variable from zero to the total number of seconds in the recorded session. The actions that were issued by the AppleScript program within the loop body include the following:

(1) Positioned the current recorded frame to match the value of the time variable. If the time variable was zero, the program simulated a mouse click on the *Start Project* button of the ScreenFlow GUI to position the first frame in the recording as the current frame. If the the time variable was equal to the total number of seconds, the program simulated a mouse click on the *End Project* button to position the the last frame in the recording as the current frame. Otherwise, the program simulated 30 consecutive mouse clicks of the *Next Frame* button to advance the current frame to the next second.

(2) Simulated a mouse click to the *File* > *Save Frame As* ScreenFlow menu command, which saves the current frame into a specified PNG file. As a result of this action, ScreenFlow displayed a file save dialog that requested the path of the output file where the frame is to be saved.

(3) Simulated keystrokes that completed the file save dialog box with the pre-determined directory name and a file name constructed from the participant id and value of the current time variable.

(4) Simulated a mouse click on the *Save* button in the file save dialog box to save the current frame to the specified file.

(5) Paused for several second to ensure that the file save action had completely finished.

After the main loop terminated, the AppleScript program simulated mouse clicks to the ScreenFlow GUI menus that requested it to close the current recording file and, finally, to quit.

Output

The program produced multiple PNG files that each contain a recorded frame selected from the recording at one second intervals.

Program 2: Extract Radar

Purpose

The purpose of this program was to copy the radar widget image in each recorded frame file of a participant's session to separate files for further processing.

Assumptions

The program assumed that PNG files of session recording frames for a participant, one for each second of the participant's elapsed session time, had been created and were residing in a pre-determined directory location. Each file name consisted of the participant id followed by the elapsed time the frame was recorded in minutes and seconds. For example, file *P1_3_4.png* was the frame image for elapsed time 3 min, 4 s in PNG format. Output files were written to a pre-determined directory that has been created.

Input

Inputs included the participant id, the input directory name, the output directory name, the minute and second of the last recorded frame in the session.

Processing

The program first calculated the total number of seconds in the session from the minute and second of the last recorded frame. The following steps were executed in a loop, incrementing the current second from zero to the total number of seconds:

1. Constructed the input file path from the input directory, participant id, and the minute and second corresponding to the current second.

2. Read the input file from the path constructed in step 1 into a buffered image. Note: a buffered image is an in-memory representation of that data contained in a PNG image file.

3. Copied a 270 square pixel area that encompasses the radar widget area from the buffered image created in step 2 to a new buffered image.

4. Wrote the newly created buffered image copy to an output file with a path constructed from the output directory, the participant id, and the minute and second corresponding to the current second.

Output

Outputs of the program were a set of PNG image file that contain the radar image, one for each second of the participant's elapsed session time. Each file name consisted of the participant id followed by the elapsed time in minutes and seconds the radar widget image was recorded. An image of a typical output file is shown in Figure G1.

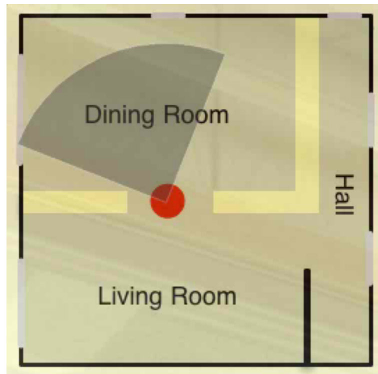

Figure G1. Output file from program 2.

Program 3: Insert Recording Snapshot By Participant

Purpose

The purpose of this program was to calculate the FOV and heading for each radar widget image file of a participant's session and insert that data in a data base.

Assumptions

This program used the services of Program 4 to calculate the FOV and heading values for a single radar widget image file. To ensure proper operation of Program 4, the files produced by Program 2 that constituted Program 3's input were edited to mark the shaded sector of each radar widget image as transparent by using the instant alpha tool of the Mac OS X Preview program. Further details are documented in the Processing section of Program 4. The program also assumed that the output data base has been created but did not contain data.

Input

Inputs included the participant id, the input directory name, the output directory name, the minute and second of the last recorded frame in the session in the session, and the name of the output data base.

Processing

The program first calculated the number of seconds in the session from the inputs of the minute and second of the last recorded frame. The following steps were executed in a loop, incrementing the current second from zero to the total number of seconds:

1. Constructed the input file path from the input directory, participant id, and minute and second corresponding to the current second.

2. Read the input file from the path formed in Step 1 into a new buffered image.

3. Used the Radar Position program to calculate the FOV and heading for the buffered image that was created in Step 2.

4. Inserted the FOV and heading data, along with the participant id and the current second, into the data base.

Output

The data base was updated with the FOV and heading for each second of a participant's session.

Program 4: Radar Position

Purpose

The purpose of this program was to calculate the FOV and heading values from a single radar widget image file.

Assumptions

A potential basic approach of this computer program is to locate the boundaries of the radar widget's shaded sector and calculate the FOV and heading from the angles the boundary lines form with a local xy-coordinate system centered at the apex of the sector. One way of locating the boundary angle is to incrementally rotate a ray of fixed length anchored at the center sector a fixed angular distance from a known starting point. At the end of each rotation and the color of the pixel at the end of the ray would be compared with with the color of the pixel at the ray's previous position. A change in pixel color from the color of the non-shaded area to the color of the shaded area (or vice versa) would indicated that the last incremental rotation of the ray had crossed a boundary. The angle of the boundary line would then coincide with the known angle of the test ray. Unfortunately, the colors of the shaded area and non-shaded areas are not a consistent solid color because the VR system renders the radar widget on the computer screen as a partially transparent image layered over the current VR scene. The image of underlying scene can be noted by carefully examining the radar widget in Figure G1.

Pixels in the shaded sector area of the radar widget can be made reliably distinguishable from other parts of the radar widget image, however, by marking the area as totally transparent, a common function of image editing programs. The basic approach to finding the boundary angles remains, but the program test for transparency changes rather than color changes Each output file produced by Program 2, therefore, was edited with the *instant alpha* tool of the Mac OS X Preview program to mark the shaded sector of each radar widget image file as transparent.

The program assumed that the center of the radar widget image is always located 142 pixels below the top edge of the image and 116 pixels to the right of the left edge. This location serves as the center point for a Cartesian xy-coordinate system used to perform trigonometric calculations within the program.

Input

The program's single input was the buffered image of a radar widget.

Processing

First, the program examined a pixel that is arbitrarily located at the end of a 100-pixel long ray that is anchored at the sectors apex and located at a 90º angle from horizontal. The tested pixel's x and y coordinates in the radar widget image were calculated by multiplying the length of the ray (100 pixels) by the cosine and sine trigonometric functions, respectively, of the ray's rotated angle. If the pixel at the location was transparent, the staring position was within the shaded sector; otherwise the starting position was outside the shaded sector.

If the starting position was in the shaded sector, the program commenced a search process that incrementally rotates the ray one-degree counter clockwise, calculated the x and y coordinates of the pixel at the end of the ray, and then tests the pixel for transparency. The program continued the search process until the rotated pixel tests as not transparent, indicating a rotation had crossed the boundary line and moved out of the shaded The angle of the prior rotation was saved in a variable called *theta1*. A similar search process found the other boundary edge of the sector area by restarting at the original position and rotating in the clockwise direction. The angle of that prior rotation was saved in a variable called *theta0*.

If the starting position is not in the shaded sector, then the test ray was rotated one degree clockwise, the x and y coordinates of the pixel at the end of the ray were calculated, and that pixel was tested for transparency. The program continued to search until the pixel at the end of the rotated ray tested as transparent, indicating a boundary edge had been passed and the position was now in the in the shaded sector. The prior angle of rotation was saved in a variable called *theta1*. The search then continued in the clockwise direction within the shaded sector area until the pixel at the end of the ray tested as not transparent, indicating that the sector's other boundary edge has been passed. The angle of that prior rotation was saved in a variable called *theta0*.

Given the *theta0* and *theta1* angles, as seen in Figure 2, FOV is calculated as their absolute difference, and heading is calculated as the sum of *theta0* plus one half of the FOV. Calculation of the FOV and heading angles were based on a Cartesian coordinate system, which was anchored at 0º on the positive horizontal x-axis and increases through 360º in a counter-clockwise direction. Directional headings generally used to describe VR scene positions, however, are expressed in a compass-based coordinate system which is anchored at 0º on the vertical positive-y axis and increases through 360º in a clockwise direction. The final step of this program, therefore, was to convert the FOV and heading data to compass-based directional headings.

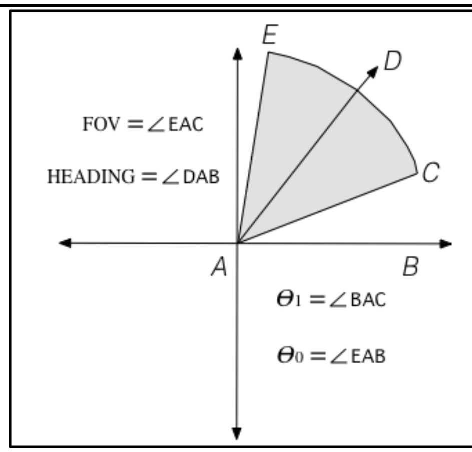

Figure G2. Trigonometric relationships determined by program 4.

Output

The outputs of the program are the FOV and heading data derived from the buffered image provided as input.

APPENDIX H: FIELD OF VIEW AND HEADING DATA

Appendix H presents summary tables of FOV and heading interval frequency distributions are presented on the following pages.

Table H1

FOV Interval Distribution for Participants

Participant	*N*	[0º-30º)		[30º-60º)		[60º-90º)		[90º-120º)		[120º-150º)	
		f	%	*f*	%	*f*	%	*f*	%	*f*	%
P1	281	0	0.0	37	13.2	70	24.9	105	37.4	69	24.6
P3	616	0	0.0	103	16.7	190	30.8	246	39.9	77	12.5
P4	881	3	0.3	512	58.1	192	21.8	119	13.5	55	6.2
P6	196	0	0.0	10	5.1	48	24.5	35	17.9	103	52.6
P10	941	0	0.0	644	68.4	161	17.1	117	12.4	19	2.0
P15	246	0	0.0	145	58.9	101	41.1	0	0.0	0	0.0
P16	441	0	0.0	285	64.6	91	20.6	34	7.7	31	7.0
P17	221	0	0.0	0	0.0	76	34.4	4	1.8	141	63.8
P18	456	0	0.0	98	21.5	312	68.4	33	7.2	13	2.9
P19	116	0	0.0	0	0.0	116	100.0	0	0.0	0	0.0
P20	571	0	0.0	265	46.4	234	41.0	46	8.1	26	4.6

Table H2

Heading Interval Distribution for Participants (0º-180º)

Participant	*N*	[0º-30º)		[30º-60º)		[60º-90º)		[90º-120º)		[120º-150º)		[150º-180º)	
		f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
P1	281	38	13.5	15	5.3	15	5.3	30	10.7	13	4.6	26	9.3
P3	616	58	9.4	50	8.1	66	10.7	19	3.1	55	8.9	76	12.3
P4	881	120	13.6	62	7.0	68	7.7	38	4.3	24	2.7	126	14.3
P6	196	34	17.3	8	4.1	4	2.0	44	22.4	10	5.1	12	6.1
P10	941	37	3.9	49	5.2	41	4.4	24	2.6	115	12.2	245	26
P12	246	8	3.3	13	5.3	16	6.5	3	1.2	8	3.3	2	0.8
P15	441	45	10.2	69	15.6	12	2.7	11	2.5	76	17.2	31	7.0
P16	221	18	8.1	6	2.7	10	4.5	24	10.9	24	10.9	30	13.6
P17	456	34	7.5	58	12.7	50	11.0	22	4.8	56	12.3	43	9.4
P18	116	17	14.7	4	3.4	3	2.6	5	4.3	5	4.3	5	4.3
P19	571	54	9.5	39	6.8	60	10.5	23	4.0	56	9.8	39	6.8
P20	621	86	13.8	45	7.2	66	10.6	21	3.4	77	12.4	55	8.9

Table H3

Heading Interval Distribution for Participants (180º-360º)

Participant	*N*	[180º-210º)		[210º-240º)		[240º-270º)		[300º-330º)		[300º-330º)		[330º-360º)	
		f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
P1	281	14	5	15	5.3	36	12.8	13	4.6	11	3.9	55	19.6
P3	616	46	7.5	74	12.0	11	1.8	8	1.3	48	7.8	105	17.0
P4	881	112	12.7	65	7.4	49	5.6	56	6.4	76	8.6	85	9.6
P6	196	9	4.6	10	5.1	1	0.5	2	1.0	3	1.5	59	30.1
P10	941	217	23.1	111	11.8	18	1.9	24	2.6	24	2.6	36	3.8
P12	246	10	4.1	17	6.9	16	6.5	15	6.1	59	24.0	79	32.1
P15	441	41	9.3	54	12.2	0	0.0	26	5.9	24	5.4	52	11.8
P16	221	40	18.1	6	2.7	8	3.6	32	14.5	1	0.5	22	10.0
P17	456	47	10.3	25	5.5	7	1.5	38	8.3	25	5.5	51	11.2
P18	116	3	2.6	9	7.8	6	5.2	10	8.6	6	5.2	43	37.1
P19	571	65	11.4	57	10.0	12	2.1	46	8.1	41	7.2	79	13.8
P20	621	95	15.3	39	6.3	18	2.9	45	7.2	25	4.0	49	7.9

APPENDIX I: STUDY CODE BOOK

This appendix contains the descriptive codes that emerged from coding the study's think-aloud transcripts. The codes are arranged in tables according to the study's major categories and associated subcategories. Each table entry contains the name of the code and a sample segment from the think-aloud transcripts.

Identifying

Naming

Table I1

Naming Subcategory Codes

Code	Example
naming boundary	There's also a window and what looks to be a door to outside.
naming fixture	Then, we also have a few of the, uh, light switches
naming furniture	a couple more chairs
naming item	a serving bowl of some kind
naming picture	another painting or two

Describing

Table I2

Describing Subcategory Codes (Boundary and Fixture)

Code	Example
describing boundary material	More of that paneling
describing boundary size	Another large window that goes outside
describing fixture color	Curtains that are cream-colored
describing fixture decoration	with darker lines going through
describing fixture feature	kind of a, the walls kind of a cross-patterned with holes in it
describing fixture function	divides the living room from the dining room
describing fixture material	uh, wooden, two wooden beams
describing fixture shape	goes from floor-to-ceiling and extends out from the wall a little bit, probably about a foot.
describing fixture size	big shelves

Table I3

Describing Subcategory Codes (Furniture and Item)

Code	Example
describing furniture age	piano is older
describing furniture color	white seat
describing furniture condition	The, the leather looks kind of torn in the center of the seat.
describing furniture decoration	chair, pinkish-red flowers
describing furniture feature	lamp that has kind of a glass fixture in the center of it
describing furniture material	with that soft material on the chairs
describing furniture shape	A round table
describing furniture size	another little end table
describing furniture style	elephant lamp holder which looks kind of India in nature.
describing item age	an old, uh, one of those clocks
describing item color	most of them cream-colored or a darker brown color
describing item decoration	the one's on the top that have flowers
describing item feature	one that's got a tube with something in it.
describing item function	couple of other serving dishes like we'd use for gravy,
describing item material	wooden model sailboat
describing item shape	kind of spiral-looking, ah cream-colored shell
describing item size	small metal tree, a little small tree fixture.
describing item style	Looks like Iranian rug

Table I4

Describing Subcategory Codes (Outdoor, Picture, and Room)

Code	Examples
describing outdoor setting	Looks like it's maybe out in the country or something.
describing picture feature	ribbon in the picture frame over here.
describing picture size	little picture
describing picture subject	some of them are pictures of fruit
describing room age	pretty old style house, in general
describing room color	Um, kind of a darker wood finish for the room
describing room feature	Um, the porch is railed in,
describing room function	living room or family, probably sitting and talking
describing room housekeeping	It's clean
describing room material	There's a lot of wood
describing room size	good, large space
describing room style	kinds of reminds me of like a western-style house.

Associating

Table I5

Associating Subcategory Codes

Code	Example
associating furniture	reminds me of actually my one of my tables I used to have
associating item	they looked like those giant horses in front of P.F. Chang's
associating room	Looking around, that looks like something my grandma had

Locating

Allocentric

Table I6

Allocentric Subcategory Codes (Boundary and Fixture)

Code	Examples
locating boundary allocentric to boundary	on the wall next to the second windows
locating boundary allocentric to fixture	and a light switch. An next to that is a wall.
locating boundary allocentric to furniture	next to that (grandfather clock) is the wall that connects to the hallway with a doorway
locating boundary allocentric to item	on the wall opposite of the sailboat
locating boundary allocentric to picture	On the wall with the butterfly and basket of grapes
locating boundary allocentric to room	which has windows in that room
locating fixture allocentric to boundary	Next to the window there is a set of shelves
locating fixture allocentric to fixture	shelf over, over the fireplace
locating fixture allocentric to furniture	Next to those two chairs is a fireplace
locating fixture allocentric to item	Above the clock, uh, above the book on the desk is a shelf
locating fixture allocentric to picture	Um, the fireplace itself has a small, uh, chain mail-ish, uh, kind of net in front of it
locating fixture allocentric to room	um, table, set in the living room,

Table I7

Allocentric Subcategory Codes (Furniture, Item, Picture, and Room)

Code	Example
locating furniture allocentric to boundary	there's a small chair on this side of the wall
locating furniture allocentric to fixture	Um, on the right side of the divider there is a table
locating furniture allocentric to furniture	another little end table next to the couch
locating furniture allocentric to picture	two chairs underneath those pictures
locating furniture allocentric to room	Um, there's a piano in the other room.
locating item allocentric to boundary	clock against the wall
locating item allocentric to fixture	Um, statues on the fireplace.
locating item allocentric to furniture	has some white china inside of it.
locating item allocentric to item	I see a couple of giraffes by the globe.
locating item allocentric to room	globe in the living room
locating picture allocentric to boundary	pictures hanging near the door
locating picture allocentric to fixture	looks like a little picture above the light switch
locating picture allocentric to item	couple of pictures next to the clock
locating picture allocentric to room	in the hallway, there's more pictures
locating picturing allocentric to furniture	Above the chairs and the table are two paintings
locating room allocentric to boundary	that's the kitchen through that doorway

Egocentric

Table I8

Egocentric Subcategory Codes

Code	Example
locating boundary egocentric	here is a double glass window, door/window to my left,
locating fixture egocentric	Um, there's a shelf over here
locating furniture egocentric	table to my left
locating item egocentric	and these here are a lot of boxes, box-like type things
locating picture egocentric	Probably a picture of a looks to be a basket with grapes in it on the right.

Regulating

Planning

Table I9

Planning Subcategory Codes

Code	Example
stating initial action	All right, the first thing that I would, uh, check out is the glassware because it's really the, uh, attention-getter

Monitoring

Table I10

Monitoring Subcategory Codes

Code	Example
asking researcher if task is complete	I'm doing to go into this room? No?
determining position from radar widget	I can see on the bird's eye view that I am between the living and the dining room
did not previously notice	didn't notice the globe before.
high scene complexity	Oh, goodness, there's a lot going on in this room.
judgment of learning task completion	And, I think I've basically got this place figured out.
low scene complexity	Pretty simple layout.
poor quality or clarity of scene display	Can't really make it out too well, kind of fuzzy.
revising description	which from the designs on them they actually look more of the American horse styles not the ah Japanese war horses which when I first saw them
revising zoom direction	actually, wrong way,
system interface negative	I don't much like that mouse.
unsure of the exact nature of an object	I’m, not sure what that is, I guess it's the, hmm.

Controlling

Table I11

Controlling Subcategory Codes

Code	Example
looking around the scene	Just looking around in the room. in the room.
looking to a direction	Look to the left, there, um, directly to the left
memorizing object location	Just trying to memorize where things are.
moving in unspecified	we move a little bit
moving in a direction	As we move to the right
moving to a room	Um, let's going on outside.
moving to furniture	going to the table and see
returning to furniture	Back around to the dining room table
returning to room	let's see, going back into the room I started in,
zooming in	moving in a little closer to the cabinet,
zooming out	I just kind of zoomed out so I could more of the layout of the rooms see what I'm doing, potentially, missing with the, uh, being zoomed in

Contextualizing

Interpreting

Table I12

Interpreting Subcategory Codes

Code	Example
demographics and interests of residents	I think this person likes to collect something about ocean because it has ship, some fish, and that's some ocean view. He has collection here, too.
origin or history of object	Looks like somebody's done a, uh, some state fair fair work with the awards.

Reacting

Table I13

Reacting Subcategory Codes

Code	Examples
different furniture	The rug is, hmm, different, bright.
different item	kind of odd-looking statues
different room	But this (room) hmm, kind of different.
feel good about room	It makes me feel much better about being in this house
negatively to fixture	the curtains are so drab
negatively to furniture	um, a little bit too much
negatively to item	and the fish are weird
negatively to room	There's a lot of wood in the room which kind of makes me feel, um, likes it's too much for my eyes.
positively to boundary	I really like that wall.
positively to fixture	Like the fireplace.
positively to furniture	wonderful elephant lamp holder
positively to item	really pretty clock
positively to landscape	nice trees
positively to picture	really pretty ocean pictures
positively to room	Give nice, classic look

APPENDIX J: CODING DISTRIBUTION DATA

This appendix includes tables of descriptive code occurrence counts for each participant. The tables are grouped by event categories and subcategories.

Identifying

Naming

Table J1

Naming Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
naming boundary	0	0	0	0	0	0	0	0	1	0	3	3	7
naming fixture	1	4	0	0	3	0	2	1	1	1	1	1	15
naming furniture	3	7	1	0	4	1	7	3	0	3	3	9	41
naming item	3	13	8	1	5	0	10	8	8	6	3	9	74
naming picture	1	1	0	0	0	0	2	0	2	0	0	3	9
Totals	8	25	9	1	12	1	21	12	12	10	10	25	146

Describing

Table J2

Describing Subcategory Code (Boundary and Fixture) Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
describing boundary material	0	1	0	0	0	1	0	0	1	0	0	0	3
describing boundary size	0	2	0	1	0	0	0	0	0	0	2	0	5
describing fixture color	0	2	1	0	5	0	0	0	0	0	0	0	8
describing fixture decoration	0	0	1	0	0	0	0	0	0	0	0	0	1
describing fixture feature	0	0	2	0	2	0	0	0	0	0	0	0	4
describing fixture function	0	0	3	0	1	0	0	0	1	0	0	0	5
describing fixture material	0	2	0	0	6	3	0	0	0	0	0	0	11
describing fixture shape	0	0	0	0	1	0	0	0	0	0	0	0	1
describing fixture size	0	1	0	0	2	0	0	0	0	0	1	0	4
Total	0	8	7	1	17	4	0	0	2	0	3	0	42

Table J3

Describing Subcategory Code (Furniture and Item)

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
describing furniture age	0	0	0	0	1	0	0	0	1	0	0	0	2
describing furniture color	1	5	3	2	11	2	1	0	1	0	0	0	26
describing furniture condition	0	0	0	0	1	0	0	0	0	0	0	0	1
describing furniture decoration	0	3	0	0	6	0	0	0	0	0	0	0	9
describing furniture feature	1	0	5	1	7	0	1	0	2	0	0	2	19
describing furniture material	0	3	0	0	6	1	0	0	2	0	0	0	12
describing furniture shape	0	1	1	0	0	0	0	0	0	0	0	0	2
describing furniture size	1	2	0	1	4	0	0	0	1	0	5	1	15
describing furniture style	0	1	0	0	1	0	2	1	0	0	0	0	5
describing item age	0	0	1	0	0	0	1	1	1	1	0	0	5
describing item color	0	5	5	0	21	0	0	0	1	0	1	0	33
describing item decoration	0	1	1	0	1	0	0	0	0	0	0	0	3
describing item feature	0	2	10	0	7	0	1	0	1	0	0	1	22
describing item function	0	0	2	0	0	0	1	0	0	0	0	0	3
describing item material	0	5	0	0	13	0	2	0	4	0	0	1	25
describing item shape	0	0	0	0	2	0	1	0	0	0	0	0	3
describing item size	1	3	2	0	13	1	0	0	2	0	4	1	27
describing item style	0	0	0	0	0	0	2	2	2	0	0	2	8
Total	4	31	30	4	94	4	12	4	18	1	10	8	220

Table J4

Describing Subcategory Code (Outdoor, Picture, and Room) Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
describing outdoor setting	0	0	0	0	0	0	0	0	1	0	0	1	2
describing picture feature	0	0	1	0	1	0	0	0	2	0	0	1	5
describing picture size	0	1	0	0	0	0	0	0	0	0	0	0	1
describing picture subject	0	4	14	2	3	0	6	6	0	0	6	3	44
describing room age	0	0	0	0	0	0	0	0	1	0	0	0	1
describing room color	0	0	0	0	1	0	0	0	0	0	0	0	1
describing room feature	0	0	1	0	0	0	2	0	0	0	0	0	3
describing room function	0	0	0	0	0	0	0	2	0	0	0	0	2
describing room housekeeping	0	0	0	0	0	5	0	0	0	1	0	1	7
describing material	0	0	0	0	0	1	0	0	0	1	0	0	2
describing size	2	0	0	0	0	0	0	0	0	1	0	0	3
describing style	0	0	0	0	0	5	0	0	1	0	0	0	6
Total	2	5	16	2	5	11	8	8	4	3	6	5	75

Associating

Table J5

Associating Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
associating furniture	0	0	0	0	2	0	1	0	1	0	0	0	4
associating item	3	0	0	0	1	0	3	0	1	0	0	0	8
associating room	1	0	0	0	0	0	0	0	0	0	0	0	1
Total	4	0	0	0	3	0	4	0	2	0	0	0	13

Locating

Allocentric

Table J6

Allocentric Subcategory Code Distribution (Boundary and Fixture)

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
locating boundary allocentric to boundary	0	1	0	0	0	0	0	0	0	0	1	0	2
locating boundary allocentric to fixture	0	0	0	0	0	0	0	0	0	0	1	0	1
locating boundary allocentric to furniture	0	0	0	0	0	0	0	0	0	0	1	0	1
locating boundary allocentric to item	0	0	1	0	0	0	0	0	0	0	0	0	1
locating boundary allocentric to picture	0	0	1	0	1	0	0	0	0	0	1	0	3
locating boundary allocentric to room	0	0	0	0	0	0	0	0	1	0	6	1	8
locating fixture allocentric to boundary	0	1	3	0	6	0	1	0	0	0	2	2	15
locating fixture allocentric to fixture	0	0	3	0	4	0	0	1	1	0	2	0	11
locating fixture allocentric to furniture	0	0	2	1	5	0	0	0	0	0	1	0	9
locating fixture allocentric to item	0	0	2	0	0	0	0	0	0	0	0	0	2
locating fixture allocentric to picture	0	0	1	0	0	0	0	0	0	0	0	0	1
locating fixture allocentric to room	0	0	2	0	2	0	0	1	0	0	2	0	7
Total	0	2	15	1	18	0	1	2	2	0	17	3	61

Table J7

Allocentric Subcategory Code Distribution (Furniture, Item, Picture, and Room)

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
locating furniture allocentric to boundary	0	2	3	1	0	0	0	0	0	0	4	1	11
locating furniture allocentric to fixture	0	1	4	0	0	0	1	1	0	0	2	0	9
locating furniture allocentric to furniture	0	0	7	1	9	0	0	0	1	0	4	0	22
locating furniture allocentric to picture	0	0	1	0	0	0	0	0	0	0	1	0	2
locating furniture allocentric to room	1	1	3	0	2	0	0	1	0	0	7	1	16
locating item allocentric to boundary	1	5	2	1	3	0	3	0	3	0	2	2	22
locating item allocentric to fixture	1	0	9	1	8	0	0	0	4	0	4	4	31
locating item allocentric to furniture	1	11	13	8	13	0	6	1	2	0	16	10	81
locating item allocentric to item	0	0	15	0	23	0	0	0	2	0	1	0	41
locating item allocentric to room	0	1	1	0	0	0	0	0	1	0	4	1	8
locating picture allocentric to boundary	0	3	4	2	3	0	0	0	1	0	2	0	15
locating picture allocentric to fixture	0	2	5	0	0	0	0	0	0	0	0	0	7
locating picture allocentric to item	0	1	0	0	1	0	0	0	0	0	0	0	2
locating picture allocentric to room	0	0	1	0	0	0	0	0	0	0	2	2	5
locating picturing allocentric to furniture	0	0	2	1	1	0	1	0	0	0	3	0	8
locating room allocentric to boundary	0	1	0	0	1	0	0	1	1	0	2	1	7
Total	4	28	70	15	64	0	11	4	15	0	54	22	287

Egocentric

Table J8

Egocentric Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
locating boundary egocentric	0	0	0	1	1	0	0	0	0	0	0	0	2
locating fixture egocentric	0	1	0	0	0	0	0	0	1	0	0	0	2
locating furniture egocentric	0	1	3	2	5	1	1	0	0	0	0	2	15
locating item egocentric	1	1	0	1	1	1	2	0	0	0	0	2	9
locating picture egocentric	0	0	0	0	1	0	0	0	0	0	1	1	3
Total	1	3	3	4	8	2	3	0	1	0	1	5	31

Regulating

Planning

Table J9

Planning Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
stating initial action	0	0	0	0	0	0	1	0	0	0	0	0	1

Monitoring

Table J10

Monitoring Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
asking researcher if task is complete	0	0	0	0	0	0	0	0	0	0	0	1	1
determining position from radar widget	0	0	0	0	0	0	0	0	0	0	1	0	1
did not previously notice	0	0	0	1	2	0	1	0	0	0	1	1	6
high scene complexity	0	0	0	0	0	1	0	0	0	0	0	0	1
judgment of learning task completion	2	1	0	1	1	0	1	1	0	2	1	3	13
low scene complexity	1	0	0	0	0	0	0	0	0	0	0	0	1
poor quality or clarity of scene display	0	0	1	0	7	0	5	0	1	0	1	0	15
revising description	0	0	0	0	0	0	2	0	0	0	0	0	2
revising zoom direction	0	0	0	0	0	0	1	0	0	0	0	0	1
system interface negative	1	0	0	0	0	0	0	0	0	0	0	0	1
unsure of the exact nature of an object	2	1	11	0	18	1	5	0	4	0	5	10	57
Total	6	2	12	2	28	2	15	1	5	2	9	15	99

Controlling

Table J11

Controlling Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
looking around the scene	0	0	0	0	0	0	0	0	0	0	3	0	3
looking to a direction	0	1	0	1	0	0	0	0	0	0	0	0	2
memorizing object location	1	0	0	0	0	0	0	0	0	0	0	0	1
moving in unspecified direction	0	0	0	3	0	0	0	0	0	0	0	0	3
move in a direction	0	1	0	3	0	0	0	0	0	0	0	0	4
moving to a room	0	0	0	0	0	1	0	0	0	0	0	0	1
moving to furniture	0	1	0	0	0	0	0	0	0	0	0	0	1
returning to furniture	0	0	0	0	0	0	0	0	1	0	0	0	1
returning to room	0	0	0	0	2	0	0	0	1	0	3	0	6
zooming in	0	0	0	1	0	0	1	0	0	0	0	0	2
zooming out	0	0	0	1	0	0	1	0	0	0	0	0	2
Total	1	3	0	9	2	1	2	0	2	0	6	0	26

Contextualizing

Interpreting

Table J12

Interpreting Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
demographics and interests of residents	0	0	0	0	0	0	2	2	1	0	0	0	5
origin or history of object	1	0	0	0	0	0	1	0	1	0	0	0	3
Total	1	0	0	0	0	0	3	2	2	0	0	0	8

Reacting

Table J13

Reacting Subcategory Code Distribution

Code	P1	P3	P4	P6	P10	P12	P15	P16	P17	P18	P19	P20	Total
different furniture	0	0	0	0	0	1	0	0	0	0	0	0	1
different item	0	0	0	0	0	0	0	0	2	0	0	0	2
different room	0	0	0	0	0	2	0	0	0	0	0	0	2
feeling good about room	0	0	0	0	0	1	0	0	0	0	0	0	1
negatively to fixture	0	0	0	0	0	1	0	0	0	0	0	0	1
negatively to furniture	0	1	0	0	0	1	0	0	0	0	0	0	2
negatively to item	0	0	0	0	0	3	1	0	0	0	0	0	4
negatively to room	0	0	0	0	0	3	0	0	0	0	0	0	3
positively to boundary	0	1	0	0	0	0	0	0	0	0	0	0	1
positively to fixture	2	0	0	0	0	1	1	0	0	0	0	0	4
positively to furniture	1	2	0	0	0	1	2	1	0	0	0	0	7
positively to item	1	3	0	0	0	0	1	1	0	1	0	0	7
positively to outdoor setting	0	0	1	0	0	1	0	0	0	0	0	0	2
positively to picture	0	1	0	0	0	0	0	0	0	0	0	0	1
positively to room	0	0	0	0	0	1	0	1	0	0	0	0	2
Totals	4	8	1	0	0	16	5	3	2	1	0	0	40

APPENDIX K: CRITICAL INCIDENT INTERVIEW SUMMARY

Table K1

Critical Incident Interview Summaries (P1, P3, P4, P6, P10, and P12)

Participant	Problem	Why difficult?	Attempted action	Severity	Impact	Work Around?
P1	Answering questions on paper	Trying to remember everything	NA	Minor	None	Yes
P3	Pan working opposite from expected	Frustrating looking at something but having display move in opposite direction	Looking towards fireplace in left to right direction	Minor	None	Yes
P4	Zoom coasts too far when using mouse	End up at different place then intending	Zooming in or out	Not severe	No	Yes, tried to ignore it.
P6	Didn't know if dining room slider was door or window	Unable to see whole area due to slider view being blocked	Trying to describe scene	Not difficult	None	Yes
P10	Lack of detail when zooming	Could not get better look at object	NA	NA	NA	NA
P12	None	None	NA	None	None	Yes

Note. Not Applicable (NA) responses for P10 were due technical recording problems.

Table K2

Critical Incident Interview Summaries (P15, P16, P17, P18, P19, and P20)

Participant	Problem	Why difficult?	Attempted action	Severity	Impact	Work Around?
P15	System unresponsive to pan with mouse	Hardware wasn't responding as requested	Examine chandelier	2 on a scale from 1 to 5	More careful moving mouse	Yes
P16	Didn't pay attention to details like location of tables between sofas	Lots to memorize	Trying to memorize locations	No	None, could continue	Yes
P17	No difficulties	No difficulties	NA	Easy session	No	Yes
P18	Remembering details of scene	Only seen VR once before	Remember details	Too many details	Details made it harder	Somewhat
P19	Using shift and command to zoom produced result opposite of what expected	Had to keep correcting after zooming in wrong direction	Looking though doorway to kitchen	Easily fixed	Not much	Yes
P20	Mouse moved to right when expected it to move left	Had to keep correcting problem.	Moving right or left	Very minor	No, corrected as needed	Yes

VITA

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