NAVIGATION IN DESKTOP GEOVIRTUAL ENVIRONMENTS: USABILITY ASSESSMENT

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Abstract
Emerging desktop geovirtual environments (GeoVEs) offer new ways to display and interact with high dimensional geospatial structures and phenomena, thus enabling geospatial information access and geovisualization over the Internet. Although technical problems associated with implementing such environments remain to be addressed, core problems for users of these desktop GeoVEs are to navigate through, and remain oriented in, the display space and to relate that display space to the geographic space it depicts. These shortcomings are apparent when users of desktop GeoVEs mention that they feel "lost".

Navigation problems are also not uncommon for real world travelers. The phenomenon of being lost in the real world is often described as an utter disaster (Lynch 1960). A primary goal of the research described here is to avoid such disasters in virtual environments (VE) and, thus, to design more productive geovisualization applications, where users spend their time exploring data relationships or making decisions rather than trying to figure out where they are. This paper describes the initial phase of a research program directed specifically to the design of interface methods that support movement within desktop GeoVEs and reports the application of usability engineering methods to geovisualization environments.

Keywords: Geovisualization, Navigation, Wayfinding, Metaphors, Geovirtual Environments, Usability, Web Cartography

Introduction
In an ambitious vision, former U.S. Vice President Al Gore (1998) introduced the concept of a “Digital Earth". The Gore speech (apparently never presented) describes an immersive VE (head-mounted display with a data glove as an interaction device) that can be used to explore and learn about all aspects of earth. Users would be presented with a depiction of earth as an interface to geospatially indexed information, not only to traditional geospatial data but also to the many other kinds of information for which some form of geographic referencing can be applied. As such, the Digital Earth envisioned can be considered a prototypical example of what has been termed a geovirtual environment (GeoVE). GeoVEs make use of one or more “aspects of virtuality” to reflect components of the real world in intuitive ways. The key aspects identified thus far are immersion (a sensation of being in the environment rather than manipulating an object that depicts an environment), information intensity (details that are similar in quantity to those observed for real objects, and detail that varies in intensity with distance), interactivity (the ability to manipulate features in the environment in ways similar to experiences in the real world, such as to pick up and move a feature or to change its color by painting), and intelligence of display objects (the ability to exhibit context sensitive behaviors that resemble those of animate objects encountered in the world) (MacEachren et al. 1999).

The particular GeoVE envisioned by Gore is fully immersive and highly interactive, thus users will feel like they are part of the information environment they are exploring. While such immersive environments have considerable potential, desktop GeoVEs, particularly those that can be made available through the World Wide Web (WWW), are likely to have the most impact on science and society in the short run, due to the shear numbers of people who can access them (Pesce 1995; Göbel 1996; Dykes et al. 1999). Such desktop (PC-based) GeoVEs extend the potential for visual analysis of the geospatial information accessed, in contexts that range from scientific research and science education to environmental management and urban and regional planning (Mundle 1999; Reddy et al. 1999; Russ and Wetherelt 1999; Besser and Schildwächter 2000).

The focus here is on the intersection of developments in geovisualization (Kraak 2000; MacEachren and Kraak 2001) and geovirtual environments in a WWW context (Fairbairn et al. 2001). For both, a core problem for users is to navigate through and remain oriented in the display space and to relate that display space to the geographic space it depicts (Slocum et al. 2001). The prevalence of map-based interfaces for geographic information access and the calls for research to achieve the goals outlined for the Digital Earth project contain an implicit assumption that a map or earth metaphor is all that the user requires to make navigation in GeoVEs easy. We believe that this is not the case. Here, we address issues related to use and usefulness of this metaphor as it relates to navigation metaphors for geovisualization in desktop geovirtual environments.

Navigation and wayfinding in relation to virtual environments

During wayfinding, orientation and navigation are crucial. Before expanding upon this contention, however, it is necessary to define these terms. Orientation is our awareness of the space around us, including the location of objects and places. Thus it facilitates the understanding of the relations between current and target location (Downs and Stea 1977; Hunt and Waller 1999). Arthur and Passini (1992) describe wayfinding as "spatial problem solving," a "process of reaching a destination, whether in a familiar or unfamiliar environment". Peponis et al. (1990) describe wayfinding as "the ability to find a way [from a starting point] to a particular location in an expedient manner and to recognize the destination when reached". Navigation is most often defined as "the process of determining a path to be traveled by any object through the environment" (Darken and Sibert 1993). Elvins (1997) concludes that "without wayfinding a navigator won't know in which direction to steer and without navigating, a wayfinder will not have the means to move toward his destination".

Gärling et al. (1986) introduced a model of information processing stages during wayfinding. They recognized wayfinding as a travel plan, a successful execution of sequences. They argue that, at the beginning of a wayfinding situation, a destination is decided upon and localized using information from the cognitive map and media, e.g. a topographic map. Thereafter, selection of a route to the destination takes place and the travel plan is executed. Changes in the travel plan might be necessary during execution, depending upon trip length, the complexity of the environment, and the familiarity with the environment. At arrival, the wayfinding process can be terminated (figure 1).

Gärling et al. (1986) proposed their model for wayfinding in real environments. Here we need to consider how and if this model can be applied in virtual wayfinding and where the differences in information processing between real and virtual wayfinding are. Recently, psychologists and others have begun to investigate wayfinding issues related to virtual environment travel but many questions are currently unanswered and under investigation e.g. Darken (1998), Cutmore et al. (2000) and Freksa et al. (2000). One reason for this uncertainty regarding VE wayfinding issues lies in the broad variety of possible VEs that range from desktop worlds to fully-immersive environments and, thus, can have substantially different demands on and use of the human visual, haptic, balancing and auditory senses (Hunt and Waller 1999; Leplow et al. 2000).

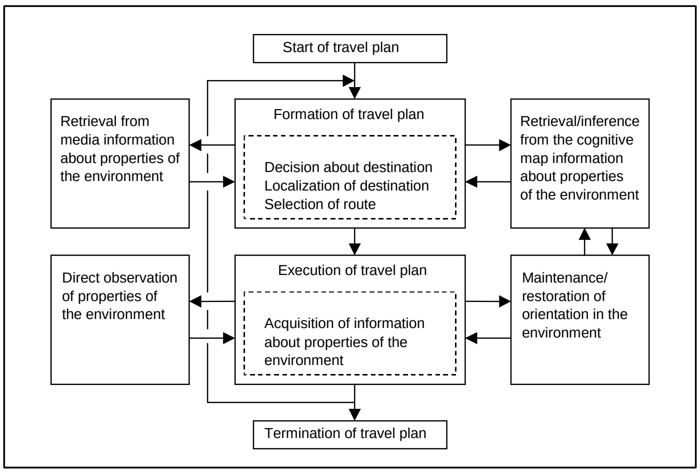

Figure 1: Information processing model of spatial orientation and wayfinding (Gärling et al. 1986)

In real environments kinesthetic feedback is directly given to the traveler (Hunt and Waller 1999) and can be considered part of the data acquisition process (indicated as interaction with

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lower left box in figure 1). It directly influences the formation, change and execution of a travel plan, e.g. if a path is steep, icy or bumpy a person might not take the most direct route. In VEs (particularly desktop ones) kinesthetic feedback is usually not given and user movement is usually not much restricted if the virtual ground is icy or blocked by an obstacle. In addition to the lack of kinesthetic feedback, navigation in virtual environments is generally controlled indirectly with interaction tools such as joysticks, cyber gloves, gesture recognition, etc. (Youngblut et al. 1996). Thus it is more like navigation in the real world using a vehicle with indirect controls (an automobile steering wheel) than like walking through the world. Since desktop VEs are seldom immersive, navigation in such a virtual environment is even less similar to real world navigation (than for immersive VE) because navigation in addition to being indirect is typically controlled from the "outside" of the environment (like controlling a toy car by remote control). Control is through a graphical user interface (GUI) that provides 2D tools for indirect manipulation of user viewpoint, display parameters, and objects in the scene by applying the mouse or the keyboard as interaction tools (Fuhrmann and MacEachren 1999). It is likely that this indirect and remote control is one of the factors responsible for current navigation problems in such virtual environments. Below we assess these navigation problems in more detail.

Assessing navigation problems in standard desktop virtual environment browsers

Currently, many desktop VEs are distributed over the Internet using the Virtual Reality Modeling Language (VRML). These three-dimensional environments are platform independent and can be viewed in any WWW-browser that supports the VRML standard or uses a program extension (Ames et al. 1997; Kloss et al. 1998). In order to find reasons for current navigation problems in desktop GeoVEs, we conducted a usability test using one standard desktop VE browser, Cosmoplayer. This Web browser plug-in was selected because (at the time) it was one of the favorite VRML browsers on the Internet (see http://www.vapourtech.com/vrmlguide/polls/ -- alternatives include Cortona, Blaxxun and Worldview). Cosmoplayer is freely distributed, but its development and maintenance stopped two years ago.

To collect relevant usability information, we developed a GeoVE using VRML that depicted topography for a local environment. The specific geographic context for the usability assessment was the catchment of Spring Creek, which runs through Centre County, Pennsylvania. Thus the region depicted was known to participants. A Digital Elevation Model of the Spring Creek watershed and a digital raster USGS topographic map were integrated in the VRML environment.

Two usability test methods were applied: a user questionnaire and a focus group. Questionnaires allow predetermined response options, with usually limited flexibility in answers, directed to questions that developers know at the outset they need answers to. For the assessment of navigation problems in novel display environments, a more flexible usability technique is also needed. Focus groups are informal techniques that (when applied to system design, as here) allow investigators to assess user needs and feelings before, during and after the design of software. They are particularly good at raising and addressing fundamental design issues that the developers did not anticipate. Focus group methods are often applied in social science research and marketing studies but have also found their way into geovisualization research (Monmonier and Gluck 1994; Olson et al. 1998; Harrower et al. 2000). Focus groups can be described as moderated, structured discussions. When applied to computer software assessment, the typical procedure is for a group of users (5-12 participants) to work with the software for a period of time, and then participate in a moderated discussion that is focused on highlighting their concerns and opinions (Morgan 1998). Morgan (1998) and Stewart and Shamdasani (1990) both suggest that focus groups are particularly appropriate in the early stages of a project, in order to gain general background information and problem identification about a topic of interest. Both authors contend that early focus group tests can serve to generate hypotheses about new areas of investigation. Focus groups and questionnaires are both low cost usability-testing methods. For identifying fundamental usability problems and generating hypotheses for subsequent research their use in tandem with more traditional questionnaires can be productive due to the differences in kinds of information they generate (Stewart and Shamdasani 1990; Nielsen 1997).

The first focus group session that we conducted assessed navigation problems in a standard desktop VE browser (Cosmoplayer). The assessment was done on average performance PCs. The focus group consisted of seven participants: five geography and two landscape ecology male and female graduate students (age 23-26). The students had not used Cosmoplayer before. In the first 5 minutes the group was introduced to the study and the test environment was presented to them briefly. This was followed by a 15-minute session with the test environment where participants were asked to explore the virtual landscape freely and navigate from one place to another. The participants were instructed to try all of the navigation functions provided. A short questionnaire was handed out after 15 minutes and the participants answered the questions within 10 minutes. This was followed by a 30 minute structured group discussion. The moderator followed a set of predefined questions during the later session, allowing enough time for discussion and involvement of each participant. The session was recorded on tape for later analysis. The next section presents the results of this focus group and questionnaire.

Results from the focus group and the questionnaires

The usability assessment identified several problems that users encountered while using a standard VRML browser to navigate in the desktop geovirtual environment provided. Overall, the participants (university students) were not satisfied with the functions provided. They spent some time trying to learn the software functions but at the end they were not sure whether they did understand how the interface worked. One student said: "In the beginning, I figured it should be easy to understand the usage of the system but the system response was often different from what I expected". Another said: "I pressed several buttons but nothing happened". A third student commented: "It took longer to understand the functions of the system than I expected". The focus group facilitators, the first author and a graduate student who had previous experience with focus groups, asked about the usage of specific travel functions: "Did everyone change between the fly/walk modus and examine modus?" No one had done this, except for one person who "accidentally" used the switch to change from one into the other mode. These and other comments revealed that not all functions and modes of travel and related navigation functions were found, and that those found were often not properly and intuitively understood. Overall, participants did not understand the provided navigation functions or the underlying metaphors. They tended to work through the interface by "trial and error". Few found and made use of the help file. Only one participant changed preference settings for the viewer software.

Beyond the problems cited above, half of the group remarked that the colors of the interface were too dark, resulting in less than adequate contrast between the background and the function labeling. One participant also remarked that because of the poor contrast, system functions such as help, preferences and change of travel mode were not recognized. Most participants did not see the function explanation in the status field when they moved their mouse pointer over a navigation function. In relation to wayfinding problems specifically, several participants stated that they were quickly lost in the geovirtual environment. Almost all participants argued that they needed, but did not find, help for orientation. One person suggested a compass for maintaining orientation. Some participants moved quickly "under the surface" of the geovirtual model and did not find their way back. The viewpoint (camera) function of Cosmoplayer was, however, used successfully by several participants in order to return to the starting point. In addition to the user interface issues discussed, several users stated that computer processing speed was generally slow.

In spite of the problems identified, there were some positive reactions. In general, participants found that the field of view provided on the desktop GeoVE was adequate and that the size of the interface controls was sufficient. Overall, however, the user interface was not compatible with user conventions and expectations of geoscience graduate students. The participants did not feel that they were in control of the application. The user was not given clear informative feedback on what actions they had taken and whether these actions had been successful. Many navigation errors were reported during the focus group discussion.

The usability assessment detailed above revealed that, with at least one popular desktop virtual environment browser applied to geovisualization, participants did not execute their travel plans properly, mainly because of an inadequate, non-intuitively graphical user interface. In order to facilitate navigation functions in geovirtual environments applied to geovisualization, it seems necessary to design and test geo-domain-specific interaction metaphors (Fuhrmann and MacEachren 1999). A first research step would be to develop special navigation metaphors for geovirtual environment travel. If human information processing during virtual wayfinding is hindered because of inadequate navigation metaphors, users of virtual environments can become disoriented and not able to find their ways. In order to execute a proper travel plan in virtual environments, an intuitive GUI consisting of strong metaphors is needed. Thus the next section will focus briefly on the development of one navigation metaphor.

Designing and implementing a new metaphor for navigation

The main role of metaphors in GUI design is to afford ways of interacting with the, often abstract, computer environment and to help users master complex tasks (Shneiderman 1992; Kuhn 1995). Here, we focus on the design requirements to support wayfinding in a desktop GeoVE and development of a new navigation metaphor to fit this context.

Since the navigation metaphors provided in a standard browser did not function successfully, we undertook the task of developing a navigation metaphor for GeoVEs that would be meaningful to (and useful for) users within the domain of geo- and environmental sciences. Our target users were expected to be knowledgeable (experts) in the task domain but novices in the use of VEs. To support such users, the navigation metaphor had to: a) allow navigating a large geographic space, b) support freedom of movement (similar to, or more flexible than, our movement in real geographic space), c) invoke little cognitive effort, and d) suggest practical and understandable interface controls for necessary navigation operations. In an earlier publication we provide details about the metaphor design decision process (Fuhrmann and MacEachren 1999). Here we will summarize the results.

A starting point in designing such a "special" navigation metaphor was to consider ways humans move in geographic space. The most important distinction is that between walking and moving by vehicles. For exploring larger spaces, e.g. a country, walking seemed impractical as a metaphor because of the slow progress across the terrain walking would suggest, and the restrictions in directional movement (e.g., it is not possible to walk into the sky to obtain a better view). One alternative considered, surface vehicles, suggested that travel would also be restricted to the paths typical for that vehicle (e.g., roads, sidewalks). It was decided that an air travel vehicle metaphor would be much more flexible and, thus, more suitable for navigating large environments. Most of the air travel vehicles, however, had distinct limitations:

- the average user has no experience in maneuvering air vehicles,
- the controls in air vehicles are far too complex and would distract the user from his or her visualization goals (e.g. identifying, geographic brushing),
- most air travel vehicles (e.g. airplanes), by their nature, do not move backwards.

Alternative navigation metaphors are provided through science fiction. Participants of the Cosmoplayer focus group discussed the possibility that a useful interface to a desktop GeoVE should provide some kind of "science fiction atmosphere" since the environment displayed is a virtual model. Two science fiction metaphors were discussed subsequently, during the design process. One, teleportation, gives freedom to move in all directions with travel time not dependent on distance between locations. However, travel is restricted to the use of fixed "portals" and the sudden relocations involved are likely to result in disorientation. A "flying saucer" as a core metaphor for a fictional vehicle met the proposed navigation criteria. Using a virtual, rather than a physical, vehicle as a source metaphor gave an opportunity to design easy to learn navigation interface controls that would allow users to move in all directions. The selection of a flying saucer as the vehicle metaphor offered several specific advantages:

- its movement characteristics are commonly conceived, and movement in all directions is expected to be possible,
- the metaphor is understood in the context of GeoVEs (the flying saucers of science fiction often operate in geographic scale environments),
- expertise in controlling flying saucers is not an issue (no particular user, such as a pilot, has an advantage or disadvantage in using the GUI),
- because the vehicle has no apparent moving parts, and there is an assumption of a sophisticated system that is accessed easily and control design and arrangement can be simple (e.g., levers that correspond directly to intended movements),
- graphically, a flying saucer has a very simple object shape, resulting in a clean user interface.

The proposed navigation advantages of the flying saucer metaphor over a standard desktop VE browser needed to be assessed. Thus a prototype using a flying saucer as the navigation metaphor was designed for the Spring Creek data. Implementing the virtual vehicle metaphor required linking a custom GUI based upon the metaphor to the VRML world (with the custom GUI replacing functions of a standard VRML browser). The navigation tools of the "flying saucer" interface were designed as a heads up display (HUD) in the VRML scene. Due to the character of HUDs, the tools are "fixed" in relation to the frame that represents the "bridge" or "control center" of the virtual vehicle and move (in relation to the environment) with any change in position. The navigation tools schematically display the flying saucer (light colored spheres) and translate user actions directly into changes in viewpoint within the scene (figure 2). As the user drags the schematic flying saucer over the interface, the vehicle moves as indicated (see arrows), thus, there is little cognitive effort to use the controls. The dashboard has four basic movements (figure 2): changing the altitude, gliding over the 'ground' plane, switching the viewing/traveling direction and changing the vehicle's pitch.

Additional functions of the prototype include an orientation window that informs the user about his/her current position in the virtual model, displaying the virtual vehicle above an orientation map of the environment (not shown in the figure). Further directional information is given through a compass, which can be directly called up in the HUD. Using the reset button, the vehicle/viewpoint is set back to the original starting position. A help system is included that features narrative audio files, which explain to first time users the operation of the interface.

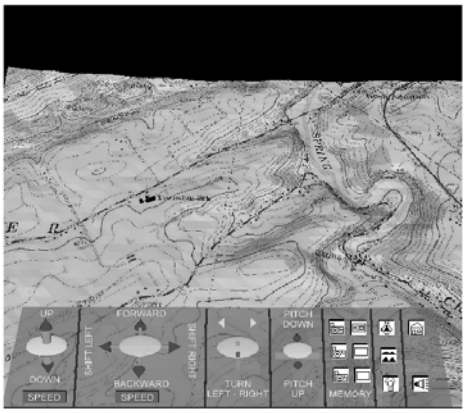

Figure 2: Initial virtual vehicle interface for exploring a desktop GeoVE

Usability assessment of the designed navigation metaphor

As done for the GeoVE using the standard browser, we assessed the environment that incorporates our geo-specific virtual vehicle metaphor using focus groups and questionnaires. Three different focus groups were executed, addressing two differences: age of users and navigation skills with and without an orientation window. All focus groups participants were introduced in the first 5 minutes to the test environment assessment procedure. As in the standard VE browser study, participants were instructed to freely explore the virtual catchment of Spring Creek. A short questionnaire (essential findings are included in this section) was handed out after 15 minutes and the participants answered the questions within 10 minutes, followed by a 30 minute moderated group discussion. The focus group was lead by two facilitators, graduate students who had experience in conducting focus groups.

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The first focus group consisted of six male geography graduate students and a physical geography professor (average age: 34). The group assessed an application that was composed of only the navigation window (figure 2). After using the interface, most of the group felt that learning the application functions were easy. Most participants understood how the majority of their interactions related to responses in the application. Computer processing speed made the travel through the GeoVE sometimes choppy, resulting in delayed reactions for the controls. One participant wrote, "I guess I am spoiled by 3D videogames on fast computers, but the application seems simple". The graphic design of the interface was judged to be clear and well organized. Participants suggested that smaller navigation controls would be better and it should be possible to hide unnecessary functions in other menus.

Many participants found it easy to determine the functions of the navigation controls. Most people were able to change altitude, move over the surface, change direction and the pitch. Some participants, however, found the controls to be counterintuitive. The group discussion (which was echoed by that in focus group two) produced a very interesting result. Some users interpreted the navigation metaphor as intended, and could envision moving over the landscape (they understood the interface metaphor as a vehicle which could be dragged and would change their position and viewpoint in the virtual environment). Other users interpreted the metaphor differently, and expected to use the controls to move the landscape (they interpreted the disc as a steering knob which would move the landscape around). Some users requested a more flight-like appearance of the interface, in order to more easily distinguish between both understandings. This outcome requires further investigation.

The focus group also discussed another problem: the loss of orientation. "If you are very close to the surface, it would be still nice to know where you are on the landscape. […] Why not having a little map in the corner with a position icon?" Most users in the group voted for some kind of map as an orientation support device because, as one participant stated, "I was moving over the topo-map and it made me lose a sense where I was. It did not provide me [with] enough information to know where to navigate". It seems that orientation and wayfinding in desktop geovirtual environments requires some kind of orientation facilitation with real time user positioning. A moving "you are here symbol" in an overview map could be a solution.

The second focus group consisted of three male and three female geography graduate students (average age: 28). The application, for this session, included both a navigation window (as in the first session) and an orientation window. Generally, the graduate students described the same pros and cons of the navigation window interface as the first group did. They also encountered different problems with the navigation interface. One participant stated, "I kept wanting to click on the arrows rather than move the disc for navigation". This statement was supported by another participant "it is easier to click on the arrows" (see figure 2). Here, we encountered competitive metaphors in the user interface. The arrows are certainly metaphors for directional movement and were included in the application as an intuitive signal for direction of movement to be achieved by rotating the saucer icon. However, some participants identified these movement indicators as navigation interaction metaphors and clearly wanted to use them. Here, the focus group revealed short-comings of the interface design and gave helpful hints for the redesign.

The second focus group test also revealed that most of the graduate students were used to interacting with keyboard strokes in desktop flight-simulator-like environments. Instead of a mouse controlled virtual movement, participants suggested that the arrow keys and other letter keys on the keyboard could be used for navigation. These keyboard-orientated interaction suggestions are likely to reflect software familiarization and age of this group of participants. Further testing will be required to determine what this finding means for the development of graphical navigation interfaces for desktop GeoVEs generally.

Overall, the orientation window was very much appreciated by most users. "I liked the connection of both windows. [It allows you] to know where you are and helps a lot [in] orientation". The interactive change of viewing position by moving the "you are here pointer" in the orientation window was also appreciated: "the drag function on the orientation window was nice". Generally, loss of orientation was not a great issue compared to the first focus group discussion. Users of the second focus group judged the navigation interface and its general usability as moderately satisfactory.

The third focus group consisted of one female and seven male undergraduate students (six geography majors, 2 geography minors; average age: 24). The application setting was similar to that for focus group two. Generally, participants were satisfied with the application. Most of the impressions listed above could be also found in this focus group. Interestingly, undergraduate students generally understood the application and basic navigation functions more quickly than had the older participants. Most undergraduate students stated that the controls were sufficiently labeled and the meanings of the controls were simple to understand. Few of the participants felt lost in the geovirtual environment. The orientation window helped them to "see themselves on the map". Overall users felt that they were in control of the application. Computer speed was generally judged as too slow. Many participants had experience with videogames and this experience may explain the quicker learning curve. The differences in our second and third focus groups support the contention that it will be important to investigate implications of the "Nintendo Generation" (Cartwright 1999) for future design of GUIs for desktop geovirtual environments.

Conclusion

In the current research agenda of the ICA commission on visualization and virtual environments, the development of methods to assist users in navigating and maintaining orientation in GeoVEs has been identified as one of several major research challenges (MacEachren and Kraak 2001). This study introduced initial research directed towards the design of interface methods that support intuitive movement within desktop GeoVEs. Usability engineering methods were applied to a geo-specific metaphor designed for facilitating navigation. The results of this study indicate that user-domain-specific designed interaction metaphors support virtual navigation in desktop geovirtual environments but do not necessarily facilitate orientation. An overview (birds eye view) map in desktop GeoVEs seems to assist in navigation and orientation. Further assessment of these dependencies is necessary.

The designed flying saucer metaphor provided both advantages and disadvantages for virtual environment travel. Overall it provided a good test bed for refining methods directed to designing navigation metaphors. This study is a first step in a comprehensive investigation of navigation, orientation and wayfinding research directed to facilitating travel in desktop geovirtual environments. Further research on cognitive aspects of virtual travel, especially in designing an information processing model for spatial orientation and wayfinding in different immersive geovirtual environments, is certainly required and could be best done through interdisciplinary research involving cognitive scientists, geographers, cartographers and computer scientists.

Acknowledgements

Portions of the work reported here were supported by the U.S. Environmental Protection Agency grant # R825195-01-0, by the U.S. National Science Foundation grant #9978052. and by the 'Deutscher Akademischer Austauschdienst'. Support of the Penn State Center for Academic Computing is also appreciated.

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