Decision making in a virtual environment: effectiveness of a semi-immersive “Decision Theater” in understanding and assessing human-environment interactions

Rob Edsall
Assistant Professor, Department of Geography, Arizona State University

Kelli L. Larson
Assistant Professor, Department of Geography and Global Institute of Sustainability, Arizona State University

Abstract

The Decision Theater (DT) at Arizona State University is a multimillion-dollar semi-immersive virtual environment facility purported to help policy makers and the larger community in making decisions about scientific issues and in visualizing output of predictive and scenario-based models. The DT has, like other virtual environments and related technology, generated interest and excitement, and its power is strengthened with evidence of its utility for the facilitation of scientific inquiry. We conducted a series of human-subjects tests with students, educators, and policy makers in which we evaluated the influence of the DT on aiding understanding, altering mental models, and correcting misconceptions. We compared responses of subjects saw a presentation about environmental issues in the DT to those of subjects that saw the same presentation on a flat screen in a classroom. We also compared, within subjects, a pre- and post-test, the differences between which address the degree to which the presentations influenced the subjects’ conceptions of the problems and the hypothetical decisions that they were asked to make. Preliminary analysis shows that some, but not all, of these dependent variables showed significant differences between groups, indicating a limited (but present) effect of the DT environment on decision making.

1. Introduction

The appeal of immersive and semi-immersive virtual reality (VR) systems is undeniable, particularly when their mission is the facilitation of decision making among users who would normally not have access to such technology. When the systems and the associated animated, interactive, three-dimensional representations are designed well, they can engage and fascinate users in affective and intangible ways that more conventional displays and representations cannot. Universities and research laboratories have introduced visualization environments with features such as three-dimensional animations that can be viewed with stereoscopic glasses on multiple screens that surround users. These environments are, at least to the present generations of users, still novel and exciting, and the technology may serve a vital role in enabling informed decision making among an engaged and dazzled audience. Non-technological aspects of these rooms, such as their size, furnishings, and acoustics, may also enable effective use.

Such claims require critical scrutiny in order to convince both users and developers that the financial and time investment required is merited. In the case of VR and associated research, the technology is advancing quickly enough to overtake the empirical evidence of its usefulness, and the result can be complex feature-filled systems designed from a developers' perspective with insufficient consideration of the end-users for whom the system is ultimately designed. The research reported here seeks to address this need. We report on pilot experiments in environmental understanding and perceptions in a semi-immersive visualization environment, Arizona State University's recently opened Decision Theater (DT).

In these experiments, we sought to find evidence to support the claim that the theater indeed facilitates understanding of – and decision making about – community problems. We asked participants their opinions and impressions about two geographical human-environment issues relevant to the Phoenix region, and then compared the responses of participants who were exposed to the DT to a control group. The experimental group was shown an animated three-dimensional presentation inside the facility, while a control group was shown a presentation of the same material through a non-animated two-dimensional presentation using Microsoft PowerPoint in a standard university classroom. The results of the experiments in this paper are preliminary, as data continue to be collected at the time of writing. Here we focus on preliminary and expected results, lessons learned from designing the experiment, and plans and needs for future research.

2. Background

"Virtual reality" is a term that encompasses a wide variety of technologies. Despite the wide variety of applications and technologies, most virtual reality environments (VEs) attempt to replicate a three-dimensional space that can be explored and examined, often because such exploration would be difficult or cost prohibitive in the real world (Demiralp, Jackson et al. 2006; Ragusa and Bochenek 2001). For example, these spaces may only exist in the future, may be dangerous, abstract, or at a scale that is unreasonable to explore at the human scale. Because of this transformation of "real" space to "virtual" space, cartographers and GIScientists have been interested in adopting the technology to the study of geographic phenomena (Fung, Leung et al. 2004).

There is evidence of the usefulness of VEs in training applications for the military, industry, and medicine (Stone 2001). VEs are useful for acquiring spatial knowledge about the world and for aiding spatial orientation, wayfinding, and navigation (Durlach et al. 2001; Koh et al. 1999). These benefits are not surprising because virtually interacting with a 3D space is specifically designed to mimic physical interaction in the real world. However, there is evidence that photorealism and immersion is limited in its effectiveness. Mak, Lai, et al. (2005) recently compared 2D and 3D virtual representations in environmental impact statements. They concluded that the more simplified 2D virtual model was less complicated and took less time for the average user to interpret. This reflects the opinion of Fisher et al. (1997), who argued that 3D graphs may be visually more pleasing but simple 2D graphs are better in terms of extracting information with respect to accuracy and ease.

The effectiveness of VEs on decision making may also be dependent on factors more attributable to the users than the technology. While information technologies may aid group decision-making and negotiations, cognitive understanding, trust in computer technology and other factors constrain their utility (Carver, Frysinger, and Reitsma 1995; Reitsma et al. 1996). Research is needed to fully understand how computer-generated visualizations and other information displays differentially influence human understanding, perceptions and preferences (Gerson and Eick 1997; Medyckyj-Scott 1994), especially in environmental decision-making situations that are often plagued by complex, multifaceted problems and conflicting interests. Key benefits of using computerized information in decision-making include focusing participants on particular aspects of a policy problem, constraining the scope of the problem, and involving stakeholders (Carver, Frysinger, and Reitsma 1995; Zigurs et al 1999).

This research seeks to understand the differential impacts of two media settings on developing a shared understanding of environmental problems through examining awareness and perceptions of environmental issues before and after viewing visual informational presentations. In addition, the degree to which value-based beliefs and views of computers, science and technology mediate the impact of visualized information and affect shared understanding of environmental problems is assessed.

3. Experimental Design

3.1. The Decision Theater

In May 2005, Arizona State University unveiled the Decision Theater ("DT"), a visualization environment consisting of a ten-sided windowless room (the "drum") approximately 20 feet in diameter with an 8-foot ceiling. On seven of the ten walls are rear-projection high-definition 10'x 8' display screens. Onto these screens are projected computer displays rendered in stereo, such that they appear three-dimensional when viewed through polarized glasses (one image appears in one eye, the other, slightly offset, image is shown in the other). Soft swivel chairs with casters are positioned around the carpeted floor, and tables can be brought in if the application warrants it. Presentations in the DT are produced by visualization specialists and graphic designers, and are run by a staff member who can communicate with users via a microphone and speaker from a room adjacent to the drum.

Several features of the Decision Theater make it appealing for decision making applications, particularly concerning environmental and geographical issues. The DT, as a semi-immersive VE, allows for the exploitation of depth cues in its three-dimensional representations, including motion, immersive presence, and stereo vision. In addition, the size, set up, and furnishings of the DT are designed for comfort and to facilitate interaction among participants. Future plans for the Theater include the incorporation of "wingman" joysticks and motion sensors such that the participants' actions can be translated onto the screen through a variety of interaction forms. It is worth noting that the experiment described herein did not exploit the full potential of the DT. We will discuss this in more detail below, but the results from this pilot study correspond only to the relatively limited set of features of the DT that were used in this project.

3.2. The Presentations

Subjects in our pilot study viewed presentations on two environmental issues in the Phoenix region – groundwater overdraft and the urban heat island – that require the conceptualization of abstract three-dimensional concepts. These presentations were not created for this study; rather, we utilized demonstrations created by the DT staff for the grand opening in May 2005 (Figure 1). We chose to use these demonstrations both because it was convenient to do so and because they were created in order to exhibit the purported power of the DT, including animation, three-dimensional flyovers, and high-resolution large-scale displays. The experimental presentations were "hosted" by a single live narrator familiar with the phenomena in the DT demonstrations.

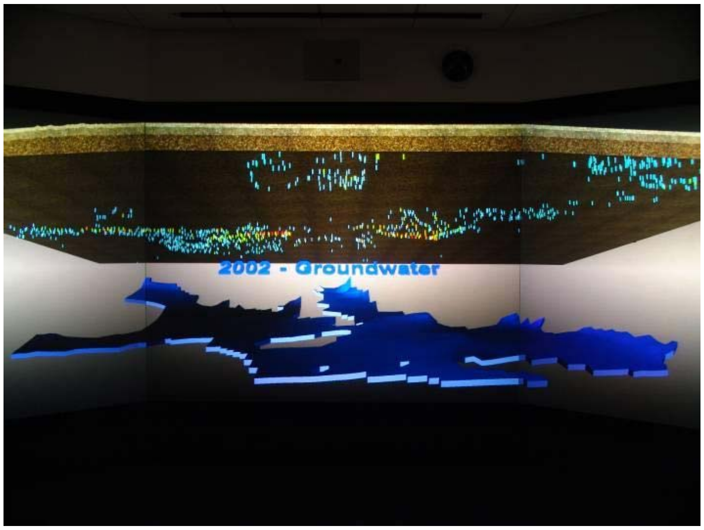

Figure 1. This photo was taken inside the Decision Theater. The 3D groundwater image here is rear-projected onto the three front walls of the DT.

The control subjects saw a modified version of the demonstration, altered for presentation as a static-image slideshow in PowerPoint. For experimental robustness, we designed the PowerPoint presentation to replicate the DT presentation as closely as possible. This involved carefully selecting and extracting those images from the demonstrations that were necessary to illustrate the concepts described by the host. We felt that it was necessary to add trapezoidal "neatlines" around the oblique surfaces in the PowerPoint presentation to provide a depth-perspective cue (Figure 2). These were the only elements of the images in the modified version not in the experimental version.

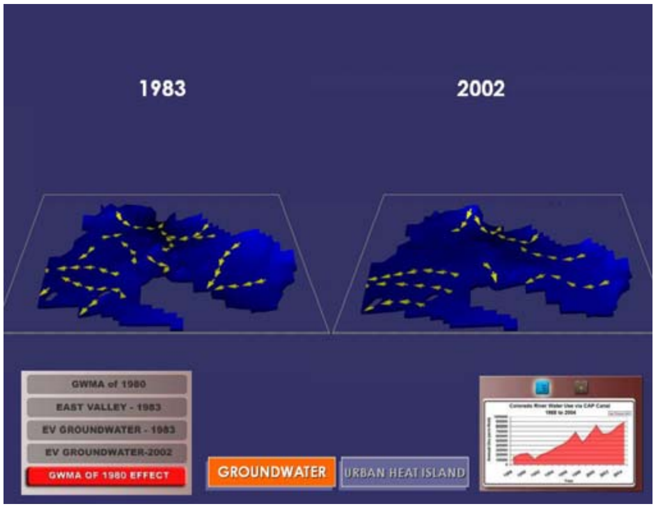

Figure 2. slide from control group PowerPoint presentation, showing side-by-side groundwater surfaces and trapezoidal frames added to static images to give depth cues.

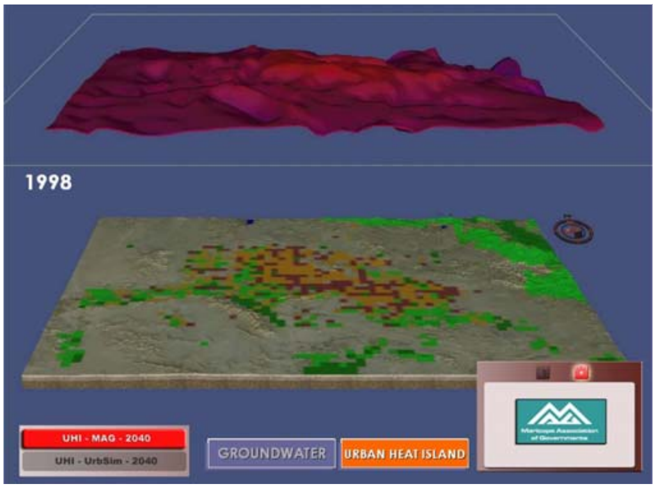

Figure 3. Urban heat island demonstration, showing temperature surface (top) and corresponding LANDSAT-population composite image (bottom).

For both the experimental and control group, the presentation lasted about 15 minutes. The first half of the presentation addresses the overdraft of groundwater in the Phoenix region, discussing agricultural land uses, well water infrastructure and pumpage volumes, population growth and urban development. During the presentation, relevant representations of groundwater surfaces, population growth, well locations and pumpage volumes, and the cone of depression are shown as part of the visualization demonstration.

The second half of the presentation documents increasing temperatures in the region due to urban development that results in greater heat emitted at night from cement and asphalt from highways and other surfaces. The heat island is depicted as a surface with high points and red-pink color over places that are warmer (high density urban areas) and low points and bluish color over places that are cooler (desert mountain preserves and rural areas; Figure 3).[1]

3.3. Research questions

We set out to evaluate the following hypotheses:

1. *that the two presentation styles (DT and PowerPoint, described above) would differentially influence understanding of both general and specific aspects of environmental issues, and*

[1] The color scheme is redundant with the surface height information, though it is interesting to note that neither symbolization is particularly effective: relative heights are difficult to judge, and in some cases impossible to see, given the oblique angle of the surfaces, and colors are difficult to perceive given the shadowing effects of the terrain shading.

2. *that the two presentation styles would differentially influence perceptions regarding various causes of problems and the effectiveness of various policy approaches to mitigating them.*

Our survey, described further below, included causes and policy approaches that were selected based on realistic alternatives; some alternatives in the survey were emphasized in the presentation while others were not in order to assess the effect of visual and verbal cues on perceptions (Table 1). We anticipated that the immersive presentation would be more likely to lead users to conclusions based on the content of the presentations than the PowerPoint slide show. Perceptions regarding causes will be evaluated along theoretical important dimensions including natural versus human-induced factors. Meanwhile, those toward mitigation efforts are expected to vary by policies such as regulatory or economic-based approaches. If the visual demonstrations do indeed influence human understanding, we expect perceptions to vary less along these dimensions and, instead, to reflect those aspects of environmental problems emphasized (or not) in the presentations. The demonstrations generally highlight population growth and urban development, land use planning and water policy, and technology and infrastructure, while drought and the dry regional climate, educational programs and economic-based policies were not underscored.

Table 1. Survey Question Design

How much does each contribute to…?	1 = NOT AT ALL…5 = A LOT
Water shortages	***Rising temperatures***
Amount of water used for farming	Closely spaced houses and buildings
Low levels of rainfall in the Arizona desert	Conversion of farmland to urban uses
Naturally occurring droughts	Emissions from cars and industry
Poor planning and management of water	Global warming
Population growth	Inadequate land use planning
Residents overuse of water in yards	Paved surfaces such as highways and parking lots
How effective is each for…?	1 = NOT…5 =VERY
Preventing water shortages	***Stopping temperatures from rising***
Converting land from farms into houses	Developing new paving materials (e.g. rubberized asphalt)
Educating public about conserving water	Investing in public transportation such as buses
Finding new sources of water	Limiting urban sprawl
Increasing the price of water	Planting more trees and vegetation
Investing in low water using technology	Preserving native desert areas
Restricting the use of water from wells	Restricting roofing materials that give off a lot of heat

We also hypothesized

3. *that the presentation will have a greater impact on lay understanding and perceptions compared to relatively informed experts, given the latter's more detailed and nuanced understanding of the issues prior to and beyond the information presented.*

To evaluate this effect, we included both students (non-experts) and professionals (experts) in the assessment.

3.4. The Survey

The survey consisted of an online “pre-survey,” completed before the presentation, and a paper “post-survey,” completed afterwards, focused on perceptions of the two environmental problems in the presentations in terms of their magnitude, their natural and human-induced causes, and policy options for their mitigation. The majority of survey questions were answered on five-point ordinal scales (see Table 1 for an example).

On both pre- and post-surveys, questions were asked with respect to generalized issues (water shortages, climate changes) and specific aspects of issues (groundwater overdraft, cone of depression, urban heat island). Additional factors hypothesized to influence environmental perceptions and the influence of the presentation style include environmental values and political beliefs (pre-survey only) as well as views of science and technology and experience with computers and demographic factors (post-survey only). Open-ended questions gathered comments capturing what participants thought of the presentation including how it changed their understanding and views, in addition to their general opinions on the water and heat issues discussed.

One disadvantage of using the pre-/post-survey method is that we were unable to allow questions and comments from the participants, as we worked hard to keep the presentations given to the groups as similar as possible. We did invite participants to ask questions following the completion of their post-surveys.

3.5. Research Sample and Recruitment of Participants

We consider this entire experiment a “pilot” study to a larger and more comprehensive project in which we will have more control over the factors we are evaluating. At the time of writing, we have completed a preliminary evaluation (n = 21) to evaluate the survey and techniques (perhaps we could call it a “pilot of the pilot”), and we are near completion of the data collection for the non-expert participants (n ~ 70).

The preliminary pilot survey was conducted using just the DT presentation with two groups: seven students involved with the Community of Undergraduate Research Scholars (COURS) program, and fourteen water educators from public and non-profit entities. As this is an inadequate sample for statistical analysis, we used the results and feedback from this study primarily to refine the survey questions and the presentation. However, we present summary statistics in Tables 2 and 3 to illustrate the data collected and patterns that may emerge from this study.

The non-expert sample was drawn from students enrolled in three undergraduate geography classes. We used a convenience sampling method, targeting students by offering extra credit in their courses. Expert professionals were solicited with a pair of movie tickets through a referral-based, snowball sampling method (Bryman 2000) initiated by e-mailing division directors in local and regional public agencies (e.g., land use planning, water utilities).

Summary statistics from the pre-surveys and written comments from the post-surveys are summarized in the following section, along with those from the pilot test of the survey.

4. Preliminary Results

4.1. Summary statistics from preliminary study

The preliminary (n = 21) survey revealed that the DT presentation did affect how knowledgeable participants feel about specific water issues but not water resource issues generally (Table 2). These results followed our expectations, as awareness of those issues discussed during the demonstration was increased. Awareness changes varied between lay and expert groups, as students came away (again, not surprisingly) with a greater increase in awareness, particularly with water issues, than experts. Participants reported increased knowledge of the urban heat island but a decreased understanding of global warming, the issue about which students reported the most knowledge prior to watching the demonstration. We will analyze the data from our larger survey with appropriate tests for significance.

Table 2. Reported Knowledge about Different Environmental Issues among Lay and Expert Participants: Comparing Pre- and Post-Demo Responses

		Water Resources	Groundwater Management Act	Groundwater Overdraft	Cone of Depression	Global Warming	Urban Heat Island
Professionals	PRE	3.93	3.07	**3.07**	**2.64**	**3.14**	**3.21**
	POST	3.93	3.07	**3.29**	**3.36**	**3.00**	**3.67**
Students	PRE	4.00	**2.33**	**2.30**	**1.86**	**4.14**	**3.00**
	POST	4.00	**3.50**	**3.25**	**4.00**	**3.50**	**4.20**

Note: Response scale: 1 = not knowledgeable, 5 = very knowledgeable. **Bolded** means represent differences between pre- and post-test surveys. **Gray-shading** highlights greater reported knowledge.

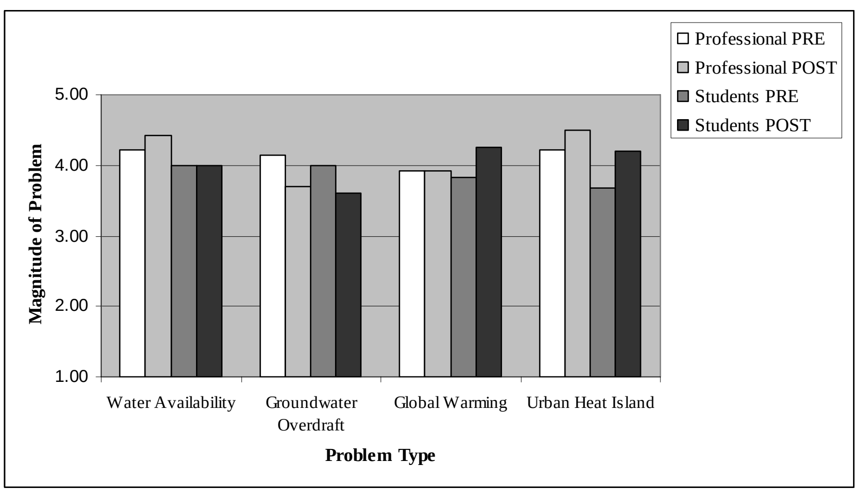

Figure 4. Changes in Perceived Magnitude of Various Problems among Lay-Expert Participants Before and After Viewing the DT demonstration

The DT demonstrations also appeared to affect perceptions about the magnitude of environmental problems in the pilot test of the survey (Figure 4). As suspected, the visual presentation had a greater impact on non-expert perceptions compared to those of experts. The issues explicitly addressed in the 3-D demonstration changed the most among both groups, and in the expected directions. The presentation is clear in arguing that the cone of depression problems in the Phoenix area are lessening with the passage of the Groundwater Management Act in 1980, and both non-expert and expert survey respondents reported that the magnitude of the corresponding groundwater overdraft problem was decreasing. However, the urban heat island was seen as an increasing problem, consistent with the message of the presentation. Other results regarding magnitudes of problems also followed expectations, though it is worth noting that non-experts seemed to confound the urban heat island with global warming, which was not mentioned in the demonstration. These effects will also be examined more critically with our larger sample.

4.2. Participants' comments

Though have not yet completed the data collection and analyses, we have examined some of the written comments from the non-expert student participants (n ~ 70), half of whom saw the DT demonstration, and half of whom saw the classroom PowerPoint presentation. Overall, both the DT and PowerPoint presentations seemed to improve understanding and heighten interest in environmental issues.

> **DT viewer:** "[The presentation] definitely opened my eyes to the urban heat island…and helped explain why the temp. stays so high, even at night. It makes me think twice about if all this new development is a good idea."
> **PowerPoint viewer:** "It helped educate me on the issues of water consumption and heat in the valley. When it comes to voting on any relating issues, I feel like will be able to come to an educated decision about what needs to be done with a higher degree of confidence."

While both presentations generated greater awareness of the issues, the 3D/immersive group offered more positive and enthusiastic comments about the information.

> "Sweet 3D."
> "I saw everything as an image rather than numbers. Usually helps a lot!"
> "[The presentation] was very good and impressive. The presentation in 3D was amazing and the data was substantial… (*sic*)."

Meanwhile, a student in the classroom presentation group critiqued the PowerPoint images as well as the presentation:

> "The information was interesting but the graphs and visuals were terrible. I had a hard time reading the three dimensional images and the oddly slanting map of Phoenix was impossible to match up to the graphs…"

As discussed below, a limitation of this study was our reliance on existing demonstrations and readily available images for the PowerPoint presentation. Future work is planned to improve upon the information displays and further evaluate changes in mental models of the phenomenon due to exposure and interaction with varying visual displays of information and virtual environments.

5. Discussion

It is clear from our preliminary results that the DT is effective for supporting understanding and decision-making about complex three-dimensional environmental issues, in both experts and non-experts. This is a positive result, though one might expect that, by watching a 15-minute presentation on an environmental topic, understanding of that topic would increase, even without any visual representations. This experiment, however, is less clear in showing that the DT presentation led to more understanding, or different decisions and conclusions, than the PowerPoint presentation in a university classroom. Our first examination of the data supported the frequent and intuitive result that users are more impressed with virtual representations than more traditional presentation styles, and some comments lead us to believe that the PowerPoint presentation was indeed less effective at representing these phenomena.

Even after the final analysis of the data from the larger survey, several factors reduce the potential of this experiment to generalize about the power of the DT or similar semi-immersive virtual environments. Having run this pilot study, for example, we found it difficult to separate independent variables from one another using our methodology. Future research in this area needs to be more explicit about which factors are being tested and which are being controlled. For example, there are several possible factors about the DT environment that may play a part in the variance of understanding and decision-making of our subjects. It is unclear if variance exists due to the animated graphics, their three dimensionality, the immersion and peripheral "presence," the furnishings and environment, or the more affective "wow" factor of virtual reality.

Despite our efforts, we are aware that the images we created for the PowerPoint presentations lacked the context and cues necessary to adequately display the phenomena in the demonstrations. We were limited by our choice of using an existing demonstration designed for the multiple screens and immersive character of the DT, and we found it impossible to create a comparable PowerPoint presentation. If we were to create, from scratch, an experimental instrument that could be as easily displayed in PowerPoint (and show that simplified version in the DT), we would better be able to isolate those factors about the DT that lead to differential responses (e.g., the room, the furnishings, the display). We would also be able to create graphics and maps that followed widely accepted cartographic guidelines for data representation (thereby simply improving the representations and their ability to communicate information). However, using a demonstration created to exploit the power of the DT allows a more realistic portrayal of the Theater in a decision-making application.

The presentations in the DT we used for this study have already been superseded with more interactive and better designed representations. We controlled for many factors, attempting to keep the images and the narration as identical as the technology would allow between the two presentation types. As with research of this type, the differences (or lack thereof) in responses between the presentation types likely also depend on the quality of the presentations and the exploitation of the potential of the technology tested as the difference between the presentation types.

6. Future research agenda and conclusion

Limitations of the pilot project will be addressed in follow-up research. First, improved design of visual graphics and alternative media settings will better assess their influence on environmental perceptions. Some options considered include development of traditional displays such as contour maps or cross-sectional diagrams, in addition to classroom and web-based settings. Second, additional methods will be incorporated to better evaluate how different visual information affects understanding and mental models of environmental problems. For example, recording questions and comments throughout presentations and conducting focus groups following demonstrations would aid understanding of how different visual environments elicit understanding, inquiry and other responses from participants. Third, greater emphasis on the educational benefits of such technology will be evaluated in terms of multi-disciplinary (mis)understanding of environmental systems through closer evaluation of knowledge and mental models of phenomena before, during and after exposure to various media displays.

Acknowledgements: This material is based upon work supported by the National Science Foundation (NSF) under Grant No. SES-0345945 Decision Center for a Desert City (DCDC). The Office of the Vice President for Research and Economic Affairs of Arizona State University is acknowledged for their contributions in supporting research at the Decision Theater. Any opinions, findings, conclusions or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of NSF. We also thank Patricia Gober, Bill Edwards, Matthew Kruger, Jessica Block, Deirdre Hahn, John Shaeffer, Barbara Trapido-Lurie and Margaret Nelson for their assistance with this project.
For more information about the Decision Theater at Arizona State University, please visit www.decisiontheater.org

7. References

Bryman, A. 2001. *Social Research Methods*. New York City, NY: Oxford University Press, 540 pp.

Carver, S., S. Frysinger, and R. Reitsma. 1995. *Environmental Modeling and Collaborative Spatial Decision-Making: Some Thoughts and Experiences Arising from the I-17Meeting Proceedings*.

Davies, D. and D. Medyckyj-Scott. 1994. Introduction: The Importance of Human Factors. In H. M. Hearnshaw and D. J. Unwin (eds). *Visualization in Geographic Information Systems* (New York, NY: John Wiley & Sons), 189-192.

Demiralp, C., C.D. Jackson, D.B. Karelitz, Z. Song, and D.H. Laidlaw 2006. CAVE and Fishtank Virtual-Reality Displays: A Qualitative and Quantitative Comparison. *IEEE Transactions on Visualization and Computer Graphics*, 12(3): 323 – 330.

Durlach, N., G. Allan, R. Darken, R.L. Garnett, J. Loomis, J. Templeman, and T.E. von Weigand, 2000. Virtual Environments and the Enhancement of Spatial Behavior. *Presence* 9(6): 593-615.

Fisher, SH, J.V. Dempsey, and R.T. Marousky 1997. Data visualization, preference and use of two-dimensional and three-dimensional graphs, *Social Science Computer Review* 15(3), 256-263.

Fung T., Y. Leung Y, and H. Lin, 2004. From paper maps to virtual reality: a view from Hong Kong. Cartographic Journal 41(3): 261-264.

Gershon, N. and S. G. Eick, 1997. Information Visualization. *IEEE Computer Graphics and Applications*, 17(4): 29-31.

Koh, G., T.E. von Weigand, R.L. Garnett, N. Durlach, and B. Shinn-Cunningham, 1999. Use of virtual environments for acquiring configurational knowledge about specific real-world spaces. *Presence* 8(6):632-656.

Mak, A., P.C. Lai, R. K.-H. Kwong, S. Leung, 2005. Too Much or Too Little: Visual Considerations of Public Engagement Tools in Environment Impact Assessments. in S. Bres and R. Laurini (Eds.). VISUAL 2005, *Lecture Notes in Computer Science* 3736, 189-202

Reitsma, R. F. 1996. Structure and Support of Water-Resources Management and Decision-Making. *Journal of Hydrology*, 177(1): 253-268.

Salkind, N. J. 2000. *Exploring Research* (4th edition). Prentice Hall, 320 pp.

Stone, R. 2001. Virtual reality for interactive training: an industrial practitioner's viewpoint. *Int. J. Human-Computer Studies* (2001) 55, 699-711.

Zigurs, I., R. Reitsma, C. Lewis, R. Hubscher, and C. Hayes. 1999. Accessibility of Computer-based Simulation Models in Inherently Conflict-Laden Negotiations. *Group Decision and Negotiations*, 8: 511-533.