ANSWERING QUESTIONS WITH 2D AND 3D TOPOGRAPHIC MAPS: USE OF EYE-TRACKING TO UNDERSTAND REPRESENTATIONAL REASONING

Topographic maps are a common representational form used in earth science education. Increasingly sophisticated computer-based tools make it easier to create alternative representations to the traditional 2D topographic map. However, very little research has been conducted showing which representational type is best for a particular instructional context. This study looks at the potential for eye tracking methods to provide insight as to how students acquire information from different topographic representations. The results indicated that the type of question asked (and, therefore, the information needed from the representation) had a substantial impact on how students viewed the topographic representations.

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Rationale

The use of topographic maps in science education has long been recognized as an important tool in instructional areas such as earth and environmental science education and in allied professional areas (MacEachren, 1995; Piburn et al., 2002). More recently, research has been done on the relationship between the specific nature of the cognitive task and the type of topographic representation being used (St. John, Cowen, Smallman, & Oonk, 2001). The effective use of contour maps and other topographic representations in instructional settings needs to be determined to further work to date on understanding the underlying cognitive processes being employed to make use of information contained in these representations. Eye tracking technology is one tool that has been investigated to help understand representational reasoning with both contour maps and other types of representations used in science education (Chang, Lenzen, & Antes, 1985; Tai, 2004). Eye tracking and, more specifically, points of fixation, can be used to help interpret cognitive processes related to visual perception (Carpenter & Just, 1978). This paper is an exploratory study looking at the potential for eye tracking to be used as a means of investigating cognitive processes employed by learners when using topographic representations. More specifically, for examining the interaction between types of topographic representations and instructional tasks that require either local or global interpretation of topographic information.

Subjects & Instructional Materials

A set of twenty multiple choice questions were developed, each of which corresponded to a topographic representation. Two sets of topographic representations were created in a GIS system. One set (called 2D) represented the terrain as contour lines with the region between each line shaded in gray using a value scale that represented the lowest area in black and the highest in white. The same terrain models were used to create the other representation (called 3D) by "draping" the contour map over a 3D model of the terrain and viewing it as a pictorial from an angle and azimuth that would allow a clear view of the critical features in the terrain.

The questions paired with these terrains were generated to either require the acquisition of local information from the terrain (e.g., what is the elevation at point A?) or require the synthesis of information across a region of the terrain (e.g., would a dam breaking at point A more likely flood a house at point B or point C?). Questions requiring only local information were called "focused" questions while those requiring synthesis were called "integrative" questions. In addition, both sets of questions would either require elevation information or not. These two factors crossed to create four question types with six questions written for each cell. These question/representation pairings were originally created for a study looking at student performance (Savage, Wiebe, & Devine, 2004).

Methodology

Thirteen undergraduate students completed this study, ranging in age from 19 to 39, with approximately twice as many females as males. Students participating in the study were randomly assigned to groups that either answered the twenty-four questions using the 2D or 3D representations. In all, 5 participants viewed the 2D representations while 8 viewed the 3D. All questions of each type were presented on a computer screen to participants in randomized order. Response time was measured, as was correctness of response. Students were instructed to answer as quickly and accurately as possible. Once the students were ready to view the topographic representations, they had an eye-tracking system placed on their head and calibrated. The system used was the Applied Sciences Laboratory (ASL) 504 eye-tracker that allows six degree freedom of head motion by the subject throughout the testing period. The system collected data 60 times/sec on the gaze direction of the left pupil relative to the computer screen. Calculations using this data allowed points of perceptual fixation on the computer screen and related measures to be determined.

At the conclusion of the data collection, eye tracking data was broken down by question for each student. Specific questions were chosen for further analysis based on their representativeness of the key question types. In addition to quantitative analysis of the eye tracking data, movies were generated that overlaid the gaze data onto the question/representation shown on the computer screen. These overlays were used to provide triangulating qualitative analysis of the data.

Results

For the quantitative analysis, the primary dependent values of interest were all derived from the gaze location from which fixation data was derived. A fixation is essentially any 2 degree visual arc where the eye dwells for more than 100 msec. Note that not all the time spent looking at a scene is taken up with fixations (as just defined). The initial pass at the eye tracking data determined which region of the screen the eye was gazing at: the topographic representation (called Map), the Question, or elsewhere (called Other). Fixation time and time gazing (both total and percentage) were calculated for each region. Within these regions, calculations were made determining the total number of fixations, the mean fixation time, and interfixation distance (saccade length).

The number of students involved in the study ruled out the use of significance level statistics. Instead, effect size statistics were used (Kramer & Rosenthal, 1999). Two focused questions and three integrative questions were chosen for detailed analysis. The analysis was done on both the 2D and 3D representations of these questions. These questions were chosen based on the question type and the quality eye tracking data. Table 1 shows the breakdown of gaze data between the two key regions and the independent measures.

Table 1. Mean Values of Total Eye Gaze Time in each Region by Question Type and Representation Type (Standard Deviation in parentheses)

		Region		
		Total	**Question**	**Map**
Question Type	Focused	25.45 (7.36)	7.56 (3.30)	13.26 (4.24)
	Integrative	30.97 (8.08)	10.17 (3.93)	16.63 (5.86)
Difference/Effect Size		-5.52/-0.71	-2.61/-0.72	-3.38/-0.66
Representation Type	2D	28.34 (8.80)	8.59 (2.96)	14.88 (6.91)
	3D	29.19 (5.58)	9.66 (3.83)	15.68 (3.19)
Difference/Effect Size		-0.85/-0.12	-1.06/-0.31	-0.81/-0.15

Note that more time was spent total and in both the Question and Map regions for both Integrative questions and for those looking at the 3D representations. However, the effect sizes only reached meaningful levels for the Question Type (Focused vs. Integrative). Table 2 presents the quantitative data broken down by the independent and dependent variables of interest for the Map region.

Table 2. Mean Values of Fixation Measures in the Map Region by Question Type and Representation Type (Standard Deviation in parentheses)

		Fixation Measure		
		Interfixation Distance (mm)	**No. of Fixations**	**Mean Fixation Duration (sec)**
Question Type	Focused	124.91 (51.50)	21.7 (3.15)	0.468 (0.063)
	Integrative	147.97 (30.88)	29.6 (9.58)	0.412 (0.064)
Difference/Effect Size		-23.06/-0.54	-7.94/-1.11	0.06/0.89
Representation Type	2D	136.77 (45.00)	26.6 (10.87)	0.425 (0.081)
	3D	140.72 (38.28)	26.3 (6.46)	0.444 (0.057)
Difference/Effect Size		-3.95/-0.09	0.30/0.03	-0.02/-0.27

When answering integrative questions, students had larger interfixation distances and a higher number of fixations, though the mean fixation duration was smaller. The effect size measures indicated that these differences were particularly notable for the number of fixations and mean fixation duration. These measures did not demonstrate notable differences when looking between 2D and 3D representations.

Qualitative analysis of the fixation patterns indicated that regardless of the question or representation type, students spent little time fixating on areas of the map that were not directly related to the question being asked. That is, their fixations clustered around the key points marked on the map. In addition, their fixation sequences showed regular movement back and forth between the question text and the points of interest on the representation, especially for the integrative questions.

Conclusions and Implications

This exploratory study has revealed interesting relationships with earlier findings: a previous study using these representations and earlier work using eye tracking with topographic maps. Based on other eye tracking research, Chang, et al. (1985) concluded that experts made better use of peripheral vision in processing topographic map information, resulting in a larger "useful field of view." This was exhibited in the eye tracking data as larger mean interfixation distances. Similarly, experts had less difficulty processing the individual features on the map, as exhibited by shorter mean fixation durations. While this current study did not look at the distinction between expert and novice map users, these measures can also be used to indicate the relative difficulty in extracting useful information from the map representation to answer the questions at hand. Other literature indicates that the total number of fixations and time spent in a region is indicative of the perceived usefulness and complexity of the information (Carpenter & Just, 1978). Examining the results of the current study, it seems that the 3D map did not affect students' ability (either positively or negatively) to gather information from the topographic maps. These results aligned with the earlier study by Savage, et al. (2004) which only found minimal differences in performance between the 2D and 3D representations with the only advantage showing in the use of a 2D representation for focused questions.

Focused and integrative questions, on the other hand, showed differences on every eye tracking measure reported. Students spent more time looking at the integrative questions and maps. In addition, they had longer interfixation distances, more fixations, and shorter mean fixation durations. Chang's, et al. (1985) notion of "useful field of view" helps interpret the larger interfixation distances for the integrative questions as indicating that a larger area of the topographic map had to be used to answer the questions. Similarly, more fixations were needed with the integrative questions to pull multiple information elements together to answer the questions. Both the visual spread and the amount of information that needed to be synthesized for the integrative questions may point to potential difficulties on the part of novices to answer integrative questions from topographic maps. It seems the 3D representations did not alter either of these key eye tracking measures substantially.

The qualitative analysis sheds some light as to why the interfixation distances and total number of fixations were larger for the integrative questions. While with the focused questions, the fixation locations stayed close to the marked points on the map, the integrative questions had two or three points (in addition to important topographic information between the points) that were needed to address the question. The increased amount of fixation exchange between the Map and the Question regions also indicated the increased difficulty in managing all of the necessary information. Both these factors would result in increased mean interfixation lengths and number of fixations.

Interpretation as to why the mean fixation duration was shorter for the integrative questions is more difficult to interpret. It could be that the use of more fixations with the integrative questions meant that they divided their time between more areas of the map rather than concentrating in fewer areas. This would be parsimonious with the need to read exact elevation, latitude, or longitude values for the focused questions.

These interpretations of the difference between the integrative and focused eye tracking data aligns with Savage's, et al. (2004) findings that integrative questions were the most difficult to answer, regardless of whether a 2D or 3D representation was used. This study points to the potential for eye tracking data to be used as a tool for gauging not only the difficulty of a particular problem, but what type of representation might best support the construction of knowledge around that question. Eye tracking data is likely to be most powerful when it can be used in conjunction with other data collection methods, both quantitative and qualitative.

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