Fostering Students' Comprehension of Topographic Maps

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ABSTRACT

Novice earth science students often have difficulty visualizing three-dimensional interpretations of flat, two-dimensional displays. This challenge becomes apparent when students attempt to comprehend topographic maps. In this study, we investigated conditions that influence such activity. Earth science students viewed standard topographic maps, maps that included shading, maps that included stereo visualization (affording a three-dimensional percept of the map), or maps with both stereo visualization and shading. Students answered line-of-sight questions (i.e., intervisibility tasks) while viewing their assigned map. These questions required students to visualize a route-perspective from the map's survey-perspective, with particular attention to the terrain relief. Tasks like this are routinely completed during topographic map experiences, and provide insight into a user's understanding of the dynamic land surfaces conveyed by those maps. Overall, stereo visualization was more successful than shading in facilitating students' completion of the task. Students' general performance was not influenced by gender, but was influenced by other background characteristics (e.g., expected course grades, prior map experience, and predilections for outdoors activity). Students also preferred maps employing three-dimensional cues more than maps without them. Classroom activities in the earth sciences may benefit from incorporating stereo visualizations into map-learning exercises.

INTRODUCTION

Topographic maps are two-dimensional depictions of landscapes that use contour lines to convey information about the actual shape of the earth. Points that lie along a single contour line are part of the same elevation in the real world; each contour serves as a conceptual line joining points of equal height. The relationships between contour lines (i.e., the relief of the land surface) convey detail about the nature of terrain and the topography of a region (e.g., the height, depth, and steepness of slopes). To experienced geographers and geologists (and even hikers), this information affords inferences about the geometry of the land surface, the probable origins of landscape features, current water flow, distance relationships, and the ease or difficulty of particular travel routes. Thus, topographic maps are indispensable tools for understanding a region's geologic development, describing its current state, and forecasting potential change. Scientists use these symbolic two-dimensional representations to construct the complex, three-dimensional mental models necessary to "truly know" an environment (Rapp, 2005; Rapp and Uttal, 2006).

But consider, in stark contrast, novice geoscience students' comprehension of such maps. Given their lack of training or experience with these maps, topographic displays can resemble a jumbled array of randomly converging lines, circling and curving in haphazard directions across a map's surface. The relationships among these lines are not immediately apparent, and students may ask relatively naïve questions such as: Does a line convey height or distance in some specific way, and if so how? Do the lines indicate slope or terraced relationships? How do these lines relate to one another - are they grooves or boundaries of some sort? Yet the novice is still expected to generate informed scientific explanations from these maps despite a lack of familiarity with map features, limited overall experience with earth science theories, and little specific training as to how novel symbolic representations of the world might relate or 'map on to' real world locations (e.g., Gilhooly et al., 1988; Liben and Downs, 1989; MacEachren, 1995; Shimron, 1978; Thorndyke and Stasz, 1980; Tversky, 2000; Uttal, 2000). Simply put, novices are often confused as to how a flat depiction represents a dynamic, complex 3-D landscape.

The discrepancy in knowledge and performance between expert and novice map users is a critical issue in introductory earth science classrooms. Instructors often must plan protracted sequences of lessons and practice activities to help students learn to read and use topographic maps. Such tasks are intended to familiarize students with the basics of map use (e.g., recognizing features and identifying landmarks). For example, students are often asked to graph vertical profiles along selected lines on a map, to draw successive contour lines as an irregular surface is incrementally flooded in a tank, or to compare a contour map with a three-dimensional model of the depicted surface. On campuses with some relief, the campus area itself is often recruited as a teaching aid with students constructing or using contour maps of the campus to complete tasks.

However, the ultimate goal of map instruction is not just for students to easily recognize or identify fixed aspects of maps, but to also use that information to generate inferences that go beyond the explicit features of the map itself, such as the relationships between locations that are not explicitly depicted or immediately obvious (e.g., Morrow et al., 1987; Taylor and Tversky, 1992, 1996). And, of course, the intention is for students to transfer these skills to new maps and unfamiliar regions. Thus, instruction seeks to help students think deeply about the real-world locations that underlie the symbolic representation of a map. Activities that test whether students can do this successfully might require them to determine the direction of water or lava flow as a function of terrain, to hypothesize how particular land formations developed, to identify real-world locations on a survey map using route-perspective photos, or to consider what someone at a particular location would be able to see; in other words, to complete the types of tasks experts normally do when they use topographic maps (Ishikawa and Kastens, 2005). Despite extended training, students often find these tasks considerably difficult to complete, and their difficulty may begin with simply understanding that the two-dimensional map is a depiction of three-dimensional space (Pick et al., 1995).

The primary purpose of this study was to examine whether map features can be modified to help students develop a basic understanding of the 2-D to 3-D relationships conveyed in topographic displays. Specifically, we were interested in whether particular visualization manipulations that naturally afforded salient, perceptual experiences of elevation might convey these relationships in a more direct way. A secondary purpose of this study was to investigate whether differences in students' background characteristics (i.e., gender, previous topographic map experiences, self-identified performance in earth science classes, and predilections for outdoors activity) might provide insight into some of the conditions that foster general topographic map comprehension. Examining these factors in a single project allowed us to assess the contributions of map type and prior experience on learning from topographic maps. Research in cognitive science has successfully outlined conditions that foster effective learning experiences by studying these types of participant and task content influences (e.g., Rapp and van den Broek, 2005; Taylor et al., 1999). A similar approach should prove useful for elucidating conditions that facilitate general map comprehension (e.g., Kulhavy and Stock, 1996; Lobben, 2004), and in this particular project, the comprehension of topographic maps (also see Schofield and Kirby, 1994). Below we describe our theoretical motivations for these manipulations and our assessment measures.

MAP MANIPULATIONS AND MAP COMPREHENSION

Beyond the obvious importance of the *content* of a map, map *features* also have direct influences on learning (MacEachren, 1995). Borders and roads depicted on a map, for instance, constrain the ways in which map users group and organize locations (e.g., McNamara et al., 1984; McNamara et al., 1989; Stevens and Coupe, 1978). In some cases, these groupings can create comprehension difficulties, such as when they lead to perceptual confusion or to biased interpretations. For example, borders can convey the notion that certain regions are closer or farther apart than actually true (McNamara, 1986), with a concomitant impact on memory for the locations depicted in those maps. Other types of map cues, in contrast, can enhance comprehension by explicitly identifying important spatial features and relationships. For example, arrows can indicate the importance of map elements for understanding particular areas of interest on a map (e.g., Tversky et al., 2000).

Existing work has investigated whether such cues specifically influence interpretations of relief. These studies have looked directly at the role of map manipulations designed to highlight particular features of maps, and the related benefits to map legibility and map comprehension that accrue as a function of such manipulations. Cues such as color, tints, shading, layering, height labeling, and map symbols have all proven potentially useful as aids for understanding two-dimensional presentations of dynamic landscapes (e.g., Eley, 1987; Phillips et al., 1975; Shurtleff and Geiselman, 1986). The design and selection of relief maps, and the cues to be implemented in those maps, should certainly be guided by the particular task at hand, as there are many cartographic methods available for presenting dynamic geographic data (e.g., Brandes, 1983). Obviously, the utility of a map and its particular set of cues depend critically upon factors such as the expertise of the map user and the nature of the map task. Consider that while experts can rely upon their background knowledge to generate inferences about the information depicted in a map, novices do not have the same resources and practiced skills to draw upon during comprehension tasks.

Map activities can be particularly difficult for novice students, as comprehension requires devoting cognitive resources to multiple processes (e.g., Baddeley, 1992; Kahneman, 1973; Mayer, 2001), such as the basic identification and categorization of map regions and features, as well as inferential problem solving. That is, students must recognize the parts of a map, connect those parts into a coherent whole, and derive hypotheses from those products. Visualizing a two-dimensional map in three-dimensions, as is necessary with topographic maps, requires considerable effort on the part of the novice student (Taylor et al., 2004). It involves processes including spatial orientation, mental rotation, and spatial visualization (Pellegrino et al., 1984; Schofield and Kirby, 1994). Thus, we sought to implement map features that would embody the third-dimension of topographic maps in accord with perceptual experience, alleviating some of the mental effort necessary for such visualization. In the following study, we assessed map shading and stereo visualization as methods for emphasizing the elevation-based relationships inherent in topographic maps. We hypothesized that shading might provide one method for more directly conveying the relationships represented by contour lines in a topographic map. Shading is a cue that can convey information about height and depth, as a function of the extent or reach of shadow from various points on a physical structure (e.g., Langer and Bülthoff, 2000). To build shading into topographic maps, we imagined an illuminating source on one side of the map, and then modeled appropriate darkened regions to the opposite side of the terrain, taking height into account.

While shading may be effective, another method of making topographic relief more explicit and salient is through stereo visualization. During stereo visualization experiences, anaglyph images are presented to each eye, with each image taken from a slightly different yet overlapping perspective. When these two perspectives are viewed simultaneously (usually using specially designed lenses, as for example, red-cyan lens anaglyph glasses), the perception of depth is conveyed by the disparity of the flat images. Stereo visualization has often been used in entertainment experiences, including movies and comic books, to make viewers feel as if visual stimuli are 'popping out at them.' Thus, a flat image can be changed into a 3-D perceptual experience. In this manner, we used stereo visualization to make the terrain appear to 'pop out' of the map. When a topographic map is designed using 3-D stereo visualization, landscapes with higher elevation appear closer to the viewer than landscapes with lower elevation; from a survey view of the map, for example, mountaintops appear closer than valleys. Contour lines overlaid on these landscapes then more directly embody actual landscape formations.

STUDENT CHARACTERISTICS AND MAP COMPREHENSION

We also investigated how characteristics of map users might influence performance with topographic maps (Ishikawa and Kastens, 2005; Schofield and Kirby, 1994). Because our project sought to specifically examine how novice earth science students comprehend topographic maps, we considered characteristics that, based on both face validity and existing research, might obviously influence performance in introductory earth science classrooms. As one characteristic, we were interested whether earth science course grades might predict success with topographic maps. However, due to ethical considerations involved in soliciting course grades from identified participants, as well as the fact that the experiment took place during the semester so final grades were not yet available, we could not use actual grades as a measure of performance. Instead, we asked participants to self-report their expected grades in the earth science class. While there is concern over the degree to which self-reports are valid indicators of performance (Gonyea, 2005; Paulhus et al., 1998; Pohlmann and Beggs, 1974), we believed such reports would provide at least preliminary insight into map comprehension as a function of students' course experiences. In addition to predicted course performance, we also examined participants' map knowledge and predilections toward using maps, as measured, respectively, by their prior familiarity with topographic maps and their general interest in outdoors activity (queried with respect to their predilections for hiking and camping). Finally, there has been considerable interest in potential gender differences with respect to geoscientific comprehension (e.g., Libarkin and Kurdziel, 2001), map comprehension (e.g., Brown et al., 1998; Montello et al., 1999; Tlauka et al., 2005), and more generally, spatial abilities (e.g., Lawton, 1994; Lawton et al., 1996; Linn and Petersen, 1985). Consequently, we examined whether gender was related to topographic map comprehension.

ASSESSMENT OF TOPOGRAPHIC COMPREHENSION

As a dependent measure, we looked at the degree to which participants could effectively understand topographic contours, particularly with respect to the relationships between locations of differing heights. We asked participants to imagine standing at particular points on a topographic map and to identify whether they would be able to see a campfire located at another point on the map. This intervisibility task required participants to imagine route perspectives from a survey perspective and to make line-of-sight judgments. These types of activities, more formally labeled viewshed analyses, are traditionally associated with the use of topographic maps for exploration, navigation, terrain analysis, and geoscientific hypothesis-testing (Eley, 1988; Potash et al., 1978). Line-of-sight questions were used to measure students' basic perceptions of mapped land surfaces as they are easily conceptualized and understood by novice earth science students. They also do not require expert-level content knowledge to answer, in comparison to questions testing geologic interpretations and conceptual inferences. Thus, we believed this task would provide a valid test of whether particular map manipulations might facilitate novice students' basic understanding and use of topographic maps.

To recap, we examined students' performance on topographic maps that conveyed elevation using a variety of visualizations. Participants studied standard topographic maps, topographic maps that included shading, stereo visualization versions of the topographic maps, or topographic maps that included both shading and stereo visualization. These four conditions allowed us to investigate the separable contributions of each map feature, as well as their potentially combinatorial and interactive effects. Performance was also examined with consideration of student characteristics that are considered relevant to map comprehension. Our "campfire" task required both basic recognition skills (i.e., identify map points and topographies) as well as higher-order cognitive processes (i.e., consider currently viewed locations from multiple viewpoints). The experiment was intended to examine factors that influence topographic map comprehension.

METHOD

Participants - 190 undergraduate students (118 females and 72 males) enrolled in an introductory geology course at the University of Minnesota participated for extra course credit. Participants were randomly assigned to one of four map groups (a between-subjects design): traditional topographic map (n = 46), traditional topographic map with shading (n = 45), stereo visualization topographic map (n = 51), or stereo visualization topographic map with shading (n = 48).

Materials - We used two maps; one map depicted a region of Crater Lake in Oregon, and the other depicted Yosemite National Park in California. We selected these regions for their surface geometry as well as because they were relatively unfamiliar to University of Minnesota undergraduate students. For this experiment, we constructed four versions of each map: standard, shaded, stereo visualization, and stereo visualization with shading. The standard versions of the maps were obtained from the U.S. Geological Survey (USGS), and were 1:24,000 scale topographic maps. To construct the shaded versions of these maps, we used digital elevation model (DEM) data (also from USGS) to model elevation for each of the base maps, and then projected a light source onto the elevations from the Northwest region of the map using Global Mapper software (see Collier et al., 2003, for discussion of shading techniques with topographic maps). To construct the stereo visualization versions of the maps, we also used DEM data to model maps for which high elevations were pushed to the left and low elevations were pushed to the right in the image. These modified maps were then combined with standard versions of the maps using PokeScope Pro software to create a single anaglyph image. The percept of a three-dimensional map can be obtained while viewing these anaglyph images using special red-cyan lens glasses, wherein one map-image is filtered to the left eye

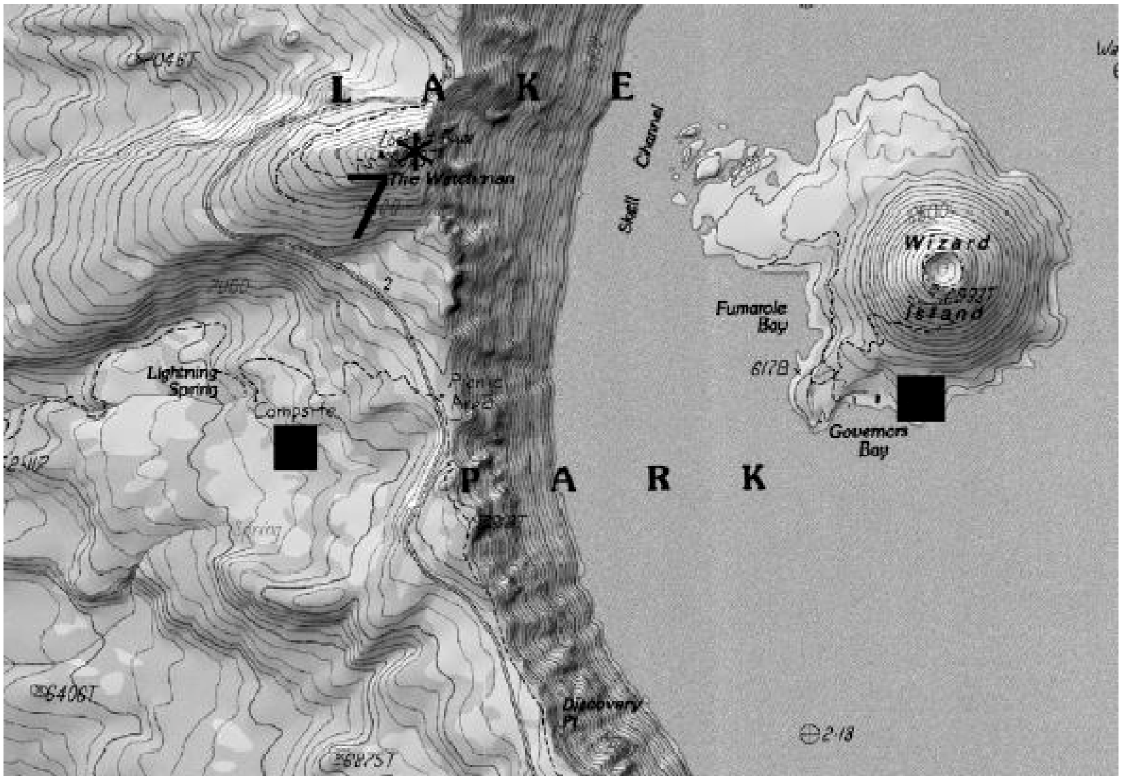

Figure 1. Sample of the Crater Lake shaded topographic map.

and the other to the right-eye. Finally, stereo visualization maps with shading were produced using both methods described above; these maps appeared as an anaglyph image with shading along the elevations. Each map was printed on an HP 5000ps graphic arts printer; the Crater Lake maps were 3'x 2' and the Yosemite maps were 1.5' x 2' in size (although, again, the same scale).

Each map included four dark squares to be used as starting points for participants to imagine whether they could view campfires located around the map. Campfire points were selected using two general criteria; we selected points that, in general 1) required a fair understanding of the land surface to make line-of-sight decisions, and 2) could clearly and definitively be answered by novices who understood the basic geometry of the land surface. With respect to this latter point, we did not place locations on the crests of ridges or peaks, but rather on slopes. We also avoided points that would rely only on vertical scale, since this scale is often difficult to grasp without extended training. Based on these general criteria, we selected nine campfire points for the Crater Lake map (each represented on the map with a large asterisk and a number from 1 to 9), and twelve campfire points for the Yosemite National Park map (again, represented with large asterisks on the map and numbered from 1 to 12). Each individual shaded location was tested with each numbered campfire, presented in a fixed numeric order. This resulted in 36 items for the Crater Lake map, and 48 items for the Yosemite National Park map. The options 'yes,' 'no,' or 'not sure' appeared below each item as answer choices.

To provide an example of this campfire task, Figure 1 presents a portion of the traditional Crater Lake map with shading. In this example, the two dark shaded squares (one close to the rim of Crater Lake and the other located on Wizard Island) would be necessary for deciding whether a campfire (in this case, the asterisk labeled 7) is visible from those starting points. Examples of items pertaining to the land surface shown in Figure 1 included:

1. You are standing near Lightning Spring on the western rim of Crater Lake. Would you be able to see the flames of campfire #7 from that location?
2. You are standing beside Governors Bay on Wizard Island. Would you be able to see the flames of campfire #7 from that location?

Participants were asked to circle either 'yes,' 'no,' or 'not sure' for each item. (Note: The correct answer is yes for both of these examples.)

We constructed test packets that included a consent form, a pre-exercise survey, a brief introduction to topographic maps, the campfire test items for Crater Lake, the campfire test items for Yosemite National Park, a Crater Lake map evaluation task, and a debriefing form, always in that fixed order. (Note: Crater Lake items always preceded the Yosemite items to provide a conceptual break before the Crater Lake evaluation task, as a means of avoiding potential map condition preferences as a function of familiarity with a particular studied map.) The pre-exercise survey was designed to collect information on participants' background characteristics. The survey questions asked participants to identify their gender (male/female), indicate their expected course grade in the class (A, B, C, or less than C), indicate their preference for engaging in outdoors activities as a function of whether they liked to hike or camp (yes/no), and specify whether they had any prior experience with topographic maps (yes/no). The introduction to topographic maps briefly described how three-dimensional surfaces can be represented by two-dimensional topographic maps. This three-page

	Crater Lake	Yosemite	Mean
Standard	54.5 (14.9)	54.8 (11.7)	54.7
Shading	56.9 (15.3)	61.8 (13.1)	59.4
Stereo Visualization	62.7 (9.6)	67.2 (11.8)	65.0
Stereo Visulization with Shading	63.2 (11.6)	71.4 (12.2)	67.3
Mean	59.3	63.8	

Table 1. Overall percent correct for Crater Lake and Yosemite National Park Test Items by Map Condition (with standard deviations in parentheses).

presentation explained what topographic maps are intended to do and how contour lines in a topographic map can represent elevation. The introduction also provided a picture of a sample land surface as well as its two-dimensional topographic representation. The campfire items followed, as previously described. The map evaluation task included four questions asking participants to evaluate the four different versions of the Crater Lake map with respect to how clearly each illustrated the land surface (in comparison to each other). Each question included a Likert-type rating scale ranking from 1 (very poor) to 7 (very good). Finally, the debriefing form briefly described the purpose of the study, and provided contact information if participants had further questions about their experience.

Procedure - Participants signed up for session times during their class; sessions were held outside of the class period. Each session included four to six students, and all participants in a single session were assigned to the same map condition (between-subjects: standard, shading, stereo visualization, or stereo visualization plus shading). Each participant was assigned a single table to themselves, with the test packet and the appropriate version of the Crater Lake map placed face down on the tabletop. Participants were instructed to open their test packet, asked to complete the packet in order without returning to previous sections, and then told they could begin. If participants were assigned to either the stereo visualization or stereo visualization plus shading conditions, they were required to wear red-cyan anaglyph glasses while viewing the maps; they were also asked to stand while viewing the maps to enhance the three-dimensional effect, as viewing the maps from an odd angle or from close proximity can distort the effect. After completing the Crater Lake items, the Crater Lake map was removed and the Yosemite map from the same condition was placed on the table. After completing the Yosemite items, each participant was taken to a second room with a table displaying all four versions of the Crater Lake maps, to complete the evaluation task. Each map in this task included a label to indicate whether participants should wear the anaglyph glasses while viewing that map.

RESULTS

For our analyses, we omitted participants who had missing data on any of the variables of interest. Two participants did not answer items on the Yosemite test and one student did not provide an expected course performance score. Thus, the final sample size was 187 (116 females and 71 males).

Successful and careful test construction requires gathering evidence concerning the reliability and dimensionality of measures. To ensure the reliability of our test items we conducted item analyses (Libarkin and Kurdziel, 2001; Netemeyer et al., 2003) of the Crater Lake and Yosemite items, and omitted items with low item-total correlations. Accordingly, nine Crater Lake and seven Yosemite items were omitted. The remaining 27 and 41 items for Crater Lake and Yosemite were internally reliable (i.e., the corresponding Cronbach alpha indices were 0.860 and 0.862, respectively, on a scale that ranges from zero to one, with one representing perfect reliability). Evidence from a multidimensional scaling analysis suggested the tests were also unidimensional (Chen and Davison, 1996), which means that only one latent trait facilitated performance on the tests.

Topographic Map Formats - Table 1 provides performance data (in percentages) for the Crater Lake and Yosemite test items as a function of map condition. We predicted that, based on the more complex pattern presented by the topography of the Yosemite map (containing many valleys and ridges) as compared to the less complex Crater Lake map (containing a large lake surrounded by a rim with few hills and valleys), that participants would in general answer more items correctly on the easier Crater Lake map. Overall, however, participants answered more items correctly for the Yosemite map (64%) than for the Crater Lake map (59%) ($t(187) = -5.27$, $p < 0.001$). This counterintuitive finding might be explained as a function of practice effects; recall that participants always completed the Crater Lake items before the Yosemite items. We discuss this finding further in the General Discussion.

In general, we were interested in how both map conditions and participants' characteristics would influence performance on the campfire task. To assess this we estimated two multiple regression equations using map conditions and participants' characteristics as independent variables and performance on the Crater Lake and Yosemite items as dependent variables. Table 2 present the results for the Crater Lake and Yosemite tests, respectively. The models were statistically significant for both the Crater Lake ($F(9, 187) = 6.21$, $p < 0.001$, $R^2 = 0.218$) and Yosemite ($F(9, 187) = 8.69$, $p < 0.001$, $R^2 = 0.281$) tests.

We predicted that map manipulations that were intended to make height and depth more perceptually salient would facilitate performance on the campfire task. In particular, we were interested which type of manipulation, shading or stereo visualization, might be associated with stronger effects on task performance. Our results were suggestive with respect to this issue: Stereo visualization improved performance on both the Crater Lake and Yosemite tests, while shading only improved scores on the Yosemite test. Overall, participants who used maps with stereo visualization, as compared to maps without, answered 9.4% and 13.1% more items correctly on the Crater Lake and Yosemite tests, respectively ($b = 9.38$, $t = 3.81$, $p < 0.001$; $b = 13.11$, $t =$

	Crater Lake			Yosemite		
	Estimate	t-Value	Sig.	Estimate	t-Value	Sig.
Intercept	45.18	16.27	***	50.28	18.62	***
Stereovisualization	9.38	3.81	***	13.11	5.48	***
Shading	1.57	0.61		6.70	2.69	**
Stereovisualization x Shading	-2.21	-0.62		-2.38	-0.69	
Self-Reported Grade, A	6.40	2.79	**	3.77	1.69	
Self-Reported Grade, B	2.50	1.05		-0.56	-0.24	
Males	-1.41	-0.74		2.98	1.61	
Previous Map Experience	5.80	3.12	**	2.75	1.52	
Outdoors Experiences	4.37	2.25	*	0.54	0.29	
F(9, 187)	6.21		***	8.69		***
R^2	0.218			0.281		

Table 2. The relationship between topographic map manipulations and student background characteristics with performance on the Crater Lake and Yosemite test items.

Note: For the dichotomous variables, gender equaled one for males and zero for females, previous map experience equaled one for students who reported experience with topographic maps and zero otherwise, and outdoors activity equaled one for students who reported engaging in outdoors activities and zero otherwise. In addition, for self-reported grade, the A and B variables each equaled one for students who reported receiving an A or B, respectively, and zero otherwise.
*** p < 0.05, ** p < 0.01, and *** p < 0.001.**

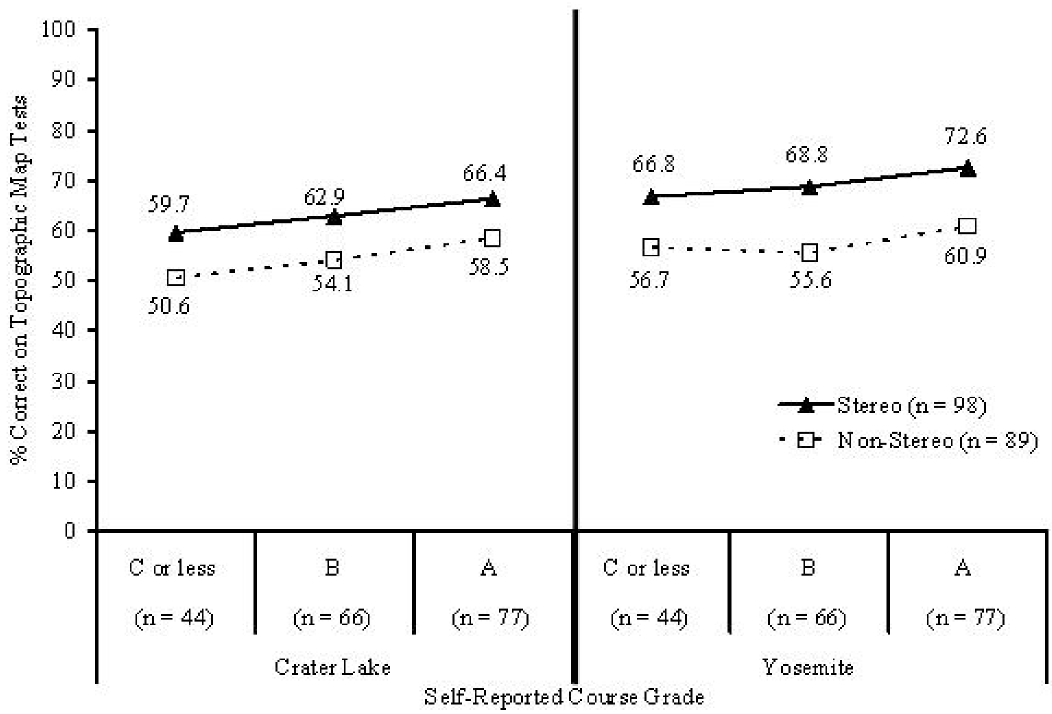

Figure 2. Average proportion correct on the Crater Lake and Yosemite items by stereo visualization and self-reported course grade.

5.48, $p < 0.001$), after controlling for the other independent variables in the regression models. The unconditional effects, i.e., the effects or average differences without controlling for the other variables in the models, are illustrated in Figure 2, across three levels of self-reported course grade (i.e., 'C or less,' 'B,' and 'A').

Figure 3 shows the unconditional effect of shading on the Crater Lake and Yosemite items across all levels of self-reported course performance. Participants who used shaded maps, as compared to maps without shading, scored 6.7% higher on the Yosemite test ($b = 6.70$, $t = 2.69$, $p < 0.01$); however, there were no significant shading benefits for Crater Lake test scores ($b = 1.57$, $t = 0.61$, $p > 0.10$).

Table 2 also provides evidence about the extent to which there was an interaction effect between stereo visualization and shading on student performance. The data did not support an interaction for the Crater Lake (b

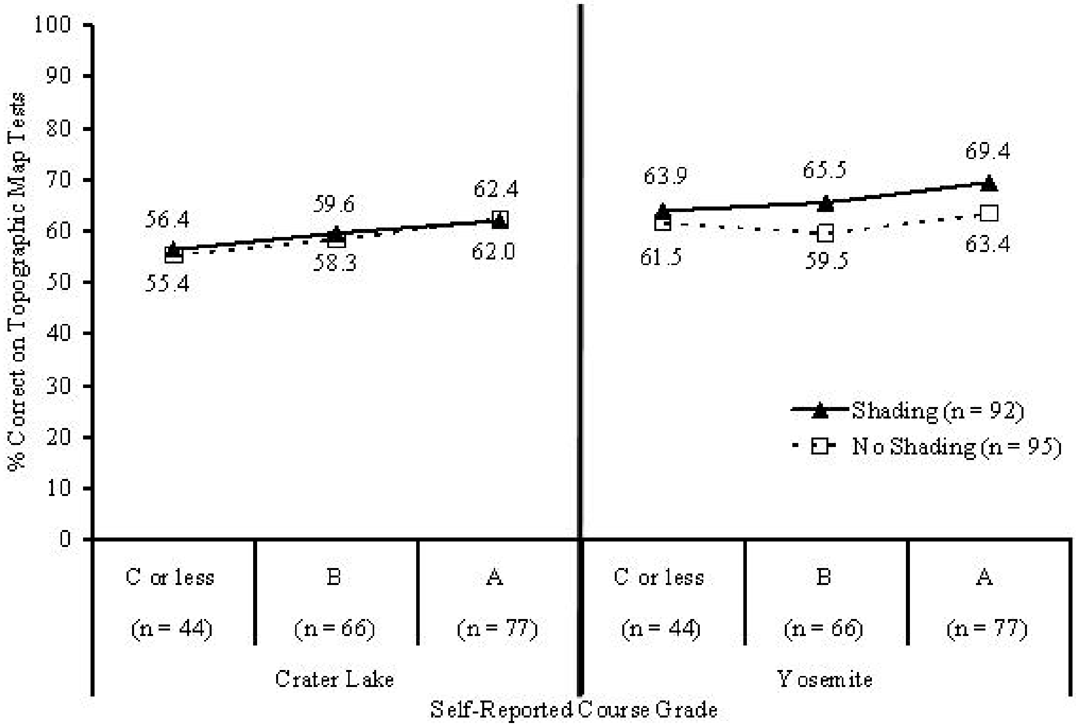

Figure 3. Average proportion correct on the Crater Lake and Yosemite items by shading and self-reported course grade.

= -2.21, t = -0.62, $p > 0.10$) or Yosemite items (b = -2.38, t = -0.69, $p > 0.10$). This suggests that shading did not moderate performance differences between participants who used a stereo visualization map with shading and participants who used a map with only stereo visualization. In other words, there was no additional effect on performance for the stereo visualization with shading version of the map as a function of shading; benefits appeared to be a function of the three-dimensional presentation.

Participants' Background Characteristics - The map manipulation variables (shading and stereo visualization) were included in regression analyses to examine the impact of map type after controlling for participants' background characteristics. Gender, predilections for outdoors activity, and prior topographic map experience were included in our analyses as dichotomous variables. Expected course grade was included as two dichotomous variables in our analyses and thus requires a short explanation: The first variable included students who expected to earn an 'A' or not, while the second variable included students who expected to earn a 'B' or not. Self-reported course grades of 'C' or 'less than C' were collapsed into one category ('C or less') since few students reported these expected grades. The 'C or less' category was not included as a dichotomous variable to prevent linear dependence with the intercept. Consequently, the 'C or less' category was defined as neither 'A' nor 'B' on the dichotomous course grade variables. This allowed us to compare the test performance of students who received an 'A' or 'B' to students who received a 'C or less.' Below we discuss the impact of each background characteristic in our regression analyses, with the hypothesis that the characteristics would correlate with performance on the line-of-sight items.

First, we tested the correlation between gender and performance, as previous work has considered differences in spatial performance as a function of gender (Lawton, 1994; Linn and Petersen, 1985). However, we obtained no evidence for gender differences (Crater Lake: b = -1.41, t = -0.74, $p > 0.10$; Yosemite: b = 2.98, t = 1.61, $p > 0.10$).

We next examined whether participants' self-reported course grades would correlate to item performance, with the general expectation that higher expected course grades would be related to better performance. Overall, 44 students indicated they expected to earn a 'C or less', 66 a 'B', and 77 an 'A'. We obtained partial support that students who expected to earn an 'A' outperformed students who expected to earn a 'C or less' for the Crater Lake test, but no such relationship for the Yosemite test (Crater Lake: b = 6.40, t = 2.79, $p < 0.01$; Yosemite: b = 3.77, t = 1.69, $p > 0.05$). There was no evidence that participants who expected a 'B' performed any better on either the Crater Lake or Yosemite test than students who expected a 'C or less' (Crater Lake: b = 2.50, t = 1.05, $p > 0.10$; Yosemite: b = -0.56, t = -0.24, $p > 0.10$).

We also investigated whether prior topographic map experience would correlate with item performance, based on relatively intuitive (and somewhat obvious) expectations that map experience should facilitate map comprehension. Evidence for this relationship was supported by the fact that participants who reported previous topographic map experience (n = 104), as compared to those who reported no experience (n = 83), scored 5.8% higher on the Crater Lake test (b = 5.80, t = 3.12, p < 0.01) after controlling for the other variables in the model; however, there was no evidence that prior experience with topographic maps had an effect on the Yosemite test (b = 2.75, t = 1.52, p > 0.10). The unconditional averages for Crater Lake and Yosemite in this regard are illustrated in Figure 4.

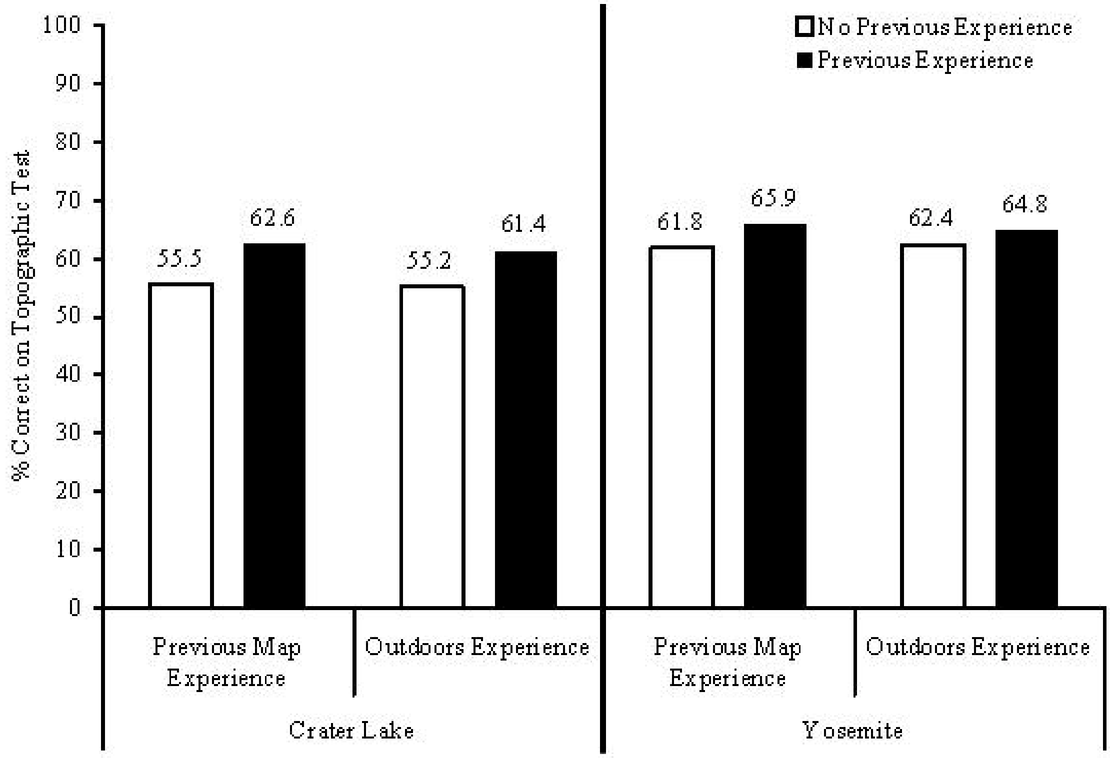

Figure 4. Performance differences on the Crater Lake and Yosemite items as a function of topographic map experience and predilections for outdoors activity.

In addition, we tested whether or not predilections for outdoors activity would correlate with performance. The results show that participants who reported engaging in hiking and camping (n = 131) scored 4.4% higher than those who did not (n = 56) on the Crater Lake test (b = 4.37, t = 2.25, $p < 0.05$); yet the evidence did not support a similar relationship for the Yosemite test (b = 0.54, t = 0.29, $p > 0.10$). The unconditional results are also illustrated in Figure 4.

Interactions between Map Formats and Background Characteristics - We also wanted to examine the combinatorial influences of map manipulations and background characteristics. Thus, an additional model was estimated to test effects between stereo visualization and the statistically significant participant characteristic variables on comprehension of the Crater Lake surface. (Note: Interactions between background characteristics and shading were not included, since shading was not statistically related to performance on the Crater Lake test.) The results suggest that the effects of expecting an 'A' (stereo x 'A' grade: b = 2.20, t = 0.61, $p > 0.10$), previous topographic experience (stereo x previous: b = -5.32, t = -1.48, $p > 0.10$), and predilections for outdoors activity (stereo x outdoors: b = -5.64, t = -1.46, $p > 0.10$) were constant across the two stereo visualization versions of the Crater Lake topographic map. (Note: An interaction model was not estimated for Yosemite items, since none of the background characteristics were statistically related to performance on the Yosemite test.)

Student Preferences for Map Formats - Finally, we assessed participants' ratings of the different map types for Crater Lake. A repeated-measures ANOVA was conducted to determine whether participants preferred a particular map, and to assess if those preferences were a function of the map type they actually viewed while completing the campfire tasks. Figure 5 shows participants' overall preference ratings for the maps. Participants quite clearly differed in their preferences ($F(3,183) = 60.35$; $p < 0.001$), with planned contrasts revealing that participants preferred the stereo visualization map with shading more than the other maps (vs. standard: $F(1, 185) = 137.94$, $p < 0.001$; vs. shaded: $F(1, 185) = 56.40$, $p < 0.001$; vs. stereo visualization $F(1, 185) = 33.47$, $p < 0.001$). Planned contrasts also provided evidence that participants actually preferred the standard map less than the shaded ($F(1, 185) = 38.09$, $p < 0.001$) and stereo visualization ($F(1, 185) = 74.85$, $p < 0.001$) versions of the maps. We found no evidence that participants' ratings were a function of the map they had actually used to complete the Crater Lake campfire tasks (stereo visualization: $F(3, 183) = 0.64$; $p > 0.1$; shading: $F(3, 183) = 1.97$; $p > 0.1$).

Overall, these results suggest that stereo visualization had a positive impact on the completion of the campfire tasks, as compared to standard and shaded maps. The findings support the view that novel visualizations that embody perceptually salient features of height and depth (i.e., stereo visualization) may benefit performance on tasks involving topographic map comprehension. Participants' characteristics (save for gender) also demonstrated an influence on map performance, particularly for the Crater Lake items (and similarly across maps incorporating stereo visualization). Finally, participants showed a preference for maps that utilized stereo visualization and shading as compared to standard map types.

GENERAL DISCUSSION

In this project, we were interested in whether novel visualizations might facilitate comprehension of topographic maps by helping to make salient the

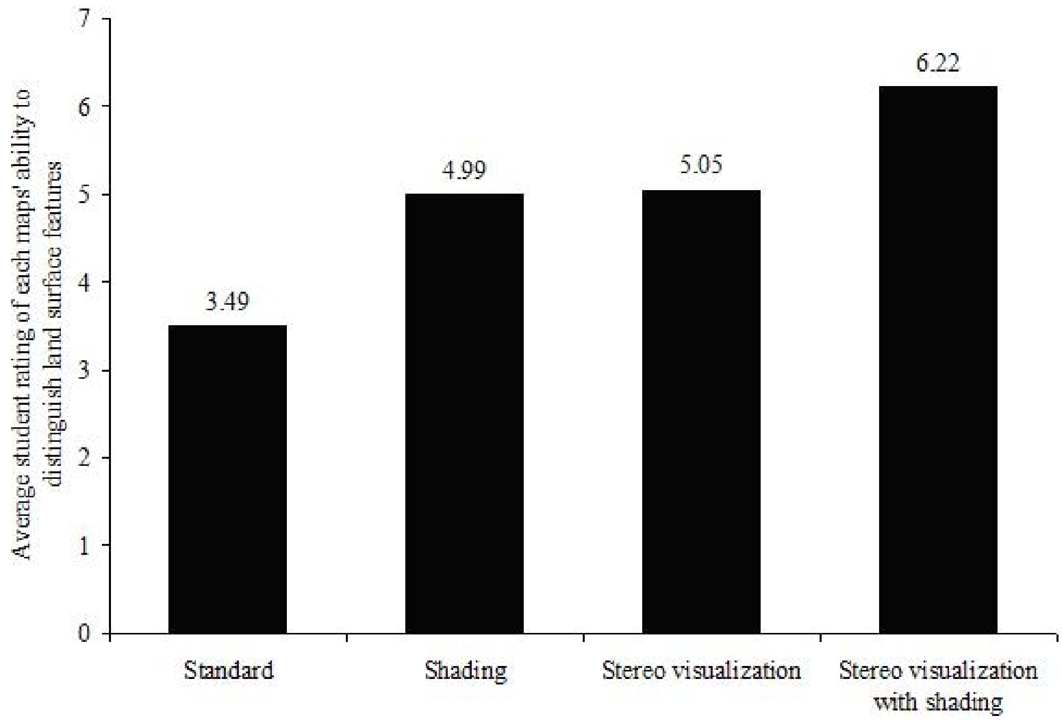

Figure 5. Participants' mean ratings of each map's utility for distinguishing land surface features.

important features of such maps. Our sample included students in an introductory earth science course. This sample allowed us to examine how different presentation formats might influence map comprehension for a group with little formal training as to the use of topographic data. To do this, we investigated the use of stereo visualization and shading as mechanisms for embodying the elevation-related features that are traditionally conveyed using two-dimensional cues (i.e., contour lines) provided in these maps. As a test of the usefulness of such manipulations, we asked participants to complete tasks that necessitated visualizing the maps' land surfaces from a route-oriented view to make line-of-sight judgments. These types of judgments are common, and often necessary, in field situations, as well as in assessments of map utility (e.g., Potash et al., 1978). These tasks also provide one method of assessing individuals' understanding and use of maps (Ishikawa and Kastens, 2005; Liben and Downs, 1993).

The data revealed performance differences as a function of map format. Participants were consistently more successful at answering test questions when they viewed maps that implemented stereo visualization as compared to maps without. Importantly, similar gains were not as consistently observed with maps that relied only on shading to convey surface features; shading promoted map comprehension only for the Yosemite map. Shading also provided little added benefit when coupled with stereo visualization; students performed equally well while viewing maps implementing stereo visualization with shading and only stereo visualization. These results suggest that stereo visualization is one method for helping students understand relationships that may be challenging to visualize using flat, two-dimensional map displays.

Previous work on topographic map comprehension has focused specifically on manipulations of features that, in some cases, simulate three-dimensional visual percepts (e.g., shading), or in others make some aspect of those features more salient (e.g., color). These manipulations do not, however, directly embody the perspectives that topographic maps intend to display. Our focus on three-dimensional presentations allowed us to test whether perceptual experiences that embody specific qualities of a dynamic landscape (e.g., height and depth), would help students complete map tasks that rely on those dynamic qualities. This approach is a more general example of how the nature of a particular learning experience should, as much as possible, match the type of mental representation, process, or skill that individuals (and their instructors) are hoping will be acquired from the experience (Glenberg et al., 2004; Rapp and Kurby, in press). The notion that particular types of embodied experiences might improve particular skills is one we hope will prove fruitful for thinking about novel ways to improve students' map learning, and more generally, foster spatial comprehension.

Overall we noted differential performance for the Crater Lake map as compared to the Yosemite map. *A priori*, we believed the Crater Lake map to be the less complex of the two. The Crater Lake region illustrated a single feature (the lake) that dominated the land surface with simple geometry (that, in fact, is similar in geometry to craters that students have likely seen from widely circulated images of the moon, which could have provided a frame of reference for the land surface). In contrast, the Yosemite region is a more dynamic pattern of interwoven ridges and valleys without any dominant, easily interpreted feature that might guide students' attention (and for which there are few widely circulated images of the area beyond those that might show a single peak, valley, or mountain range). However the data suggested participants actually had *less* difficulty with the Yosemite task. One potential explanation for these counterintuitive results may be that map content can mediate the success of particular map visualizations. That is, more complex maps may exhibit greater benefits from stereo visualizations and shading than less complex ones. For example, the enhanced effect of shading for Yosemite items could be a function of differences in surface geometry between Yosemite and Crater Lake maps. Because we did not manipulate map complexity, though, we cannot specifically assess the viability of this complexity hypothesis. In addition, since participants always completed the Crater Lake task before the Yosemite task, performance may have improved for the Yosemite task simply due to practice effects. Students may have become more familiar or comfortable with line-of-sight decisions as they completed their second campfire task, which was always the Yosemite map. Studies should continue to investigate the influence of extended practice with such questions, as well as the degree to which different types of map content (of differing complexity) (e.g., Eley, 1991; Phillips et al., 1975) may be easier to comprehend as a function of specific novel visualizations.

Beyond particular map formats, we were also interested in the effects of a variety of student characteristics on topographic map comprehension. We felt this investigation was also important as it would provide insight into individual differences that might mediate success with topographic map tasks. We obtained evidence that characteristics including grade expectations, prior topographic map experience, and predilections for outdoors activity were associated with line-of-sight task performance. While it is not surprising that these factors play a role in successful map experiences, they explicitly delineate the types of characteristics that instructors might consider as they develop and implement map training tasks in classrooms. In addition, because these results were most clearly obtained with the Crater Lake task, they again are suggestive with respect to interactions between individual differences and map content. Perhaps the less complex, relatively familiar land surface of Crater Lake was more likely to engender benefits as a function of students' characteristics, in comparison to the less familiar, more dynamic geography of Yosemite. Research on learning has contended that prior knowledge can mediate success with particular learning tasks (e.g., Kendeou et al., 2004), and thus perhaps influence the likelihood that novel visualizations will obtain performance benefits. In future projects, we hope to examine whether individual differences in prior knowledge mediate such effects as a function of the complexity of maps. We also plan on investigating the role of general spatial ability, as measured through psychometric tests, with respect to users' comprehension of such visualizations.

In addition, not all individual characteristics exerted an influence on map performance. Our data failed to reveal an influence of gender on students' success with the campfire questions. There are several possible explanations for both obtaining or failing to obtain such findings, and these explanations may appeal to developmental differences, the nature of the instructional experience, and the underlying mental processes that may drive particular map tasks (see Baenniger and Newcombe, 1989, Caplan et al., 1985, Geary et al., 1992, and Montello et al., 1999, for discussions of gender effects). We must take caution in interpreting our results with respect to claims of any generalized trends in spatial ability as a function of gender, and thus are hesitant to make claims about the current findings with respect to this literature given our experimental task. For example, spatial ability may encompass a variety of skills and processes, and one might argue that the campfire task recruits only a small subset of the characteristics, if any, that comprise such ability. In future work we hope to incorporate other assessment activities and spatial tasks (e.g., memory for the map features, distance estimates, more complex spatial manipulations) to further examine underlying mechanisms of map comprehension, which might provide insight into potential gender effects (or non-effects). Such analyses are critical in considerations of how to encourage the success of under-represented groups (i.e., women) in science (clearly not limited to the geosciences).

An important issue with respect to the map manipulation and student characteristics data is the degree to which these results are generalizable across different map displays. There is a distinct need for testing different types of map activities with different types of map content. Issues including (but not limited to) map complexity, region familiarity, and familiarity with particular types of landforms and how they might be represented on maps may all play a role in topographic map comprehension. The degree to which different types of map manipulations (e.g., stereo visualization) confer some form of benefit on these factors would provide an indication of the generalizability of the current findings. An additional core question, intended to assess the scope of any benefits, would be the extent to which practice with these "enhanced" maps might transfer to better understanding of standard topographic maps (e.g., Taylor et al., 2004).

This experiment also involved the collection of data with respect to students' stated preferences for a particular map type. Regardless of the map that participants studied over the course of the experiment, students identified maps containing novel elevation cues (i.e., more than just flat contour lines) as useful for understanding the land surface. Identifying the conditions that students expect to be most useful is important, as it can provide insight into factors that might prove more motivating for learning activities (as well as align with expectations of success, a critical component in learning self-efficacy, e.g., Bandura, 1997). Just as important, though, is the degree to which methodologies that students find motivating or useful result in *actual* learning benefits (Phillips, 1984). The preference responses, when coupled with students' performance data, provide converging evidence for the utility of elevation-focused visualizations during topographic map tasks.

Taken together, these findings suggest several implications for earth science classrooms - in particular, for situations that involve learning about topographic maps. First, map manipulations that provide salient, perceptually-driven visualizations of map content can benefit map comprehension. Contour lines are designed to convey elevation, but because they are flat cues they can be difficult for novices to visualize as relief in three dimensions. Developing a map that conveys a third dimension (as those in this study attempted to do) may be a pragmatic challenge without the appropriate computational and cartographic resources (although see www.geowall.org for a description of open-source tools and applications for many earth science topics), but other methods of conveying such relationships may confer similar benefits (e.g., presenting three-dimensional models that students can examine while simultaneously building a two-dimensional map of the region). Second, knowledge about students' prior experiences and expectations with respect to map-related activities may offer insight into which students may need extended or directed map learning activities. This could be especially relevant for classes that involve laboratory-based group work, wherein students with different backgrounds all contribute to the unfolding map lessons. To address this, curricula might offer activities that are designed to engage students in particular sets of relevant experiences (e.g., providing opportunities for outdoors exploration to help build navigational skills and encourage map fluency). Third, interventions that are novel, in the sense that they engage students by their perceived 'fun' value (i.e., viewing three-dimensional pictures) might, under the right conditions, provide a viable methodology for designing successful learning interventions. The goal, of course, is to assess whether these methodologies actually derive learning benefits, both in the short-term (e.g., better understanding of core course concepts for testing) and in the long-term (e.g., motivation to continue studying course topics and knowledge transfer). Stereo visualization appears to be one engaging method for helping students visualize information that necessarily requires extended practice and skill to comprehend.

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