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The Effect of Multiple Formats on Understanding Complex Visual Displays

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ABSTRACT

Students in introductory science courses frequently have difficulty comprehending complex graphics such as contour maps. Computer-assisted instruction (CAI), because of its ability to convey the same information in different formats, may help students gain necessary graphic interpretation skills. The present research examines effects of graphic presentation formats on interpretation of standard contour maps. Students first practiced reading two temperature maps in either a standard black and white contour or a color-enhanced contour format and were divided into four groups defined by the combination of map formats they received. Students then completed tests using only standard contour maps. Tests examined comprehension of the distribution of sea surface temperature, oceanographic phosphate concentration, and brain activation. Results suggest that having students practice with differently formatted maps of the same information improves later comprehension of standard contour maps. These findings have implications for teaching complex graphics and for computer-assisted instruction design.

INTRODUCTION

Optimizing the effectiveness of a learning exercise requires an understanding of how the complexity of the learning material influences comprehension. If the skills required to understand a learning exercise far exceed those of the students, students quickly become frustrated and the exercise is ineffective. However, oversimplifying the introductory material can also degrade learning effectiveness. For example, we have found that the educational effectiveness of a computer-based laboratory on the analysis of dinosaur trackways is reduced when the computer automatically performs the quantitative analyses. The exercise is more effective when students must complete the required algebraic calculations (Sinclair et al., 2002). In cognitive science, this result is consistent with the Depth of Processing Theory (Craik and Lockhart, 1972; Craik and Tulving, 1975) whereby greater cognitive effort results in more effective learning.

Observations and theory suggesting that greater cognitive effort results in more effective learning implies that introductory material should challenge students and that oversimplified material (i.e., material requiring little cognitive effort to interpret) decreases the effectiveness of a learning exercise (Mayer, 2001). Consider the common learning exercise in introductory Earth Science courses designed to teach students how to understand contour maps of three-dimensional data such as elevation. It might be argued that the use of computer visualization software to introduce contour maps and visually demonstrate the relationship between contours and elevation would increase the effectiveness of the learning exercise, particularly for students with less experience visualizing three dimensional data. Whether this software need be interactive or whether its effects would be seen in a passive presentation is a different empirical question that is beyond the scope of this paper. On the other hand, since it clearly requires greater cognitive effort to develop a three-dimensional mental image using just a standard contour map than is required to relate a contour map to a three-dimensional image on a computer screen, Depth of Processing Theory suggests that the use of computer visualization software may degrade the effectiveness of the learning exercise (Morris et al., 1977). In other words, if students do not have to put in the cognitive effort to develop a three-dimensional mental image, they may not develop an understanding of what contour maps represent.

Here we present the results of an experiment designed to determine how enhancing standard graphic formats impacts the effectiveness of an exercise designed to introduce students to contour maps. This experiment is part of a larger effort designed to identify specific design methodologies that increase the educational effectiveness of computer-assisted instruction (CAI). For the purposes of this paper, CAI refers to interactive computer exercises rather than computerized lecture aids, such as PowerPoint. In general, CAI may provide an effective medium for promoting graphic understanding because it has the flexibility to present the same information in different formats and allows switching between formats. While numerous studies tout the merits of CAI for rote memorization (e.g., Bitzer and Bitzer, 1973; Boettcher et al., 1981; Kulik et al., 1983; Duplass, 1995; Tjaden and Martin, 1995) and students' learning attitudes (Kulik and Kulik, 1989), only recently has CAI been shown to facilitate higher-order cognitive processes, such as decision making (Taylor et al., 1997) and problem solving (Renshaw et al., 1998). The flexibility afforded through CAI may also promote another higher-order cognitive skill, graphic interpretation.

EXPERIMENTAL DESIGN

The graphics that accompany scientific writing can greatly enhance understanding (*Wilcox*, 1964). Yet students generally pay little attention to graphics, giving them only passive attention (*Moore*, 1993). As such, students frequently do not develop sufficient graphic interpretation skills, particularly for more complex graphics and maps.

Earth and Environmental Sciences rely heavily on mapping data, which is frequently presented using contour lines. Contour lines demarcate regions that have similar values for some scalar variable such as height,

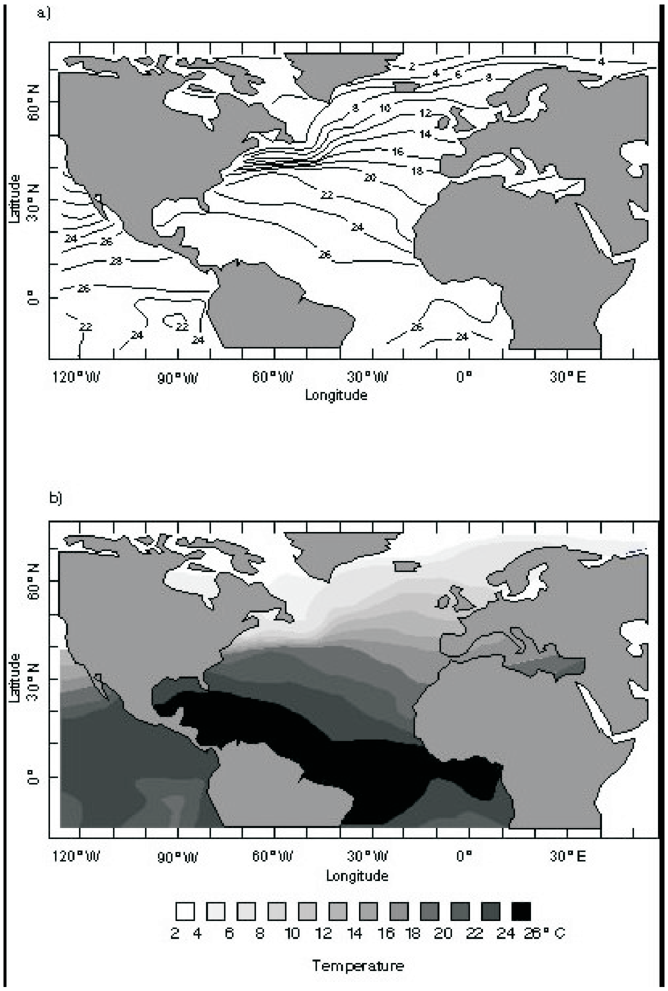

Figure 1. Standard black and white contour line and color-enhanced contour displays of sea surface temperature, taken from http://rainbow.ldeo.columbia.edu /ees/tut_data.htm.

temperature, or chemical concentration. Developing the ability to interpret complex graphics such as contour maps is an important component of a science curriculum since the effective use of such graphics can reduce comprehension errors (Shah et al., 1999). However, anecdotal evidence in our own classes and from the reports of other instructors suggests that students often have difficulty interpreting contour maps. Gilhooly et al. (1988) provide quantitative support for these observations by showing that map reading skill predicted performance for contour maps, but not for planimetric maps.

Simpler or enhanced contour representations may help students bootstrap knowledge to more complex maps. More specifically, gaining knowledge with intuitive graphic representations may facilitate knowledge transfer to more complex representations (Zacks and Tversky, 1999). Knowledge transfer is the ability to apply learned information or skills to new situations. However, students often have difficulty with knowledge transfer (Gick and Holyoak, 1983; Greeno, 1989; Bassok and Holyoak, 1993; Sternberg and Frensch, 1993) and thus the educational value of using enhanced contour maps is uncertain. In fact, Guthrie et al. (1993) argue the positive merits of standard contour maps, proposing that the abstraction process needed to comprehend contour maps leads to more generalizations in learning.

Graphic comprehension involves several cognitive processes. First, the elements of the graphic itself must be recognized and interpreted. Next, the interpretation must be integrated with other available information, such as accompanying text or graphic labels. Finally, through inferences a final interpretation is made (Carpenter and Shah, 1998). Brenner et al. (1997) suggest that these processes are enhanced by the use of multiple graphic formats. In this work we examine how different contour map formats influence graphic comprehension and whether exposure to multiple formats affects learning. In the practice portion of the present study, contour maps depicted oceanographic temperature data in one of two formats, standard black and white contour lines or color-enhanced contour displays (Figure 1). After the practice maps, we tested student understanding of standard contour displays in three different knowledge domains. As in our previous work (Taylor et al., 1997; Renshaw et al., 1998; Sinclair et al., 2002), we argue that the ability of students to transfer knowledge across domains provides a quantitative measure of the extent to which they have mastered a given skill.

Zacks and Tversky (1999) argue that the interpretation of graphics is facilitated if the relationship between graphic elements and meaning is intuitive. Thus the color-enhanced temperature maps used an intuitive mapping between colors and temperatures (i.e., blues for colder temperatures and reds for warmer temperatures). During practice, students answered questions on oceanographic temperature using either standard contour displays, color-enhanced displays, or a combination of the two display types. We then tested understanding of standard contour displays using three different types of data: sea surface temperature, oceanographic phosphate concentration, and brain activation. The latter two data types allowed us to examine both near and far knowledge transfer. Near transfer involves using information within the same major domain, but with a different focus. Far transfer involves using knowledge in a completely different domain.

EVALUATION

In this study, fifty-three Tufts University undergraduates participated as part of a course requirement. Students were enrolled in either Introductory Psychology or Behavioral Statistics and participated in the study as part of an exposure to research requirement. Students were randomly assigned to one of four experimental groups, defined by the combination of visual display formats (contour line or color-enhanced contours) used during the practice phase. At the start of the experiment, students were told that the experiment examined comprehension of maps and other graphic displays and that they were to do their best in answering questions related to graphics displayed on the computer. Participants either practiced with two color-enhanced maps, a color-enhanced map followed by a standard black and white contour map, a standard black and white contour map followed by a color-enhanced one, or two standard black and white contour maps. Males and females were approximately equally distributed across groups.

Visual displays related information on three topics, including oceanographic temperature, oceanographic phosphate, and brain activation. Both sets of oceanographic data were taken from the Department of

	ContCont	ContCol	ColCont	ColCol
Practice 1 (Temperature)	51.8	59.6	57.7	75.0
Practice 2 (Temperature)	60.7	80.8	71.2	78.8
Test – Temperature	58.9 (50/60)	80.8 (88/75)	73.1 (88/70)	84.6 (88/82)
Test – Phosphate	67.9 (100/65)	78.8 (83/75)	76.9 (62/80)	84.6 (79/89)
Test – Brain Activation	60.7 (0/65)	63.4 (79/50)	67.3 (62/68)	78.9 (83/75)

Table 1. Mean percentage correct by practice group. Numbers in parentheses indicate percent correct for males/females.

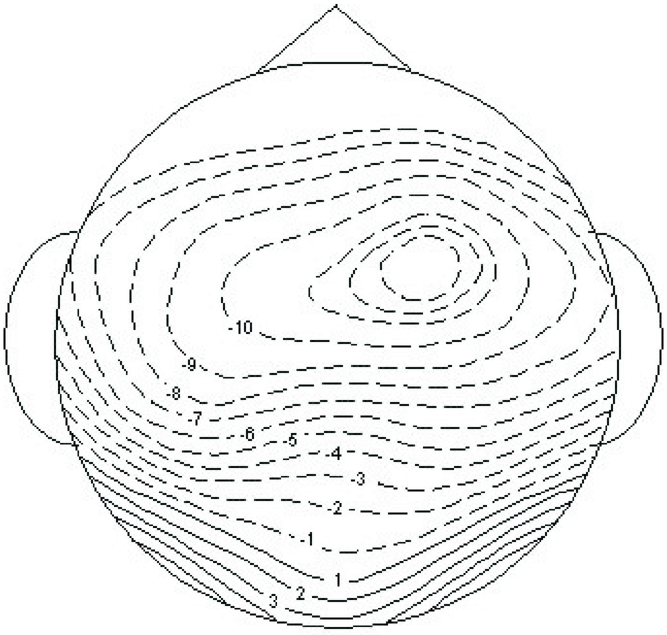

Figure 2. Example contour line display of brain activation, taken from the Cognitive Neuroscience Laboratory at Tufts University.

Earth and Environmental Sciences at Columbia University's website (http://rainbow.ldeo.columbia.edu/ees/tut_data.htm). All visual displays were presented on a computer screen.

Oceanographic data depicted annual 1994 statistics. Visuals focused on one of three geographic regions (achieved through a 2X zoom-in) corresponding to the Atlantic Ocean, the Pacific Ocean, and the Indian Ocean. Sea surface temperatures were displayed in one of two formats, either standard black and white contour or color-enhanced contour maps. Contour lines or color increments indicated temperature zones differing by 2 degrees Celsius. Interestingly, the default depictions of these data on the website differed in temperature increments between the contour line and color scale representations. Consequently, we modified the color scale data to depict 2 degree Celsius increments using a website tool, thus equating the two representations (Figure 1).

Brain activation data displayed brainwave activity mapped on a depiction of a human head. Raw electroencephalograph data were obtained from the Cognitive Neuroscience Laboratory at Tufts University and contour maps were generated using the software Electrical Magnetic Source Estimator. Contour lines indicated intervals of 1 microvolt (Figure 2).

Students worked through two practice examples on sea surface temperature, answering four questions in each example. Two questions addressed temperature identification (e.g., "Please indicate the region between 28-and 30 degrees (Celsius)"), one asked about temperature gradients (e.g., "Where on this map do the temperatures change at the fastest rate?"), and the fourth addressed east-west temperature distribution (e.g., "When examining the map along an east-west line, which side of the ocean appears cooler, if any?"). Students indicated their response by pointing with a metal pointer. The experimenter then marked the student's response on a printed copy of the map, noting the extent of the map region included in the point. If the student's point was ambiguous, the experimenter asked for clarification. They were not given feedback on their responses. The practice conditions differed in terms of the display formats used, as discussed above. Students were randomly assigned to an ocean region for each of the practice examples.

After completing the practice maps, the test phase began. The test phase consisted of three parts, used only standard contour maps, and was identical for all students. The first part again addressed oceanographic temperature data. Students viewed a sea surface temperature map of a region not seen during practice and answered the same four temperature questions used in the practice sessions. Although the questions were the same, the appropriate answers were not as the students viewed different maps in the practice and testing sessions. The second part of the testing session dealt with oceanographic phosphate concentrations; an area of near knowledge transfer. Each student received one of the three oceanographic regions and answered four questions that paralleled the temperature questions, but oceanic phosphate distribution: phosphate concentration identification, phosphate gradients, and anomalous phosphate concentrations. The third part tested far transfer and focused on diagrams of brain activity levels designated through contour lines. For this part, students received three questions, one for each brain diagram: 1) "Where does positive (+) brain activity originate?" 2) "Where does negative (-) brain activity originate?" 3) "Where do the positive (+) and negative (-) brain activities originate?" After completing all three tests, each student filled out a questionnaire asking various individual difference questions including age, gender, graduation year, major, handedness, family handedness, details of their scientific and math experience, and their level of comfort with maps.

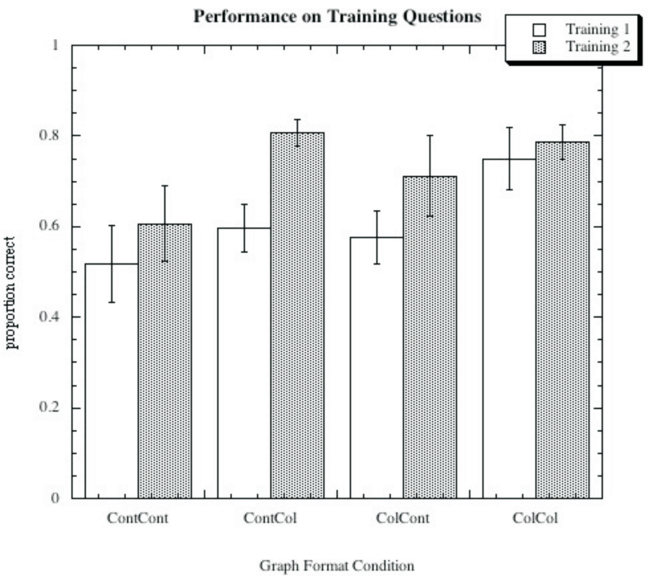

Figure 3. Response accuracy during two different practice sessions. Labels indicate map formats used in practice sessions. For example, ContCol indicates group used standard black and white contour maps during first session and color-enhanced contour maps in the second session. Student accuracy consistently improved during the second practice session. There was no signficant difference in degree of improvement during the second session between the different groups.

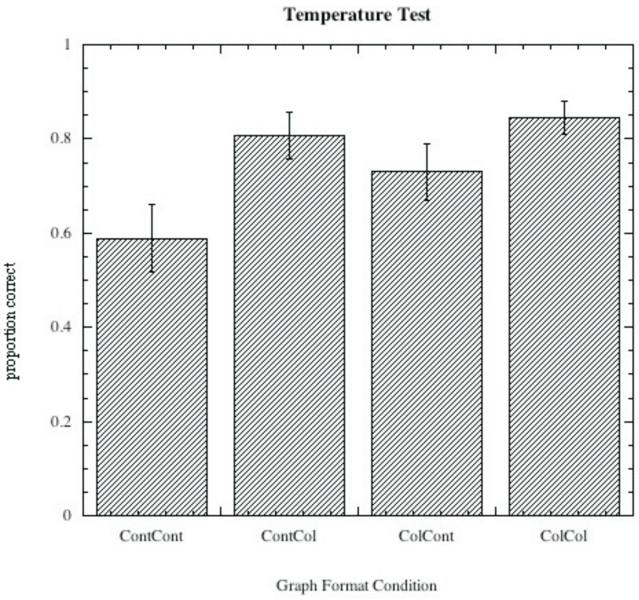

Figure 4. Response accuracy during testing of standard contour displays depicting sea surface temperature as a function of graphic format during practice. See Figure 3 for explanation of group labels. Students that used only standard contour maps in training were significantly less accurate than those using color-enhanced maps in both training sessions or using standard contour maps and then color-enhanced maps in their training sessions.

The evaluation had three goals 1) to examine the effect of format on comprehension of a complex graphic 2) to determine whether exposure to multiple graphic formats influences comprehension, and 3) to examine generalization or transfer of graphic knowledge to both near and far transfer domains.

RESULTS AND DISCUSSION

We examined the percentage of correct responses on the two practice and the three test sessions. During practice, students did significantly better on the second learning example, showing improved familiarity with the visual displays ($F(1, 49) = 9.13$, $p < .005$). There was also a marginally significant effect of graphic format ($F(3, 49) = 2.63$, $p = .06$). Students using color-enhanced contour maps in both practice exercises got the highest percentage correct (Mean ($\underline{M}$) = 76% correct, averaged across both practice exercises), followed by students using standard contour maps on the first exercise and color-enhanced contour maps on the second ($\underline{M}$ = 70%), followed by students using the color-enhanced contour map in the first exercise and a standard map in the second ($\underline{M}$ = 64%). Students using only standard black and white contour maps during practice were the least accurate ($\underline{M}$ = 56%). Statistically, the accuracy of the students using only standard black and white contour maps differed significantly from the accuracy of the students using only color-enhanced contour maps. Interestingly, the types of graphics seen and the order they were seen did not differentially affect improvement between the first and second practice sessions (Figure 3). Our practice results are consistent with those of Eley (1987), who found improved learning with color-enhanced displays. Although, Eley also found that this improvement did not carry over to later tasks using the map.

Test phase maps were all traditional contour maps. The first phase of testing, examining temperature data, mirrored the practice results. Performance varied as a function of the practice graphics ($F(3, 49) = 4.09$, $p < .05$; Figure 4). Follow-up analyses showed that the students trained using only enhanced contour maps ($\underline{M}$ = 85%) and those using a standard contour map followed by an enhanced contour maps ($\underline{M}$ = 81%) responded more accurately than students using only standard contour maps during practice ($\underline{M}$ = 59%). No other group differences reached significance.

The second testing phase, examining oceanographic phosphate data, showed a similar pattern, although the difference was only marginally significant ($F(3, 49) = 2.28$, $p < .1$; Figure 5). Performance varied as a function of the practice graphics, with students using enhanced contour maps in both practice exercises responding most accurately while those who used only standard contour maps in the practice exercises responding least accurately. The third phase of testing, examining brain activity data, showed a similar pattern, but the group difference did not approach significance (see Table 1 for summary of all data). A multivariate analysis examining results of all three tests by practice condition sums up the results nicely. This analysis shows a significant effect of the practice graphics ($F(3, 49) = 3.18$, $p < .05$). The measure of average performance across all three tests mirrored perfectly the pattern seen in analyses of individual tests ($\underline{M}$ = 83% for two enhanced maps; $\underline{M}$ = 72% for enhanced followed by standard map; $\underline{M}$ = 74% for standard followed by enhanced map; $\underline{M}$ = 63% for

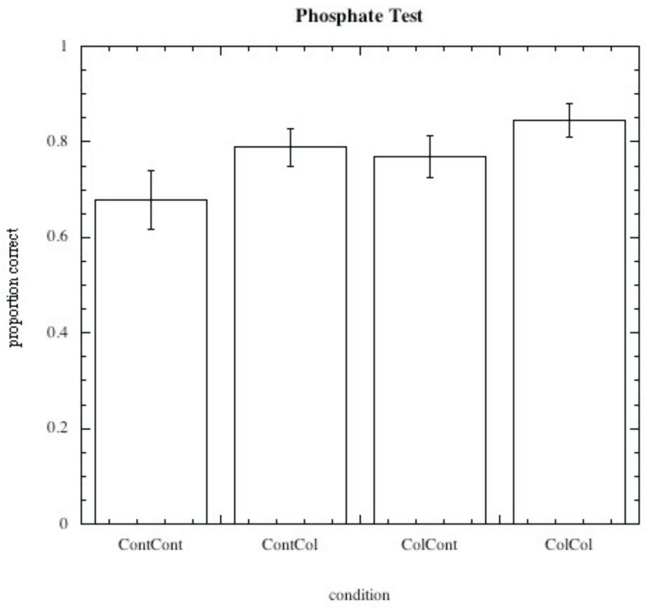

Figure 5. Response accuracy during testing of standard contour displays depicting oceanographic phosphate concentrations as a function of graphic format during practice. See Figure 3 for explanation of group labels. Note similarity in the differences between groups to that shown in Figure 4.

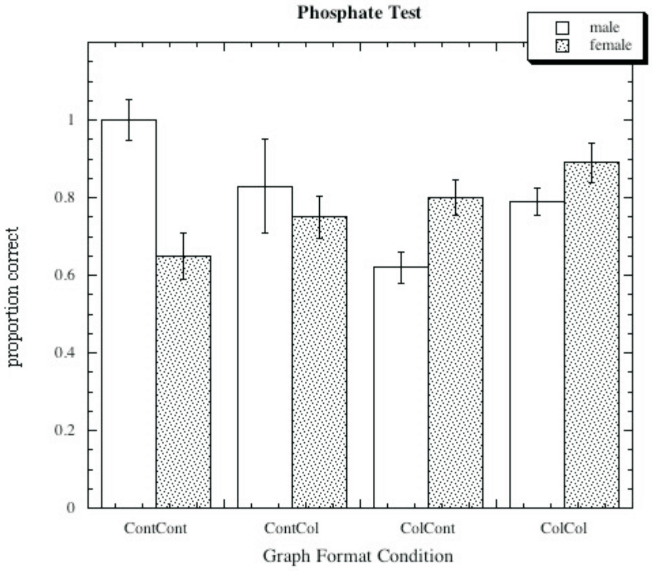

Figure 6. Gender interaction in response accuracy during testing of standard contour displays depicting oceanographic phosphate concentration data as a function of graphic format during practice. Note that none of the participants in this study reported any difficulties in color perception.

two standard maps). Performance did not differ on the three tests.

We also examined how the individual difference measures were associated with performance. Comfort level with maps correlated significantly with performance on all three tests (temperature test r = .51, p < .001; phosphate test r = .42, p < .005; brain activity test r = .30, p < .05). Because of this correlation, we examined whether the graphic format groups differed as a function of map comfort. Results showed that even though students were randomly assigned to a practice group, the groups did differ on map comfort (F(3, 49) = 9.26, p < .001). Follow-up analyses indicated that the students that used only standard contour maps during practice (M = 2.57) had a significantly lower map comfort level than those that either used only enhanced contour maps (M = 4.15) or standard maps followed by enhanced maps (M = 3.76). Further, the students that used the enhanced contour map followed by a standard map (M = 3.23) students had a lower map comfort level than the students that used only enhanced contour maps. No other group differences reached significance.

This difference in map comfort level may partially explain the learning and test performance differences, although the direction of this finding cannot be determined. Students completed the individual difference questionnaire after completing the study. Consequently, perceived performance during the study may have influenced map comfort ratings. In other words, we cannot determine whether, even though randomly assigned to a group, the groups differed in map comfort level due to preexisting factors or whether assignment to group and consequent performance influenced map comfort ratings.

Since gender differences have been associated with spatial tasks (Halpern, 1986), we also examined performance based on gender. Only the near transfer test, examining oceanographic phosphate concentrations, showed any gender effects. This test showed a marginally significant interaction between practice group and gender (F(3, 45) = 2.72, p = .056; Figure 6; see Table 1 for summary of all gender data). Males performed better on the phosphate test when they received a standard contour map first during practice. Females, on the other hand, performed better on this test when they first received an enhanced contour map during practice. Difficulties in color perception, a sex-linked trait, cannot explain this result, as no participant reported any difficulties with color perception.

CONCLUSIONS

An intuitive relationship between graphical elements and the information they convey appears to facilitate understanding. Since colors are readily perceived (Treisman and Gelade, 1980), using them intuitively to enhance contour displays reduces the need for interpretation in understanding the overall graphic. Examining average performance, students who received two color-enhanced displays during practice performed best, both during practice and test. Viewing even a single color-enhanced display during practice improved performance over viewing only standard contour maps. This finding is somewhat surprising given that all testing used standard contour maps. Transfer appropriate processing theories would suggest that the best performance would occur when test conditions matched practice conditions (Morris et al., 1977). Yet, students who viewed only color-enhanced maps during practice showed the best performance. Average performance, however, does not tell a complete story. Results based on individual differences must also be considered.

Individual differences and experience with maps may partially explain our results. Other studies have found map skill differences associated with contour map understanding (Gilhooly et al., 1988). We asked students to self-report their comfort level with maps, finding practice group differences that mirrored the test results. Students provided these self-reports after completing the practice and testing. Consequently, this parallel between map comfort and map performance data may suggest that test performance influenced student ratings, particularly since students were randomly assigned to a practice group. However, results of the first practice trial may speak against this interpretation. Results of the first practice trial showed that students in the ColCont group performed much worse than those in the ColCol group. At this point in the study, the experience of these two groups is identical, having only received a color map. This suggests that self-ratings of map comfort level may be accurate, even though taken after testing. Further, this finding suggests group differences in map reading ability, despite random assignment of students to groups. Map comfort level also differed based on gender, with males reporting higher comfort levels. However, analyses of practice and test performance using gender showed inconsistent results, making them difficult to interpret. For example, in the near transfer (oceanographic phosphate) test males from the ContCont group performed perfectly, and significantly better than males in any other group. These same males, however, got zero percent correct on the far transfer (brain activation) test.

Geoscience instructors with firsthand experience in the difficulty of teaching contour map interpretation might expect experience to play a significant role. However, none of our measures of experience showed significant effects in our results. Our experience measures included major (humanities, social science, natural science, and engineering) and number of high school and college courses in mathematics, science, and earth science. Further, even with the simple observational task employed in this study, students still got between approximately 20% to 40% of the questions wrong on average. Thus, data interpretation skills in college students cannot be assumed, even when measures of experience might intuitively suggest otherwise.

Although the present study could have been conducted using paper copies of maps, the findings have implications for CAI. CAI enables flexibility in data presentation and potentially allows students the ability to manipulate the graphical displays with immediate results. The same information can be presented in different, often user-controlled ways. Students in this study did not have a choice of which format map they viewed during practice, but the original web-site from which the oceanographic data were taken does allow user-controlled choice. Further research could examine both what format students opt to use and the effects of switching between formats on comprehension.

The present work examined simpler 2-D use of contour maps. It is possible that similar scaffolding effects on learning could be seen with contour maps depicting height. Exposing students to 3-D renderings of maps prior to use of 3-D contour maps may alleviate some difficulties in interpreting the third dimension from contours and should improve learning.

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