Issues Regarding Student Interpretation of Color as a Third Dimension on Graphical Representations

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ABSTRACT

In this study we report on issues related to the use of color as a third dimension on graphical representations provided to students. We find that a majority of the students sampled have a preconceived color map regarding temperature, with blue indicating low temperatures and red indicating high temperatures. Attempts to transfer this particular color map to representations of other quantities, however, may not be successful. In particular, when displaying a topographic map we found that students had a predilection to visualize a hill, regardless of the color map used. Moreover, many students ignored a systematic use of color in favor of seeing a hill in the representation. This suggests that a representation of a feature that seems obvious to an instructor may be interpreted to have a different meaning by a student. Hence, care should be taken to ensure that students interpret the use of color in figures the way the figures are intended.

INTRODUCTION

As experts, we are trained to understand color schemes used in visualizations in our respective scientific fields. Unfortunately, we tend to forget how complicated graphics can be when viewed for the first time. While visual representations of concepts and information can be a powerful tool for learning science under the proper circumstances [e.g., Mayer, 1997], understanding visual representations is a learned skill [Land and LoPerfido, 1993; Beichner, 1996].

The representations of complex three-dimensional objects using two-dimensional representations can prove problematic for students [Lopez and Hamed, 2004], as can the relationship between maps and what they represent [e.g., Kastens et al., 2001; Liben, 2006; Rapp et al., 2007]. Sometimes a graphical representation of a system can introduce misconceptions among students, as in the case of what causes the seasons (as documented in the video *A Private Universe*), or in the case of student understanding of the spatial extent of electric and magnetic fields in plane, transverse electromagnetic waves [e.g., Ambrose et al., 1999]. In previous studies in both physics and geography, misconceptions occur because a student is missing critical information about a particular problem that results in a mental model based on irrelevant features, which ultimately leads to an incorrect solution [e.g., Anderson and Leinhardt, 2002].

In university classrooms, professors routinely present images to aid in the explanation of abstract ideas as well as depend on textbook images to help communicate ideas. Despite whether these visual representations are used in a manner that might be deemed effective [e.g., Mayer, 1997], issues remain. For example, individuals who generate these images are subject matter experts, who have lost the ability to see things as a novice might see them [Mestre, 1994; *How People Learn*, 2000]. In addition to having more content knowledge than novices, experts possess knowledge that is organized and stored in memory in such a way as to facilitate quick access to sophisticated problem-solving strategies [Anderson and Leinhardt, 2002]. Thus, what might seem self-evident in a visual representation to the expert might not be so obvious to the novice [Rapp et al., 2007].

In this study we examine a commonly used technique: the use of color to indicate a third dimension. In the geosciences, topographic maps are frequently used to depict landforms, atmospheric geopotential heights, temperatures, etc. On most topographical maps, contour lines provide two main types of information. Quantitative information is provided about absolute height of the land, qualitative information can be obtained about the shape of the landscape by visually integrating the contour lines [Barrell and Cooper, 1986], and it is well known that novice students often have difficulty with such representations [e.g., Rapp et al., 2007, Kastens et al., 2001]. More over the shape of an object seems to be the most important feature in recognizing an object and, presumably a representation [Biederman and Ju, 1988]. Therefore, color might provide secondary information to a novice viewer while providing primary information to an expert who might not even recognize that he/she has categorized an image due to shape.

Often, these maps depend on the use of color to represent vital information. In this study, we looked at the use of color to determine if there is a preference in color schemes when rendering a three-dimensional geographic landform onto a two-dimensional surface. We also examined the use of color as a representation of temperature, because 1) temperature is generally represented with red being high and blue being low, and 2) this color scale is often used within different scientific fields to express a scale for other quantities. Thus scientists generally use a color scale where red is high and blue is low and they probably do not think much about it when viewing figures that use color to represent a quantity.

In fact, most users of the red/blue color scale probably think of it as a natural representation, similar to bars and lines that indicate an increasing or decreasing quantity. Some elements of "cognitive naturalness" appear to be supported by experiments with, for example, the slopes of lines being associated with trends and bars

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being associated with discrete quantities [Zacks and Tversky, 1999]. However, in an unfamiliar setting, the use of color might be a less obvious and natural representation and more of a "cognitive collage" as described by Tversky [1993]. Some information may be distorted by the perception/interpretation of the viewer, a perception that may be grounded in some feature of the representation that was not intended by the creator. On the other hand, there is evidence that students who have experience with both contour and grayscale representations of temperature do better on standard contour map assessments [Taylor et al., 2004]. Regardless, this does not answer the question of how "natural" such representations might be to the novice viewer.

In particular, the widespread use in science of the red/blue color scale raises the question of to what extent do novices transfer a color scale from one domain to another. Are there other visual clues in a representation that might dominate a novice interpretation of the representation, despite the use of a color scale that is seen as "natural" by the expert? As experts, do we overlook the fact that novices might have a different, embedded understanding of what the colors imply? Do these notions transfer between different representations? We address these issues in this study by examining students' responses to the use of color as a scale height on a basic topographic map, as well as the use of color as a representation of temperature.

METHODOLOGY

The target population for this study included undergraduate students taking a physical science course. The accessible population included undergraduate physics students enrolled in a small private university in east central Florida. The sample population for this study was drawn from undergraduate students enrolled at Florida Institute of Technology (Florida Tech), a small (2,500 students), independent, technologically oriented university on the Atlantic coast just south of Kennedy Space Center. During the spring and summer semesters in 2007, we administered surveys regarding the use of color to fifty-four undergraduates from two different physics courses and a Research Experience for Undergraduates (REU) program funded by the National Science Foundation (NSF) (which brought students from other universities to Florida Tech to do research for a six-week period in the summer of 2007).

The method used for selecting the sample was semi-convenient. We used two intact classes from the physics and space science department, plus four REU students. The classes were an introduction to physics course composed mainly of first year undergraduate students from a variety of Science Technology Engineering and Mathematics (STEM) majors, and an electromagnetic theory course composed mostly of junior and senior physics majors. The REU students were also STEM majors. In total, there were fifty-four students in the sample, with ages ranging from 18-39 (even though there is a large age range, only three students were over the age of 21). Of the Florida Tech students, thirty were Freshmen, five were Sophomores, nine were Juniors, and six were Seniors. The REU students were comprised of one Sophomore and three Juniors.

Fifteen of these students were female, which is 27.7% of the sample. According to statistics posted on the American Institute of Physics website, in 2005, about 22% of Bachelor's degrees in physics were earned by females. So, even though male students outnumbered female students, statistically our sample was consistent with the national average of females obtaining their Bachelor's in physics. It should also be noted that we conducted this study without taking into account if a student was colorblind, however, no students raised this issue.

A sample size of 54 students is sufficient for a random sample distribution [e.g., Gravetter and Wallnau, 2007]. However, this sample is too small to subdivide by gender or by year in school and still have statistically viable sub-samples. Therefore we will consider the behavior of the population as a whole. In the future, studies with larger data sets may be conducted to determine if there are gender differences, for example, in the way that students approach the use of color scales to communicate information in visual representations. However, those kinds of questions are beyond the scope of this paper.

We used two topographic surveys and a temperature survey. We also collected demographic information from the participants (i.e., age, gender, major, year in school) as well as their prior experience with map reading. Both topographic surveys were based on a commonly used color map, namely one in which red indicates high values of a quantity and blue indicates low values of a quantity [e.g., Tufte, 1997]. This color scale is often used in many fields when a third dimension is required, such as in space physics where the flux of energetic particles hitting a detector on a spinning spacecraft might be color coded, with the X and Y axes representing time and the direction in which the detector is pointing at a given time on a spinning spacecraft, respectively [e.g., Lopez et al., 1993].

The first survey was comprised of seven questions and one figure. Basic questions included whether or not the subject knew what a topographic map was, and whether they had ever used one in the past. The participants were then asked to indicate high and low points on the figure, and to identify the landform. The figure depicted the topography of a basic volcano (see Figure 1). The volcano was created using nearly concentric rings with slight variations in some of the rings to create a

Figure 1

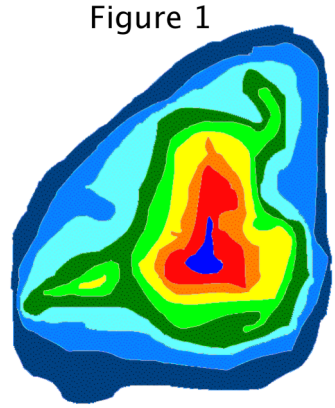

FIGURE 1: Colored, Topographic Map

small amount of complexity. Instead of using a numbering system to differentiate the elevations, we used a basic coloring system, which was composed of the following colors: dark blue, blue, light blue, very light blue, dark green, light green, yellow, orange, and red. The outermost ring was blue, then light blue, through red. The dark blue of the innermost ring represented the deep depression on the top of the volcano. We deliberately omitted a legend because we wanted to evaluate how students would orientate themselves to the color scheme.

The second survey figure was identical to the first but the color scheme was reversed. The outermost portion of the figure was orange, then yellow, light green, dark green, very light blue, light blue, blue, then dark blue. The red of the innermost ring indicated a spike in the middle of a crater (see Figure 2). Again, the legend was intentionally omitted and will be discussed in more detail later.

Half of the students, when presented with the first survey, were given Figure 1 while the other students were given Figure 2. In the second survey the order was reversed, i.e., students who received Figure 1 in the first survey were then given Figure 2 and vice-versa. The third survey was a temperature survey in which the subjects were asked what blue and red indicated in terms of temperature, why, and where they learned this association. There were no figures associated with this survey.

Of these fifty-four students, eight students were chosen to participate in follow-up interviews (conducted by author X. C. Cid) designed to investigate in more detail the responses provided. The interviews were structured using a think-aloud protocol in which the students were asked to explain their particular survey answers. The interviews, which lasted between 16 and 22 minutes, were recorded and viewed separately by the authors, who met several times to discuss their findings and to come to consensus. Because of the qualitative nature of the interview data, we followed a Grounded Theory approach [e.g. Strauss and Corbin, 1990]. Grounded Theory methodology allows for a theory to develop by reviewing the data that was collected. No preconceived hypotheses or ideas are generated before the interviews were conducted, but as a hypothesis develops, the original data are searched to provide evidence to support the hypothesis. For the interviews, we developed our interpretation of the student responses through the analysis of data, and then returned to the data (both interview and survey) to find further evidence to support our conclusions. In light of this approach, we first present our findings, and then discuss data that support those findings.

FINDINGS AND SUPPORTING DATA

Our subjects had a preference when examining the topographic map. They had a preference to see a hill.

The two topographic maps used in this study were created to represent a hill and a depression. Depending on the choice of a color scheme for encoding height information (red = high or red = low) one could decide which image was the hill and which was a depression, assuming the same color scheme was used for both images. In this study we presented the students with questions to identify how they were interpreting the images.

The question, "What might you call such a landform if you saw it in real life?" led to a variety of answers and supporting reasons as to why the students referred to the landform in a particular manner. If, in their responses, students mentioned a type of figure that rose out of the ground and came up to a point, then we called that figure a "hill". For instance, students referred to the figure as a volcano, mountain, hill, mesa, and mound.

In the first survey, 19 out of 27 students who viewed Figure 2 first called the landform a hill. Of the students who viewed Figure 1 first, 22 out of 27 called the landform a hill. In the second survey, 16 out of 27 students who viewed Figure 1 second called the image a hill. Of those students who viewed Figure 2 second, 11 out of 27 called the image a hill. Please not, these numbers are total numbers and do not give information regarding specific students or color scheme used.

An interesting note, 16 students maintained a constant color scheme, meaning they chose a color scheme based on the first image that they viewed and proceeded to stay with that color scheme when viewing the second image. Of those students who did not maintain a consistent color scheme, 21 students called both images a hill. This finding suggests that some students do not use the color scheme to interpret the image, rather they create the image first in their mind and then impose conditions on the color schemes to support their original idea of what the figure should represent. When presented with something they are told is a topographic map, most students assumed that it was a hill and created a color scheme to fit.

Because only 16 students maintained a consistent color scheme, it indicates students were using other cues to interpret the figures, and thus the number of responses identifying a hill versus a depression was unequal. Even if the students were not applying a consistent color scheme, because we presented half of the students with Figure 1 first and Figure 2 second and the other half of the students Figure 2 first and Figure 1 second, we would have expected a consistent interpretation. However, the

Figure 2

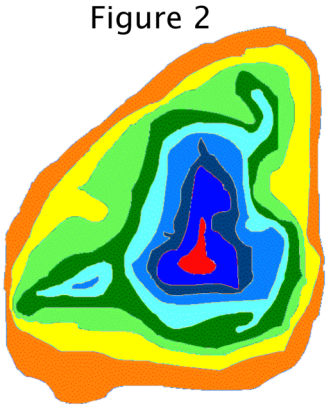

FIGURE 2: Colored, Topographic Map

students' responses did not correlate with the color scheme of the figure in a statistically significant fashion. This reinforces the conclusion that students are not utilizing the color scale in these images to the extent one might naively expect. Instead, other cues drove the interpretation.

The idea, that the color mapping was actually a secondary process, was quite clear in several interviews. For example, consider the following interview with one particular student (referred to here as Student 1) who saw Figure 2 first and considered the landform to be a volcano.

Interviewer: [3:02] How did you decide that blue was high elevation?

Student 1: [3:08] Um…To be perfectly honest I…It was almost an arbitrary decision. I just looked at it and said 'Ok, this looks like this is coming up to a peak.' At first glance the colors really didn't…um…affect my decision, but as soon as I had it in my head that…ok this is coming to a peak, then I just associated the colors to the different elevation.

When the student was given Figure 1 and asked what landform was being represented, the response was the same, a volcano.

Interviewer: [11:12] How did you use the colors to help you?Student 1: [11:16] Well…um…again once I looked at it and used the boundaries to …kinda, get a mental picture of what I thought it was…um…then I guess I automatically associated colors to different elevations and so…in this one [Figure 1], I just associated my [pause] my dark to light blues as lower elevations and then my greens to mid-level and then just getting higher with yellow orange and red.

Interviewer: [11:56] And what gave you that association that blue was low in this case and the oranges and reds were high? How did you choose the colors of blue low and orange high in this figure versus the way you had them in figure one [Figure 2]?

Student 1: [12:14] Um…I think I associated the colors to elevations after I got an idea of what it was. So I didn't really use the colors to…figure out what the actual feature was until I actually got a picture of it in my head and um… then it's like 'ok…well if this is a hill then blue must be low, red must be high.' And then I looked at it and…well if blue is low and I've got blue at the tip then maybe it's not a tip, maybe it's a divot. And so I…I kinda used the colors as a second guess or like a... like a… like a second check.

Student 1 mentioned that when Figure 1 was presented, there was an inclination to use the same color scheme as Figure 2, but once the student realized that the figures were the same, the colors were used as a secondary guide. When prompted to use the same color scheme used in Figure 2 for Figure 1, this is what was said:

Interviewer: [14:46] If you do use the same color scheme for figure two [Figure 1] what do you think that [Figure 1] land-form would be?

Student 1: [14:52] I think it would be the exact same thing.

Interviewer: [14:55] Even with the same color scheme as orange being, the orange and warmer colors being high and the blues being lower?

Student 1: [15;02] Mm Hm [yes]

Our subjects had a preference for the figure they saw first.

The hypotheses for the quantitative aspect of this study is that there is no preference for either figure, where "preference" is defined by a student response to the question "Which of the two figures did you find easiest to understand?" If there were no preference then we would expect that half of the students would choose Figure 1 and half would choose Figure 2. Therefore the statement that preferences in the population are equally divided among the figures is our null hypothesis, referred to as H_0.

H_o:

FIGURE 1	FIGURE 2
0.5	0.5

Our alternative hypothesis, H_a, is that preferences in the population were not equally divided among the figures.

The following data indicate student preference for figure by color scheme (Figure 1 vs. Figure 2):

TABLE 1: STUDENT PREFERENCE FOR FIGURE BY COLOR SCHEME

	FIGURE 1	FIGURE 2
Observed Frequencies	28	21
Expected Frequencies	27	27

*Note there were five abstentions

Because there was not a significant result with c^2 (1, n = 54) = 1.367, p = .24, there is insufficient evidence to reject the null hypothesis. Thus, there is insufficient evidence to warrant the rejection of the claim that preferences in the population are equally divided among the figures and so they did not have a preference for Figure 1 versus Figure 2.

Although students did not appear to have a preference for the color scheme used, the majority of students (37 out of 54 students) claimed that the first figure that was viewed was the easiest to understand. To demonstrate this, we examine the hypothesis that students had no preference for the first figure versus the second figure when asked which was easier to understand. Again, our null hypothesis would be that half of the students would claim that the first figure was easier to understand and half would state that the second figure was easier to understand.

H_o:

FIRST FIGURE VIEWED	SECOND FIGURE VIEWED
0.5	0.5

Our alternative hypothesis, H_a, is that preferences in the population were not equally divided by order of presentation. Table 2 presents the data for the preference indicated by the students.

TABLE 2: DATA FOR STUDENT PREFERENCE IN ORDER OF PRESENTATION

	1ST FIGURE VIEWED	2ND FIGURE VIEWED
Observed Frequencies	37	12
Expected Frequencies	27	27

*Note there were five abstentions

Because there was a significant result with c^2 (1, n = 54) = 12.03, p = 5.2E -4, there is enough evidence to reject the null hypothesis and accept the alternative hypothesis. The Chi-Squared test indicates that there was statistical evidence to support that students preferred the first figure they viewed.

Our students focused on and became distracted by aspects of the color figures that were unintentional or seemingly unimportant to the instructor.

A pre-study, conducted to investigate the use of visual representations in geoscience education, underscored the importance of figure color. We observed student reaction to the use of a number of visual representations in the Whole Earth Course (WEC), an interdisciplinary course taught at Florida Tech by six professors on aspects of the Earth system. WEC has been the subject of previous research in student learning due to the interactive qualities of the professors and students [Eason, 2000]. WEC covers six different subjects including the Biosphere, Atmosphere, Anthroposphere, Cosmosphere, Geosphere, and Hydrosphere, each of which are taught by a different professor. During one of the lectures, a professor presented a slide on global sea surface temperatures. The slide was a simple graphic intended to illustrate that the surface ocean temperatures were, in general, warmer near the equator than at the poles. In order to illustrate this, contour lines were labeled according to the temperature along with color bands between the contours, which also represented temperatures. Unfortunately, there was a 'gray' color filled region in the middle of the image that created some confusion in the classroom. The 'gray' color filled region was a repeat in the color scheme used to visually illustrate the sea surface temperatures. Even though the contour lines were clearly labeled, the seemingly out of order 'gray' color demonstrates how unimportant information to an instructor can be salient in the mind of a novice.

Just as there was confusion produced by a small discrepancy in the WEC figure, our study presented us with a similar issue. We created simple topographic diagrams, without a legend and with colors to differentiate the different heights. When we printed the images out, the printer that was used created dots that were not present when we viewed the figures on the computer screen (see Figure1 and Figure 2). The different shades of blues, the different shades of green and the orange had dots in their color bands. As the creators of the figures, we knew that the dots did not mean anything and did not pay attention to their presence.

During the interviews, it became obvious that the dots may have created confusion for the students. Four out of the eight students interviewed mentioned the presence of the dots. Some of the students simply asked if the dots were significant, and upon our reassurance that they were insignificant, they moved on with the discussion. One student tried to interpret the dots as part of the representation of varying height in the figure. The student looked for a pattern in terms of which colors had dots and was confused when no clear pattern could be discerned. Another student (referred to here as Student 2), when asked what was confusing about the surveys, specifically mentioned the dots as a source of confusion. For example,

> *Interviewer: [22:57] Was there anything confusing about the survey overall? In terms of colors, in…in those diagrams, in terms of temperature?*
> *Student 2: [23:03] Just the diagrams because when you have…just because there are dots and there are no legends to follow and you don't have…know what the dots could possibly represent so you end up just making a picture of your own and hoping for the best.*

Because the dots were unintentional, we did not include a question in the surveys about the dots. The student interviews demonstrated the importance of perceptually salient, but conceptually unimportant details when a novice observes an image for the first time. Because half of the students interviewed mentioned the dots, we speculate that many other students, who were not interviewed, probably had some issues or questions about what the dots represented. Since experts tend to ignore conceptually unimportant information, it is possible that they could construct a visual representation that inadvertently contains a distraction for novices, as in our case with dots, or in the case of the figure in the Whole Earth Course.

Our subjects had an embedded color scheme for color when representing temperature, with red being high temperature and blue being low temperature. However they did not automatically transfer this idea that red represents 'high' altitude and blue represents 'low' altitude to the colored topographic map.

As one might expect, the majority (48 out of 54) of students associated blue with low temperature and red with high temperature. This association is often formed early, as one student said in an interview "When I was really young, when you are learning your colors" in answer to the question "When did you learn this?" Interestingly enough, that student also referred to sunburns as red, showing that the association can extend to other things perceived to be "hot", even if temperature is not really a factor. However, as we have seen above, the association that blue represents low and red represents high did not automatically assert itself when students were confronted with a colored, topographic map. In fact,

the preference to see a hill, and a preference to use whichever color scheme matched the first image viewed were more important to the students than the temperature color map.

Astronomers, on the other hand, reverse the popular color scale when representing temperature. This is actually a more physically representative interpretation because blue photons have shorter wavelengths and are thus more energetic than red photons. Some students adopt this color scale for temperature if they have had exposure to modern physics (photons) and astronomy. In our sample only a few students (6 out of 54) indicated that blue was hot and red was cold. One student (in the interview) explicitly stated that blue photons have higher energy than red photons, a concept the student claimed was learned in high school. But this reversed color scale interpretation didn't appear to transfer to our topographical images since the two students (out of six) who said that they actually used the astronomical color scale for temperature did not transfer the idea that red represented 'low' altitude and blue represented 'high' altitude to their interpretation of the figures. However, as expected, a large majority of the students have an embedded color scheme for temperature whereby red represents hot and blue represents cold. Despite this, we found no evidence that there was an embedded color scheme when color was applied to height, as discussed above. The primary factors in the interpretation of the color information were the preference to see the hill and the preference for whatever figure the student saw first.

This issue of seeing what you want to see is one that is very evident in the literature on expertise [How People Learn, 2000]. Experts develop conceptual frameworks for organizing information, and the ability to confront seemingly disparate facts and to organize them and make sense out of them is one of the main benefits of expertise. At the same time, expertise makes it difficult to see things that are not in accord with expert paradigm and it also makes it difficult for experts to see things as a novice would. This issue, of course, extends beyond a narrow discussion of expertise and touches on broader issues of paradigms and paradigmatic change in science [Kuhn, 1996]. From the point of view of instruction, when dealing with non-expert or novices, there may exist, for what ever reason, a hidden paradigm or conceptual framework that drives student understanding of a visual representation and inhibits the communication of what the expert had intended, the expert having forgotten what it was like to think like a novice.

Previous (self-reported) experience with topographic maps does not seem to have influenced the results

The surveys included a question asking the subject to report what experience they had had previously with topographic maps. There were three students who reported that they used topographic maps quite a bit. Two of those students used a consistent color scheme. There were 13 students who said they sometimes used a topographic map (i.e., skiing, camping, orienteering, and a few said they had used topographic maps in a previous class). Of these 13 students only 4 used a consistent color scheme. Of the remaining students, 33 students said they rarely used a topographic map. Of the 33 students who reported that they had rarely used a topographic map, 10 students used a consistent color scheme. We recognize that these are very small samples and not statistically sufficient to establish normal distributions. However, there does not seem to be anything suggestive in the data to indicate that the 16 students who reported experience with topographic maps were significantly more disposed to use a consistent color scheme to interpret topographic information than the students who did not report such background knowledge.

CONCLUSIONS

Color is widely used as a means of representing a third dimension for two-dimensional figures. However, students, as novices, might not necessarily impose the most widely used color scale, where red is a 'high' value and blue is a 'low' value of the quantity represented. Other cues, such as the representation being a topographic map, may elicit other responses, such as a preference to see a hill. In fact, our subjects tended to adapt whatever color scheme they were given to what they wanted to see. Also, aspects of a figure (such as a misplaced color or a printer artifact) that would be typically ignored by an expert may loom large in the mind of a novice. These results underscore the importance of carefully constructing and testing visual representations, the pitfalls of erroneous image association, and the false presumption that certain elements of the images such as an implicit color scale will automatically be applied in the manner intended by the instructor.

Our results have some obvious implications for instruction. In geoscience and space science education, color is often used to encode information. It is generally assumed that students will be able to process such information appropriately using the "red=high, blue=low" color scale. This paper shows that that is not necessarily the case and that other visual cues may predominate in the minds of students. Moreover, it can be assumed that color was less important. Shape was the more dominant cue, as might be expected in general studies of object recognition [Biederman and Ju, 1988]. Thus instructors should take care to determine that students are properly interpreting the representation, perhaps by including a conceptual question based on the representation in a peer-instruction sequence [Mazur, 1998] in class. Also, when creating a new classroom representation using color to convey information, a test with a few students might be a useful exercise. Once well established, the use of a color scale along with contours in a representation should result in a more robust understanding on the part of students [e.g., Taylor et al., 2004], but until it is clear that students are properly interpreting the color scale, and using it as a primary information source, one cannot be certain that this will be the outcome.

One specific item we encountered was the preference by students to see a "hill" when confronted by a topographic map. This should be of interest to geosciences

educators who use topographic representations, whether they are of landforms or not. For example, atmospheric science uses topographic maps. One common example is the map of the altitude of the 500 mb level (approximately the midpoint of the atmosphere). One of the authors (S. M. Lazarus) has repeatedly encountered difficulty and subsequent confusion experienced by students as they try to grasp the concept of a sloping (i.e., three-dimensional) isobaric surface. It could be that an embedded desire to see a "hill" is causing an obstruction to learning the illustrated concept. Such cognitive conflict could occur at other times when contour representations are used to illustrate complex concepts that might seem straightforward to the professor, but which mystify students. The desire to see a "hill" might be part of the mystery. Further research on this topic seems warranted. However, based on our results we suggest that instructors using contour representations of any quantity be aware of the possible unintended misconceptions that might arise in the minds of novices.

In future studies, we would like to explore the following questions; "Would maps that exhibit more dynamic and complex topographies lead participants to utilize color (or other features) more directly or strategically?" Or conversely, "would less detail lead to different interpretations?" We would also like to continue this study to include a more experienced audience. We would like to see how effective an experienced audience would respond to similar question or how they would utilize the information given. We believe that such studies will uncover more effective ways in which to convey complex information and novel concepts to students.

Acknowledgments

The authors thank the students and faculty of the Whole Earth Course at Florida Tech for providing interesting observations that motivated this study. Primary support for this work came from NSF Geoscience Education grant GEO-0803981 and the supplement to that grant from the SLC program. This paper is also based upon work supported by CISM, which is funded by the STC Program of the National Science Foundation under Agreement Number ATM-0120950.

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