Must Geologists Have High Spatial Ability to be Successful in Visual Penetration?*

Dale Klopfer[1], Charles Onasch[1], Guy Zimmerman[1], Laura Marie Leventhal[1], Justin Gilkey[1], Brandi A. Klein[2], and Samuel D. Jaffee[1]

Search and Discovery Article #120158 (2014)
Posted February 25, 2014

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG Hedberg Conference, 3D-Structural Geologic Interpretation: Earth, Mind and Machine, June 23-27, 2013, Reno, Nevada, AAPG©2013

[1]Bowling Green State University, Bowling Green, OH (klopfer@bgsu.edu)
[2]Missouri University of Science and Technology, Rolla, MI

Abstract

Cognitive scientists and geoscience educators have noted the importance of spatial thinking in the geosciences and recognized that geologists typically possess good spatial thinking skills (e.g., Black, 2005; Ishikawa and Kastens, 2005; Kali and Orion, 1996; Libarkin and Brick, 2002; Rapp and Uttal, 2006; Shipley, Manduca, Resnick, and Schilling, 2009). It is also known that the quality of spatial thinking used to solve specific problems in science and engineering can improve with training and that those with greater levels of training and expertise may perform better (e.g., Duesbury and O'Neil, 1996; Hegarty, Keehner, Khooshabeh, and Montello, 2009). However, spatial thinking actually encompasses a number of dimensions and abilities (see Hegarty and Waller, 2006). One aspect of spatial thinking that seems to be particularly relevant in the geosciences but has received comparatively little attention is visual penetration ability (VPA): the ability to visualize internal or hidden structures that lie beyond visible surface structure (Kali and Orion, 1996). Data from our lab indicate that VPA varies with other measures of spatial ability (SA) and that people with high VPA are able to visualize further into a structure than those with low VPA. In this project, we operationalize VPA as the ability to create cross-sections through geologic blocks. We examined the subject variables of SA and geologic expertise and varied geologic structures and the position of cross section to understand their relation to VPA. In particular, we explored the question: must geologists have high levels of spatial ability to be successful in visual penetration?

Participants

Students from two geology courses at Bowling Green State University participated. Twelve participants were non-science majors taking an introductory geology course (GEOL 1000); fourteen were geology majors in a junior-level structural geology course (GEOL 3090). While GEOL 3090 students are not truly geology "experts," they had a higher level of domain knowledge than students in GEOL 1000. We refer to the former group as Low Knowledge (LK) and the latter as High Knowledge (HK).

Participants varied in SA as determined by scores on the Paper Folding test (PF) - a measure of visualization (cf. Ekstrom, et. al, 1976) - and the Santa Barbara Solids test (SBS) - a measure of the ability to visualize cross sections of geometric solids (Cohen and Hegarty, 2007). Studies in our lab indicate that the two tests correlate highly (*r'*s ≈ .67), suggesting that while the two tests measure something similar, a large proportion of the variance is due to something dissimilar. Consequently, for our initial analyses, we categorized as having high or low SA if they had high or low scores, respectively, on both tests. This left 10 (six low SA, four high SA) and 12 (four low SA, eight high SA) LK and HK participants, respectively.

Materials

The stimuli were geologic blocks of different structures presented at different orientations. The HK group saw more blocks than the LK group, but there was a common set of blocks across the two groups:

- Horizontal Layers: dipping E, S, or SE (north was to the back of the block)
- Horizontal Syncline: trending EW, NS, NW/SE
- Plunging Syncline: plunging S, E, or SE

Figure 1 shows examples of some of the geologic blocks used in the study.

The task was to build a front or back cross section with our cross section assembly software, described at http://voyager.cs.bgsu.edu/topo. The user interface is shown in Figure 2.

Design

Our subject and independent variables included: 1) level of domain knowledge (HK vs. LK), 2) SA (High vs. Low), 3) location of the cross section (front vs. back) and, 4) structure type. The dependent measure reported here is accuracy of each built cross section as determined by computerized grading rubric developed by Dr. Onasch, the GEOL 3090 instructor.

Procedure

The HK students participated in the 9th week of the fall semester, the LK students in the 15th week. All participants did the cross-section assembly task in the same computer laboratory after having had taken both SA tests. Prior to engaging in the cross-section assembly task, LKs went through two tutorials about cross sections, cross section construction, and cross sections of horizontal, tilted, folded strata at their own pace. HKs did not watch the tutorials as they had covered the material in class. All students were then trained to use the cross section assembly software before beginning the study. Next, participants viewed and built cross sections of the blocks, one per trial (either front or back). Only one cross-section could be submitted for any given trial. After each cross section was submitted, the correct cross section was shown in the construction window to provide feedback.

Predicted Outcomes

We predicted that building cross sections farther back in the block should be more difficult than building those near the front – the VP effect -- but not for all structures. For example, the blocks in Figure 1a and 1b would yield identical front and back cross sections, in which case the back one might be easier to build than the front owing to practice effects or having seen the feedback. A single change in the orientation of the structure from front to back – either vertically, as in Figure 1c, or laterally, as in Figure 1e – should yield a front-back difference, and two changes in orientation from front to back (Figure 1d and 1f) should yield a larger front-back difference. We also believed that the ability to construct cross sections would be related to SA and level of knowledge, but because we had no *a priori* beliefs about the relative importance of SA and knowledge level, no specific predictions were made.

Results

Our preliminary results include the finding that High SA construct more accurate cross sections than Low SA ($F(1,356) = 36.14$, $p < .05$; 96% vs. 89%). Cross sections of some structures are easier to build than others ($F(10,356) = 4.46$, $p < .05$) and there is an interaction between Structure Type X Cross Section Location ($F(10,356) = 5.036$, $p < .05$) on accuracy; see Table 1. The VP effect was seen with SE-Dipping Layer (Figure 1d), S-Plunging Syncline (Figure 1c) and SE-Plunging Syncline (Figure 1f). A block for which the front and back cross sections are the same (Figure 1b) showed the opposite effect.

To determine if there was any impact of knowledge level on VP, we analyzed the front and back cross-sections separately. For front cross sections, we found significant main effects of SA ($F(1,180) = 14.620$, $p < .05$), Structure Type ($F(10,180) = 4.810$, $p < .05$), a two-way interaction of SA X Structure Type ($F(1,180) = 5.62$, $p < .019$) and a three-way interaction of SA X Knowledge Level X Structure Type ($F(10,180) = 2.368$, $p <.011$). Unpacking the three-way interaction, we saw that with the Horizontal SE-trending Syncline (Figure 1e), High SA HK's performed best (98.7%), followed by High SA LK (89.0%) and Low SA HK (88.2%), and then by Low SA LK (68.7%). In other words, if you have High SA, learning content knowledge (i.e., going from LK to HK) boosts your accuracy nearly 11%, but if you have Low SA, knowledge boosts your performance 28%. That is, knowledge level can compensate for low SA, for this particular structure. The three-way interaction emerged because the pattern of results just described is not evident in all of the other geologic structures. Additional results will be reported.

Discussion and Conclusions

Our initial results confirm the VP effect – the finding that "near" cross sections are easier to determine than "far" ones together – suggesting that the coordination of spatial relations among layers is easier to maintain when the degree of coordination required is minimal. Indeed, with structures where no VP effect was found, increased coordination of spatial relations at the back cross section was not required because the front and back cross sections are identical. We also found persons with higher SA – as measured by PF and SBS – performed better on this task, suggesting that the VP effect is due to some sort of visualization process and that determining cross sections is not solely an analytic, algorithmic process. We do find that for some structures, having content knowledge improves accuracy regardless of spatial ability and can even substitute for low SA; why some structures and not others is under investigation. We acknowledge that students enrolled in GEOL 1000 and GEOL 3090 may differ in many more ways than level of geology content knowledge, age, motivation level, and general intelligence to name a few. Yet, to address the question with which we opened – must geologists have high levels of spatial ability to be successful in visual penetration -- our findings suggest that the answer is a nuanced "no." Geoscience educators can rest comfortably knowing that what they are teaching may enable their students to be successful despite having lesser spatial skills.

This work supported by NSF award DUE 0837626. Thanks to Sheila Roberts and Cheryl Cohen.

Selected References

Black, A.A., 2005, Spatial ability and earth science conceptual understanding: Journal of Geoscience Education, v. 53, p. 402-414.

Cohen, C.A., and M. Hegarty, 2007, Sources of difficulty in imagining cross sections of 3D objects, *in* D.S. McNamara and J.G. Trafton, eds., Proceedings of the 29th Annual Conference of the Cognitive Science Society: Cognitive Science Society, Austin Texas, p. 179-184.

Duesbury, R.T., and H.F. O'Neil, 1996, Effect of type of practice in a computer-aided design environment in visualizing three-dimensional objects from two-dimensional orthographic projections: Journal of Applied Psychology, v. 81, p. 249-260.

Ekstrom, R.B., J.W. French, H.H. Harman, and D. Deman, 1976, Manual for Kit of Factor Referenced Cognitive Tests: Educational Testing Services, Princeton, New Jersey, internet resource. http://cdm15960.contentdm.oclc.org/cdm/ref/collection/p15960coll4/id/9480

Hegarty, M., M. Keehner, P. Khooshabeh, and D.R. Montello, 2009, How spatial ability enhances, and is enhanced by, dental education: Learning and Individual Differences, v. 19, p. 61-70.

Hegarty, M., and D. Waller, 2005, Individual differences in spatial abilities, *in* P. Shah and A. Miyake, eds., Handbook of Visuospatial Thinking: Cambridge University Press, p. 121-169.

Ishikawa, T., and K.A. Kastens, 2005, Why some students have trouble with maps and other spatial representations: Journal of Geoscience Education, v. 53, p. 184-197.

Kali, Y., and N. Orion, 1996, Spatial abilities of high-school students in the perception of geologic structures: Journal of Research in Science Teaching, v. 33, p. 369-391.

Libarkin, J.C., and C. Brick, 2002, Research methodologies in science education: visualization and the geosciences: Journal of Geoscience Education, v. 50, p. 449-455.

Rapp, D., and D.H. Uttal, 2006, Understanding and enhancing visualizations: Two models of collaboration between earth science and cognitive science, *in* C. Manduca and D. Mogk, eds., Earth and mind: Interdisciplinary research in cognitive science and the geosciences: Geological Society of America Press, 188 p.

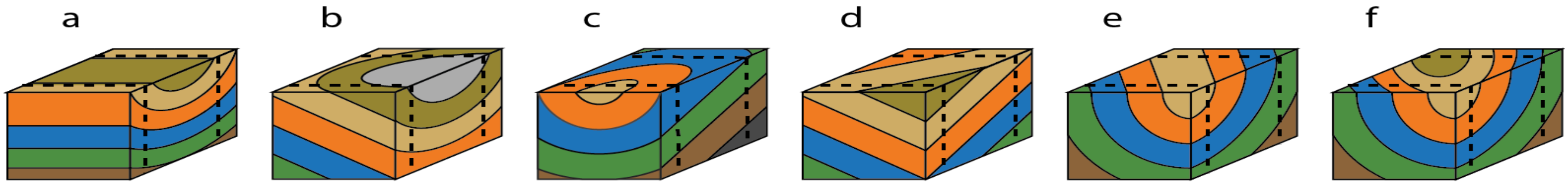

Figure 1. Easiest to hardest geologic blocks, from left to right. a) Horizontal EW-trending Syncline, b) E-Plunging Syncline, c) S-Plunging Syncline, d) SE-Dipping Layers, e) Horizontal SE-NW-trending Syncline, and f) NW-Plunging Syncline. North assumed to be toward rear of block. Location of front and back cross sections are shown with dotted lines.

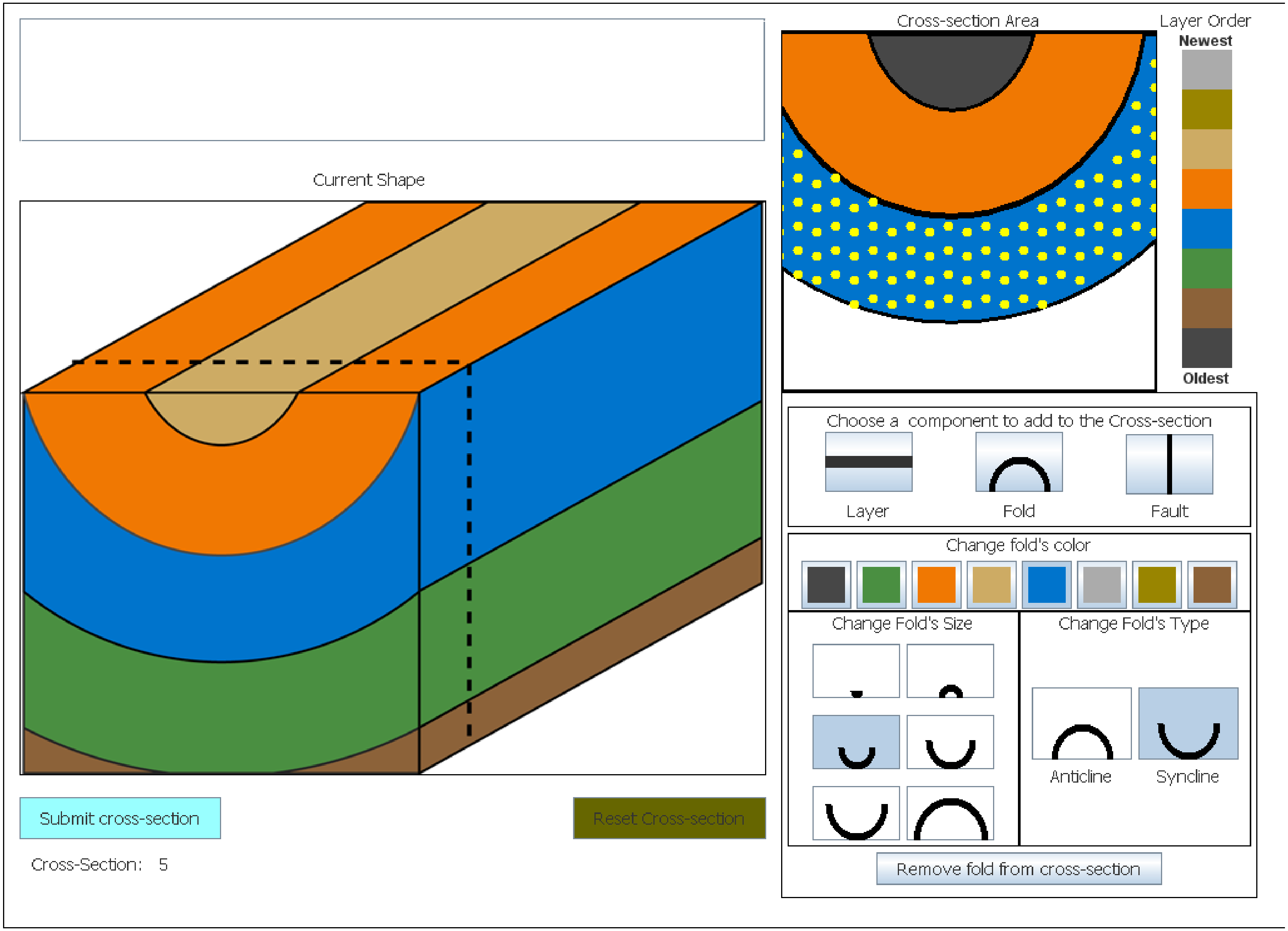

Figure 2. Cross Section Assembly Software. The left window is the geologic block with the target cross section marked with the dotted line. The upper right window is the cross section construction area. Below the cross section are the tools that the students use to build their cross section. The front cross section of a block was always constructed before the back cross section.

	SE-Dipping Layers	S-Plunging Syncline	NW-Plunging Syncline	E-Plunging Syncline
Front	93.6%,	97.8%,	98.3%,	82.0%,
Back	80.3%,	82.2%,	95.7%,	93.8%

Table 1. Mean accuracy for front and back cross sections for different structure types.