Do stereoscopic displays improve learning in introductory physical geography classes?

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ABSTRACT: Stereoscopic displays have won a substantial following among geologists, but have not yet been widely adopted for teaching college-level geography courses. In this presentation, we explore whether recent advances in projection and LED technology now make the time ripe for the dissemination of these displays for teaching geography, and discuss an ongoing project evaluating the effectiveness of stereoscopic displays.

Our ongoing research project evaluates the effectiveness of the GeoWall, a stereoscopic projection display, in introductory physical geography classes at two universities. Our basic question is whether use of stereoscopy in these classes will enhance visualization and improve educational outcomes when compared to non-stereoscopic 3-D presentations (those in which other 3-D cues, such as occlusion, aerial perspective, and motion, are used). Examining this question will help us analyze the cost/benefit of stereoscopic displays in geography courses.

We have considered a range of issues related to using stereoscopic displays in the classroom including: the nature, benefits, and limitations of various stereoscopic technologies and practical issues associated with installing stereoscopic systems in the classroom, development of 3-D content, student inability to see in stereo, and development of an experimental design to assess the effectiveness of stereoscopy.

To evaluate the educational effectiveness of stereo technology, we collected data throughout two semesters' offerings of an introductory physical geography class. We gathered data on students' prior experience with stereo media, their ability to see in stereo, their scores on three separate types of assessment, and their reflections on the classroom experience. These data help us identify the ways in which stereo is educationally effective and those in which it contributes little or nothing to educational outcomes.

KEYWORDS: GeoWall, stereo, geosciences education, learning outcomes, physical geography

For the last decade or so, geoscientists have been experimenting with stereoscopic display systems to augment teaching in geology, geography, and cartography. Haskell Indian Nations University, a small, four-year school exclusively serving Native American students, has been involved in this effort, first in the GIS curriculum and, more recently, in teaching physical geography (McDermott and Perkins, 2009). Over the past two years, this effort has taken a new turn as, in collaboration with colleagues at The University of Kansas, an attempt is now being made to actually measure the educational outcomes associated with stereoscopic display technology.

Many of the stereoscopic display technologies that geoscientists have tested fit the general definition of a “GeoWall.” The GeoWall is a technology that combines paired projectors with polarizing filters, a screen that maintains polarization, a computer to render stereo images, and stereo glasses for viewers. It is also a loose collaboration of academic, research, and commercial institutions that came together to refine and promote the technology. This paper will describe the GeoWall technology, the ways we have applied it at Haskell, and the results of our formal evaluation of educational outcomes.

Stereo viewing has won considerable support among geologists. Rapp et al. (2007) found that stereo viewing using conventional anaglyph glasses allowed students to better understand terrain features than either conventional contour representations or hillshading, though they found the best understanding of terrain when stereo representations were paired with hillshading. Kelly and Riggs (2006) endorsed stereo viewing technology for introductory physical geology courses, based on an experiment in which the GeoWall was used not as a substitute for field experience but to help prepare students for field work. Johnson et al. (2006) argued that, even at that relatively early date, stereo viewing technology was on its way to becoming the standard of practice for teaching undergraduate geology classes, observing that “more than one-third of undergraduate non-major Earth Science students in the US already use a GeoWall in their coursework” (p. 12).

At the same time, stereo viewing technology has suffered its share of criticism. In a test of stereo presentation of simple spatial tasks such as rotating letters and folding paper, Price and Lee (2010) found that students needed more time to complete tasks when the assignment was presented in stereo than when presented with two-dimensional images. They speculated that students mentally translate the unfamiliar stereo images into two-dimensional images, then base their actions on the two-dimensional visualization. In a radically different setting, testing pilots with stereo and nonstereo aircraft navigation systems, Olmos, et al. (2000) found that 3-D displays may give pilots a more ambiguous understanding of their relationship to in-flight hazards than do 2-D displays, probably because the visually compelling 3-D display actually distracts the pilot from more concise sources of navigation information. The objections raised by these authors have potential application to students and teachers of physical geography, who have limited time to devote to any given topic and should not be diverted to visually compelling stereo displays if traditional 2-D presentations communicate concepts just as well with less time or effort.

In the popular press, noted movie critic Roger Ebert (2011) argues that 3-D technology is inherently inferior to traditional screen projection technology both because it is darker and because the very act of seeing what appear to be 3-D images on what is, in fact, the two-dimensional surface of a movie screen imposes a visual burden on the viewer that distracts from the content of the film. Some of Ebert’s objection may result from the film industry practice of converting 2-D films into 3-D, rather than filming them using genuine 3-D technology.

The argument that viewing stereoscopic representations is difficult visual work is consistent with understandings of the use of perspective drawing to communicate spatial arrangements (Cosgrove, 1985; Gombrich, 1984). Visual artists have, for centuries, been developing ways to communicate 3-D data on 2-D media, typically involving linear perspective (the illusion of depth created by making distant objects smaller) and aerial perspective (the illusion of depth by rendering distant objects with diminished contrast or less-saturated color). These techniques are so ubiquitous in all forms of visual display, including art, advertising, and even everyday photography, that viewers are highly skilled at interpreting the visual cues of depth from two-dimensional representations. We should therefore not be surprised if two-dimensional representations might be as effective at communicating depth as some recently-developed stereoscopic methods.

The Haskell GeoWall, a model for small schools and small classrooms

A GeoWall is not a single product. Instead it is a family of projection technologies supported by a consortium of university labs and staff (Steinwand, et al., 2002). Haskell and KU both purchased GeoWall installations in 2010. The KU installation serves a 190-seat lecture hall while Haskell installed its GeoWall in a twenty-seat computer lab that Haskell faculty use for all their GIS, cartography, and remote sensing classes. While the KU installation needed to use very powerful projectors, the Haskell installation was built using relatively modest equipment. The installation, purchased through vendors who hold contracts to sell to federal agencies, cost just over $10,000. An institution that is prepared to do its own system integration, run its own cables, and build its own projector stand from plywood and 2” by 2” lumber, could install the same system for just over $6000.

The Haskell installation consists of:

Two Viewsonic 2700 lumen PJD6221 projectors	$1650
A custom ceiling-mounted projector stand	2070
A pair of circular polarized lenses	610
A 96-inch (diagonal measure) 3-D projection screen	1675
An off-the shelf Dell Optiplex 960 computer with	1500
PNY Quadro FX380 Graphics Card	140
TriDef video graphics software	50
30 pairs of polarized glasses	448
Cables and installation	2566
Total cost	$10,709

The installation as described here has been usable, but has revealed several weaknesses in the technology for which we had to find work-arounds (Figure 1).

Figure 1. Two small projectors in a ceiling mount.

First, and perhaps most important, the GeoWall technology requires very bright projectors. The polarizing filters reduce the amount of light hitting the screen and the gray screen that is necessary for preserving polarized images is simply not very bright. With both of our 2700-lumen projectors running and the room lights turned out, stereo images display perfectly well. But if the instructor wants to have room lights on or wants to use just one projector for a standard 2-D display, the screen becomes hard to see. In response to this problem, we installed a standard LCD projector (in addition to the GeoWall system) and kept our old display screen for use by instructors who need to use 2-D displays for photographs, maps, and PowerPoint® presentations. For this configuration, the GeoWall and the 2-D projectors were suspended side-by-side from the ceiling. We kept the GeoWall projectors centered precisely so that the axes of their lenses aligned with the centerline of the screen, to avoid any risk of distortion (horizontal keystoning) of the stereo images. The standard projector therefore had to be slightly off axis; fortunately, it was within the projector's range of adjustment for keystoning.

Second, the computer that runs the GeoWall display needs to be configured very precisely. The TriDef video graphics driver must be in use and the Windows desktop preferences must be set to use both video outputs. If instructors who are not using the GeoWall share the computer, they routinely (and innocently) wind up changing display parameters. In order to avoid the need to verify the configuration of the GeoWall computer before every class, we reserved that computer for running the GeoWall equipment by implementing a BIOS password known only to the GeoWall instructors, and provided a second computer to drive the regular 2-D projector.

The issue of computer configuration is closely related to the general delicacy of the entire installation. The two projectors must be aligned so that the images they project overlap perfectly. This precise alignment is necessary both to produce the illusion of stereo vision and to avoid eyestrain for students. The projectors, therefore, need to be protected from innocent tampering. This can be accomplished by mounting them to a reasonably high ceiling or securing them in a projection room or booth. The layout of our lab made a ceiling mount the only practical alternative. Our lowest projector is less than eight feet above the floor, vulnerable to being bumped by an outstretched arm or stepladder carried on a worker's shoulder. Ideally, a higher installation would have been better.

The handling of stereo glasses is problematical. If students are issued their glasses at the beginning of the course, there are inevitable problems of students who forget to bring glasses to class and of lost or damaged glasses over the course of the semester, as well as the need for some understanding concerning whether the student or university is responsible for providing replacements. (Haskell makes a substantial effort to reduce out-of-pocket expenses for students, going as far as paying for textbooks for all students in 100 and 200 level courses, so charging students for replacement glasses would have been a contentious issue.) On the other hand, if students return their glasses to a common bin at the end of every class, there might be hygiene risks associated with a different student using those glasses on later days. Our solution was to assign a specific pair of glasses to each student, label the plastic bags in which the glasses were delivered with an identifying number, then to have students pick up their personal set of glasses at the start of class and return them at the end of each class. This resolution worked well for our small classes, though it might be unwieldy for larger lecture classes.

Producing stereo materials

The stereo materials used consisted of graphics drawn specifically to teach introductory physical geography and tours recorded using Google Earth®. A typical presentation of a chapter's worth of material was accompanied by some of both types of materials.

The materials drawn for the class were produced using a combination of three software tools. In the absence of a single reasonably priced software product for 3-D production, we drew 3-D models in SketchUp, and then rendered them in stereo with iClone Pro 4. A third application, 3DXchange, was used to convert the SketchUp output to a format that iClone Pro could read. This cumbersome process was necessary to produce genuine 3-D images. An alternative technique, used by 3-D televisions, allows software to attempt to interpret 2-D images as 3-D; our experience suggests that it yields uneven and unreliable 3-D outputs.

The process described above only creates the stereoscopic content; additional tools are necessary to display it. We used StereoPhoto Maker, a freeware application that displays pairs of images simultaneously on the paired projectors. In a sense, StereoPhoto Maker performs a role similar to Microsoft PowerPoint® for the instructor. It also provides controls to allow the user to correct image registration problems, through software controls, without having to touch the projectors.

In contrast to the involved process for creating and displaying custom-drawn illustrations, displaying Google Earth images in stereo is refreshingly simple. TriDef 3D Ignition -- a $50 application designed primarily to serve the gaming community -- extracts and displays two stereo views from any Google Earth image. The combination of Google Earth and TriDef is remarkably simple to use. The instructor simply launches TriDef, then selects Google Earth as the input.

For purposes of our evaluation of stereo presentation, we wanted to make sure that both classes were exposed to the same graphics, so we recorded tours in Google Earth to present between 10 and 20 scenes, with about 10 seconds between scenes. We did encounter some difficulties when poor computer performance did not allow the Google Earth images to refresh completely before the tour moved on to another scene. We initially attributed this problem to the speed of internet service on the Haskell campus, but instructors at KU reported similar, though not identical, problems displaying Google Earth imagery. Further testing is necessary to determine whether the problem resides in Google Earth, the graphics drivers, or network response times.

Evaluating learning

We designed our evaluation of the effectiveness of stereo presentation around two semesters of teaching. In the Fall semester of 2011, about half the course content was taught in stereo. In the Spring semester of 2012, the other half of the course content was taught in stereo. This design gave us the opportunity to isolate the impact of stereo presentation from other factors that might be responsible for better or poorer student performance on any topic.

In order to evaluate learning outcomes from a variety of perspectives, we collected six different types of data from participating students:

1. A test of how well they could see stereo effects using the GeoWall installation
2. Formative assessment using a clicker system
3. Summative assessment using essay questions on midterm and final exams
4. Summative assessment using multiple choice questions on midterm and final exams
5. Survey of student reactions to stereo equipment for teaching
6. Focus group analysis of the use of stereo equipment in the classroom

To determine whether students could see stereo effects using the GeoWall installation, we displayed a series of stereo images of identical white squares and asked the students to identify which square appeared to be closer to (or further away from) the viewer than all others. The images contained no visual cues such as size, saturation or shadow that could be used to infer a third dimension. The only way a student could correctly identify the closest image was if he or she was seeing genuine stereo effects. An average of only two students in each semester, or about 10 percent of the student population, achieved less than 75% accuracy at recognizing the closest square. We also asked each student to list his or her experience with stereo media such as 3-D movies or video games. All students had some experience, though there was no clear correlation between amount of previous experience with stereo media and ability to recognize the closest square in our evaluation.

In order to evaluate understanding at the time that material was presented to students, we asked a total of 26 multiple-choice questions during lectures, the responses to which were captured with an iClicker® classroom response system. We also used midterm and final exams, consisting of a combination of multiple-choice and essay questions, to provide a summative evaluation of learning. The essay questions were added to the course to explore the possibility that, even if stereo presentation did not improve the retention of facts, it might contribute to more subtle understandings of earth processes (L. Scrogan, personal communication).

Table 1. Impact of presentation method on learning outcome.

All concepts, all evaluation methods, one semester

	Mean	SD
Non stereo	0.760	0.365
Stereo	0.770	0.369
	P-value	
H_0: $\mu_{NS} = \mu_S$	0.671	

Table 2. Outcomes for specific evaluation methods.

Evaluation	**Score (out of 100)**	
	Fall 2011	**Spring 2012**
Midterm exam multiple choice questions		
Material taught stereo	70	73
Material taught nonstereo	74	69

Midterm exam essay question		
Essay on material taught stereo	61	None offered
Essay on material taught nonstereo	44	65
Final exam multiple choice questions		
Material taught stereo	88	75
Material taught nonstereo	82	79
Final exam essay question		
Material taught stereo	72	77
Material taught nonstereo	68	None offered
Clicker questions		
Material taught stereo	60	51
Material taught nonstereo	59	68

As tables 1 and 2 suggest, stereo versus nonstereo presentation had no meaningful impact on student learning outcomes in our very small sample. Even within a single semester, the impact of stereo presentation on exam or clicker scores is far from statistically significant. When we make comparisons across both semesters of the test, and consider different evaluation methods separately, student scores differ by no more than a half-dozen percentage points. The multiple choice questions on midterm and final exams provide the largest and most comprehensive set of data. On the Fall 2011 midterm, students performed marginally better on questions on material taught nonstero than stereo but, in the following semester, students performed slightly better on the stereo material. On the final exam multiple choice questions, students performed slightly better on stereo questions but, in the next semester, they did slightly better on nonstereo questions.

A similarly inconsistent pattern occurred among the clicker questions, with the Fall 2011 students doing slightly better on questions pertaining to stereo material but Spring 2012 students performing slightly better on nonstereo questions. On the essay questions, stereo presentation yielded higher scores, but, given our small number of observations – a maximum of two essays on each exam -- and the subjectivity of scoring essays even when rubrics are used, no conclusion can safely be drawn from those data.

Even if the stereoscopic presentation does not demonstrably improve learning outcomes, it can still be a useful technology if it attracts students to a field of study they find rewarding. To explore student responses to the stereoscopic presentation, we conducted focus group interviews at the end of each semester of the test. Interviews were done with a structured presentation of material and interview questions, and were conducted by staff from another university to reduce the risk of response bias had the instructor or someone else with whom the students routinely worked conducted the interviews.

Focus group participants offered subtle critiques of the stereoscopic material. They all endorsed the use of stereo presentation and argued that it improved both the quality of their learning and the pleasure of the classroom experience. However, they found some situations in which the stereo material was no better than nonstereo presentations and some in which stereo material was actually a distraction.

For instance, focus group participants found that a stereo presentation of Hadley cell circulation (Figure 2) was eye-catching but did not communicate any more information than a nonstereo version of the same diagram would provide. "I mean, of course it pops out, and makes it a little more interesting, but educational wise, it kind of seems like the same" reported one student. Another concurred "Yeah I would have to agree. I mean it's not that much of a difference. But it just catches your eye a little bit more in 3-D." Participants offered the same critique of a stereo block diagram of mass wasting arguing that the features were "just as identifiable in 2-D as the 3-D."

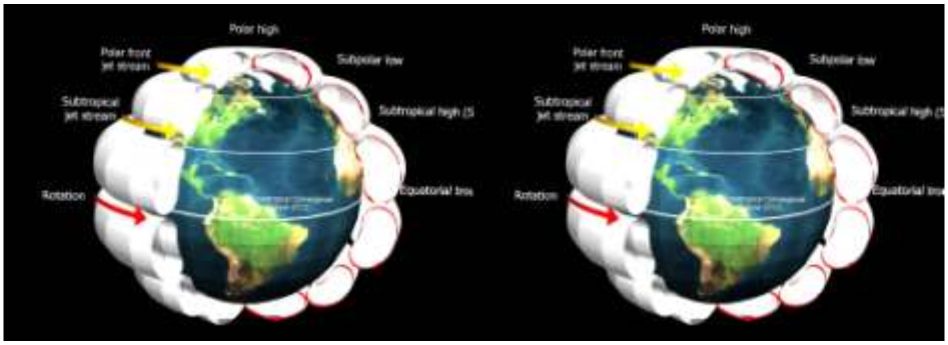

Figure 2. Global air circulation graphic presented in stereo and found, by focus group participants, to be no more effective than the same graphic presented without stereo.

Students did not reject the effectiveness of all stereo block diagrams, however. Diagrams of different types of faults were well received, with students observing that the stereo presentation helped them understand the different planes along which fault blocks moved relative to each other in a way that a nonstereo presentation could not capture (Figure 3.). The distinction students seem to be making is that simple structures or flows do not benefit from stereo but more complex motions, such as the variety of dimensions in which faults can move, profit from the three-dimensionality of a stereo presentation.

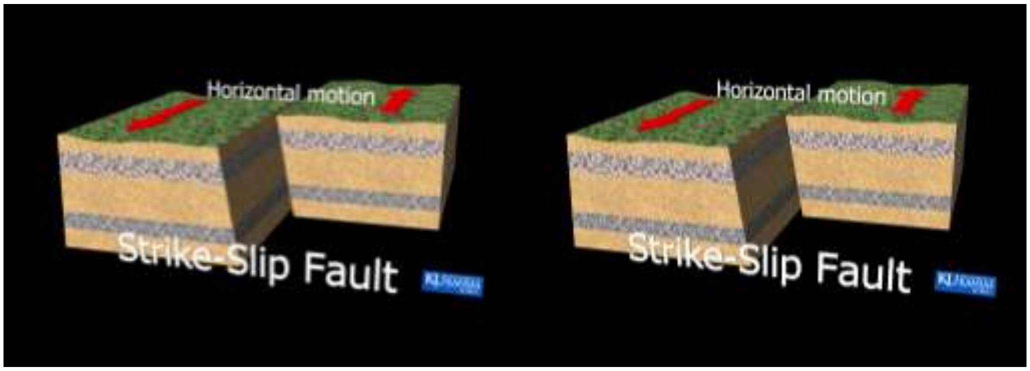

Figure 3. Fault illustration that students found useful in stereo

In contrast to the mixed evaluation of stereo block diagrams and schematics, focus group participants were almost universally positive about stereo presentation of imagery from Google Earth®. One student made the important distinction between simply recognizing a scene and understanding the process by which a feature was created, observing “Like I grasped the concept better. It helped me grasp the concept better of whatever he was talking about as far as any landscape that we were talking about, just any general idea of what it looked like, it helped a lot.” and later citing the example “We were talking about tombolos versus sea stacks, and you could definitely see more, and it helped me remember looking at this, the difference between a tombolo and a sea stack.”

In addition to arguing that stereo improved their learning in some specific cases, students also found the stereo presentation more enjoyable than standard nonstereo lecture images. One student observed “It’s kind of like, that’s what we’re waiting on was to get to the 3-D part to see what it actually looks like. It definitely made it more interesting.” Another warned “Yeah, I think a lot more people wouldn’t come to geography class if they didn’t have this here.”

Reflections

When we began this study, we were interested in determining whether the additional cost of producing and displaying stereo materials would justify their additional costs. Over the two-year life of the study, stereo viewing environments have become nearly ubiquitous. They are so common, now being offered as a matter of routine on home televisions, consumer-grade cameras, and even cell phone displays, that nonstereo display may come to be seen as archaic.

As this is written in mid-2012, a 64” flatscreen 3-D LED television costs just over $3000, a price that is likely to decline by the time this article goes to press. At the same time, even larger screens will become affordable. This price is less than half what we paid for the combination of the 96” screen, projectors, polarizers, and display stand. Use of LED technology rather than projection technology still requires a computer with good graphics capability. LED television, however, offers several benefits over projection technology. The LED screen can be cleaned with relative ease, while the silver-coated projection screen is vulnerable to marks from dry-erase markers or handprints. The LED technology also avoids the difficulties of aligning projectors when they are installed and restoring that alignment if they are disturbed by vibration or impact. Finally, the LED technology can be installed in almost any classroom, while projection technology requires a room with sufficient space and ceiling height to accommodate the projectors and mounting hardware.

As is the case with any teaching technology, there is a peril that the GeoWall is so intrusive that it interferes with communication between teacher and student. The Haskell portion of this experiment suggests that this is a genuine risk. An instructor using this technology, particularly when it is implemented as a projection system rather than with LED television equipment, encounters problems of misaligned images, cumbersome presentation software, and spontaneous technical problems that simply do not occur when using 2-D equipment such as the ubiquitous LCD projector and Microsoft PowerPoint®.

However, even though the data from this part of our study do not show improved learning outcomes using GeoWall technology, our students still find it both desirable and helpful. The combination of rising student expectations for 3-D presentations and falling prices for 3-D television equipment suggest that some variation on the GeoWall technology will become a standard platform for teaching geography in the near future.

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