My Attempts to Use Maps (and Help Students use Maps) as a Tool For Visualizing, Synthesizing, Capturing and Conveying Information about the Earth

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Background essay for the workshop on *Teaching Geoscience with Visualizations*

I have chosen to center my essay and my talk around maps. Maps were the earliest technology humans developed to visualize portions of the Earth that were too big to see from a single vantage point. Geoscientists use maps to organize, record and convey information about the Earth—today's Earth, as well as hypothesized ancient Earths, and forecast future Earths.

From 1975 through 1993, I was a sea-going marine geologist. That means I went to sea and made maps of the bottom of the ocean, and then tried to figure out the sedimentary and tectonic processes that caused the mapped seafloor to be the way it was. I made observational maps: bathymetric maps, maps of sediment type, fault distribution, and seafloor bedforms. I made interpretive maps, showing, for example, tectonic processes at various moments in a region's geological history. I published maps of portions of Long Island Sound, the Tamayo Transform Faulty, the Clipperton Fracture Zone, the Siqueiros Transform Fault, the Vema Fracture Zone, the Mississippi Fan, the Ebro Fan, and the Mediterranean Ridge. I used maps to reveal places that no human eye had ever seen. I lived and breathed maps. Maps made me feel close to the secrets of the universe.

In 1991, I began to co-teach Planet Earth, a course for non-science majors at Columbia and Barnard Colleges. I noticed that maps, which were such a powerful tool for me to organize my own understanding of the Earth and convey my insights to my colleagues, had no such power for many of my students. Most were not adept at extracting insights from maps, and were completely inexperienced at using maps to organize and convey information. Some were shaky on the difference between a map and a profile; when asked to draw a profile, some would draw a map, and vice versa. When asked to sketch and label a map of the Earth's oceans and continents from memory[1], many students left out whole continents, or misplaced continents in the wrong hemisphere.

[1] This exercise was developed by the originator of the Columbia Planet Earth course, Roger N. Anderson, who used it on the first day of class. It proved to be an excellent predictor of performance in the course.

Beginning around 1993, I became fascinated by the power of instructional technology. I had an opportunity, in collaboration with Columbia's Institute for Learning Technology (ILT), to apply for some seed-money funding to create an educational software application using a new authoring tool. I saw an opportunity to go from admirer and user of this new technology to creator. The only condition was that the application had to be for K-12 education. I asked myself how the K-12 education system had failed my undergraduate students. I came back to maps: too many of my students had passed through the K-12 educational system without learning how to use maps in any but the most simplistic fashion.

I tried to figure out what was wrong with how my students had been exposed to maps in their pre-college education. I noticed that most map-skills curriculum material for elementary schools did not require the student to "translate" between the map and the real world. In fact, many of the exercises could be done entirely in the frame of reference of the map, without thinking about the real world at all.

So, with colleagues at ILT, I designed and authored a prototype version of the *Where are We?* software (Kastens et al, 1996) and associated lessons. The goal was to set up situations in which the student would have to translate back and forth between the intricate, horizontally-viewed, constantly-changing view that you see as you stand in a terrain, and the schematic, vertically-viewed, unchanging view of the map of the same terrain. *Where are We?* shows a map of a park on one side of the screen, and video filmed within the park on the other side. Students can "move" though the park by clicking "turn left", "turn right" or "move forward" buttons at each intersection. The video responds appropriately. Users can interact with the software in four modes: In *Exploring the Park,* a red dot and arrow on the map indicate the user's position and view direction, moving and rotating as one steers a route through the environment. The red dot plays the role of the finger of a parent or other mentor, who shows a child her location on a map during a walk. *Are We There Yet?* simulates the most common real world map task: using a map to find one's way from a known starting point to a desired destination. In *Lost!,* students are "dropped" at an unknown location on the map, and must figure out where they are from the information in the video. Colleagues from my marine geology days are amused to note that *Lost!* was based on my experience diving in the submersible *Alvin* in places without good transponder navigation. *Add to the Map* introduces maps as a tool for organizing information spatially, and is analogous to field-mapping tasks undertaken by geologists, hydrologists, ecologists, and other field scientists. After much refinement, *Where are We?* was published commercially (Kastens, 2000) and is now in use in schools across the country.

Although it was thrilling to watch children using *Where are We?,* and both teachers and students seemed excited about using the software, I found myself wondering what students were actually learning from *Where are We?* With no idea how difficult it is to do good educational research, I plunged into an attempt to find out. Working with an insightful 4th grade teacher, Kottie Christy-Blick, I developed a set of outdoor map skills tests to evaluate whether the skills children are learning from *"WAW?"* transfer to real-world situations. In the "world-to-map" test, we place colored flags around the Lamont-Doherty campus, and give students a paper map and colored stickers. Their task is to place each sticker on the map at the point corresponding to the similarly colored flag. In the "map-to-world" test, each child is given a paper map with numbered stickers on it, and matching numbered dinner-plate-sized markers. Their task is to place the markers in the real world at the point corresponding to the stickers on their map. Just as *"WAW?"* is designed to exercise students' ability to go from the visually-perceived real world to the map and vice versa, our field-based tests are designed to test translation skills in both directions. Our early trials showed that average scores of *WAW?*-users improved on all of the scoring categories on both the world-to-map and map-to-world tests between pre-test and post-test (Kastens et al, 2001).

However, when we looked at individual students, we found huge student to student variation: some improved enormously, some not at all, and a few got worse. I was at a loss to say why *"Where are We?"* worked so well for some students but not for others. I was mystified about what could be going on in the minds of the students who put answers that seemed completely nonsensical to me (for example, putting a sticker on the map lawn to indicate the location of a flag that was on a building.) Fortunately, I found a collaborator with extensive expertise in the developmental psychology of how children acquire map skills: Lynn Liben of Penn State's Psychology department. Liben and I are now using extended versions of the field-based tests of map skills, plus classroom assessments, to dig into the relationship between children's spatial skills and their performance on the real-world map tasks, and the nature and causes of children's mistakes as they use maps (Liben et al, 2002, Kastens et al, 2004).

I have recently started one other project on how people understand maps. This project is a collaboration with posdoc Toru Ishikawa, Chet Ropelewski and Tony Barnston of the International Research Institute for Climate Prediction (IRI) and Pat Louchouarn of the Environmental Policy program at Columbia's School of International and Policy Affairs. IRI produces forecasts of air temperature and precipitation three months into the future. Their mission includes disseminating their forecast results to decision-makers around the world for use in agricultural and land-use planning, and other societally-important purposes. The forecasts are disseminated in the form of maps, probability maps. Our project began by asking: how well do these maps communicate with the intended audience? In a pilot project (Ishikawa et al, 2003), we showed maps of forecast and actual precipitation to students in Columbia's masters degree program in environmental policy. We asked a series of questions designed to assess how well they understood the map, and found that many students misinterpreted the more subtle aspects of the maps. We also asked students to evaluate how well the forecast precip agreed with the actual precip for that same region and time interval, and to indicate how likely they would be to recommend that the forecasts be used in agricultural decision making. This last set of questions has impressed on me the importance of distinguishing between how well map-users *understand* a map and how much they *believe* the map.

In closing, I notice that one of the other essay-writers (Gunther, 2004) wrote about concept maps, which jogged my memory about another attempt I made to synthesize and symbolize a large amount of information into a visual display. At the time (circa 1985) I was working on oceanic transform faults, and I was asked to give an introductory talk at a workshop, laying out what was known and unknown on this topic. I did this by leading the group through the process of making a giant concept map (although I, like Mickey Gunther, did not yet know this term) on three adjacent blackboards. I put quantifiable casual factors (such as spreading rate or age offset) on the left, connected by arrows through the grey zone of interpretation, connected by yet more arrows to observable outcomes (such as magnitude of the bathymetric step across the transform) on the far right side of the diagram. Dotted lines and question marks marked steps in the chain of causality that were still not understood. The workshop participants loved it, and as each subsequent speaker came up to speak, almost all of them began by going over to the blackboards and saying something like "I'm going to talk about this link from here to here", using the concept map to show where their particular research topic fit into the grand scheme of things. At the end of the workshop, the concept map was used again to identify major unanswered questions. The workshop's reception of this way of synthesizing and visualizing an entire research domain into one diagram was so positive, that I was inspired to publish it in a review paper (Kastens, 1987). The paper centered around an annotated version of the concept map; numbered notes spelled out the logic of each link in the diagram and provided citations to the relevant literature. As far as I can tell, this paper has had absolutely zero impact on either researchers or students. In retrospect, I'm convinced that the finished concept map, in all of its glorious complexity, was approximately useless in conveying information—other than the general impression that this field was hopelessly complicated. I believe that it was the process of constructing the concept map together that made it such a powerful tool for the workshop participants—not the communicative power of the final diagram. This matches my subsequent experience with concept maps; they are wonderful constructivist learning tools for the person who makes them, but mediocre as communication tools for complex ideas.

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