Wanted: Cognitive Theories Related to Geography Education

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Introduction

Gersmehl and Gersmehl (2006, p. 5) requested a "list of neurologically defensible and assessable spatial thinking skills." Before commenting specifically on their taxonomy, I would like to present a slightly different perspective on the broader problem of making progress in geography education. I would like to make a distinction between the terms *aptitude* and *skill* and briefly discuss some theories that purport to explain how spatial abilities are acquired and used. I will then discuss some practical problems and briefly consider the list of spatial thinking skills in the final section of the paper.

Genetics, Evolution, and Practice

The word *aptitude* implies something inherited, while the word *skill* implies something learned (Lloyd, 2003). Researchers frequently use the more general term *spatial ability* (or even *spatial intelligence*) because it may be difficult or unnecessary for a particular study to know how much of the performance of a task is independently affected by inherited and learned effects (Gardner, 1983).

Casey's (1996) *Bent Twig Theory* argued peoples' spatial abilities are determined by the interaction of biological and environmental factors. People who have excellent spatial abilities probably have benefited from a better spatial *aptitude* caused by genetic factors and better spatial *skills* learned through additional practice. She turned the old *nature or nurture* question into a *nature and nurture* answer. "In the human brain distinct functions tend to be localized in the left or right hemispheres, with language ability usually localized predominantly in the left and spatial recognition in the right" (Sun & Walsh, 2006, p. 655). It has been argued that biological effects determine how one's brain is lateralized and develops before one is born. Annett's (2002) *Right-Shift Theory* offers a genetic explanation for why some people have a better *aptitude* for verbal processing and others for spatial processing. There is also an accumulating body of evidence that prenatal exposure to sex hormones affect asymmetries in the human body including how the brain is structured (Manning, 2002; Janowsky, 2006).

These prenatal factors explain why some individuals start with a better *aptitude* for spatial thinking. The *Hunter-Gatherer Theory* provides an evolutionary explanation of sex differences in spatial ability (Eals & Silverman, 1994). It is based on the different experiences of pre-agricultural hunters and gatherers and how relative success with spatial experiences affected natural and sexual selection. This theory has been used to explain why modern men perform better on spatial tasks requiring mental rotation and women perform better on spatial task requiring the recall of the locations of objects in space (Ecuyer-Dab & Robert, 2004).

For research topics related to geography education, it may be necessary to separate *aptitude* and *skill* effects. For example, if you were trying to assess a students potential, the ratio of the second digit (index finger) and the fourth digit (ring finger) on the hand (2D/4D ratio) has been used as a biomarker pointing to brain asymmetry (Bronson, 2006). Lower ratios generally point to a greater exposure to prenatal testosterone and better spatial abilities. If one were trying to assess if a teaching method significantly improved a spatial skill, then measuring the performance of a task requiring the skill with a representative sample of subjects before and after the method was applied would provide the needed information to test for a significant change. It could be assumed that the *aptitude* for spatial processing would vary among the subjects, but that it would not change over time. Any change could be related to change in *skill* related to learning. A test for a significant improvement in the mean performance for the sample of subjects would infer a significant improvement for the sample caused by learning new information and practicing the task.

Cognitive Load Theory

Although additional practice should generally improve one's spatial skill, it should be obvious that not all people will benefit the same amount from equal experiences and not all experiences provide an equal benefit. *Cognitive Load Theory* offers geography education researchers a way of assessing important components of the learning process (Bunch & Lloyd, 2006). This theory assumes that learners have a limited working memory that is connected to an unlimited long-term memory. Baddeley's (2003) multi-component working memory model has one component for processing visual information, the *visiospatial sketchpad* and a separate component for processing verbal information, the *phonological loop*. Having a larger working memory capacity allows one to process greater cognitive loads. Given the expected lateralization of the brain discussed above, one might also expect the limited capacities of verbal and spatial working memory to vary from person to person. The cognitive load can be measured for media that convey geographic information such as maps, PowerPoint presentations, Web pages, or geography lessons.

A general goal of geography education researchers should be to find ways to assess and adjust the cognitive load of learning materials. Information should be provided that is useful for learning, but does not have a cognitive load that exceeds the learner's working memory capacity. Individuals with greater spatial abilities, i.e., those with greater potential and/or practice, should be able to use their prior knowledge to reduce their mental load so they can process a greater amount of external information. This notion supports the obvious assumption that novices cannot benefit from geography lessons that have too heavy a cognitive load and experts cannot benefit from geography lessons that have too light a cognitive load. Geography education researchers need to understand the cognitive load limitations of geography students and to effectively measure the cognitive load of potential teaching materials. The methods associated with cognitive load research could be used as effective assessment tools. Student progress can be linked to ability to successfully process heavier and heavier cognitive loads. A map, Web site, or lesson plan can be assessed to determine if its cognitive load is suitable for the intended learner.

Practical Considerations

The "spatial thinking skills" suggested by Gersmehl and Gersmehl (2006) can possibly be explained by cognitive experiments requiring subjects to solve various tasks involving the skills. Performance variables related to these skills can also be used to assess various components of geography education. Critical questions are:

1. What cognitive processes are required to perform a task? Successful performance of an individual task may require multiple cognitive processes, e.g., searching for a target map symbol on a map that includes many other symbols might involve individual cognitive processes involving directing visual attention, holding information in spatial working memory, and judging similarity.
2. What response variables can be used to measure the variation of

success for the task? Accuracy, reaction time, and self-efficacy are some of the likely variables that would reflect success (Lloyd & Bunch, 2003).

3. Is there any existing theoretical understanding of what variables should affect the performance of the task? This should vary from task to task. Some variables would relate to individual differences among the subjects. These could be biologically determined, e.g., sex, visual working memory capacity, or age. Other individual difference variables could relate to prior experiences, e.g., gender, college major, or practice doing the task. Other important variables could be related to the materials used in the experiment, e.g., for a map this might be colors, shapes, or locations.

Clusters of Skills

The following discussion considers broadly defined groups of skills pre-sented by Gersmehl and Gersmehl (2006) and comments on connections to existing theories and related issues. One cluster of *skills* can be grouped together because they are concerned with the storage of geographic information in working or long-term memory. Different types of geographic information can be stored in visual and verbal systems. In some special cases, visual and verbal information can be combined into spatial prototypes and mental models.

In the context of humans learning locations, understanding cognitive mapping would be the key issue. Jacobs and Schenk (2003) have proposed a *Parallel Map Theory* that explained how spatial information is encoded into memory. They argue the hippocampus encodes spaces with two mapping systems that process spatial information that can be integrated into cognitive maps. The *bearing map* provides a frame of reference that is a generalized structure of the environment. The *sketch map* is an encoding of the specific locations of the landmarks and includes the spatial relations (distances and directions) among the landmarks. Geography education researchers should be interested in the accuracy of cognitive maps learned from different information sources, the systematic patterns and distortions in cognitive maps, and differences in the cognitive maps learned by individuals. A natural extension of encoding cognitive maps is using them to navigate. The male advantage in rotating images and the female advantage in memory for objects in space has been linked to preferred navigation strategies used by the sexes (Saucier, Green, Leason, MacFadden, Bell, & Elias, 2002).

Also in the memory cluster are skills related to how humans store knowledge they have learned about places. Lloyd, Patton, and Cammack (1996) discuss alternate hierarchical storage networks that could be used to store geographic knowledge. They compared nested and basic-level hierarchical structures, and evaluated the notion that geographic knowledge is stored in a three-level hierarchy suggested by *Basic-Level Theory* (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). According to the *Basic-Level Theory,* unique information that would mark exceptions for a place is only stored in the subordinate level of the three-level hierarchy.

The creation of spatial prototypes and mental models are special cases where information is not just encoded to be recalled later. In both cases memory structure are created that summarizes a larger volume of acquired information. Rosch (1973) defined a prototype as the central tendency of a category that is created in memory by learning examples of the category. Rather than being any one example, the prototype represents the essence of the category. The prototype might be the shape of your home state in your memory based on all the maps of your home state you have ever experienced. Lloyd (1994) considered the encoding of spatial prototypes for map categories based on experiencing many examples of a map category. Results indicated the sequencing of the example maps in different orders significantly influenced people's ability to encode spatial prototypes.

Mental models can be conceptual, spatial, or temporal. They combine and organize visual and verbal information and store it as cognitive structures in our memory (Johnson-Laird, 1983). Once encoded, the mental model can be viewed from multiple perspectives to make decisions. Lloyd, Cammack, and Holliday (1995) had subjects encode information about a city from two different perspectives using either visual or verbal information. Results indicated subjects had encoded cognitive maps of the city as mental models because they were able to verify statements about the city equally well even when the question was in a perspective they had not experienced.

Another cluster of skills can be grouped together because they relate to making comparisons and judging similarity. Tversky's 1977 Contrast Model argues humans make similarity judgments by using a feature matching process that considers both common and distinctive features. Lloyd, Rostkowska-Covington, and Steinke (1996) had subjects rate the similarity of map depictions and verbal descriptions of the same maps. They reported subjects paid more attention to distinctive features when comparing maps, and paid more attention to common features when comparing verbal descriptions of map.

Conclusion

Although it may be difficult to isolate individual cognitive skills, we can examine the variation of performance for tasks that use these skills to understand what independent variables affect performance. Once we have a theoretical understanding of what affects task performance, we should also be able to assess various components of geography education.

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