“WORMHOLES” IN THE COMMON CORE: SPATIAL REASONING, LITERACY, AND MATHEMATICS EDUCATION

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RESUMEN

Las últimas décadas del sigloXX fueron testigas de una revolución en la investigación del cerebro. Usando las nuevas tecnologías de escaneo los investigadores encontraron que el razonamiento espacial humano utiliza una serie de estructuras cerebrales apartadas que funcionan con cierta independencia, a menudo simultáneamente. Por otra parte, estas estructuras y las redes del cerebro se desarrollan a ritmos diferentes en cada niño, dando lugar a importantes diferencias individuales en el rendimiento de tareas espaciales dentro del aula, incluyendo la lectura y diversos tipos de razonamiento geométrico/matemático., Tomando como base esta investigación en neurociencia, diseñamos nuevos materiales educativos para promover el razonamiento espacial. En este artículo se describen los siguientes ejemplos: una secuencia de lecciones de geografía organizadas por edades que incluye un estudio de mapas sencillos de los animales Africanos para el nível de primaria, , una serie de actividades relacionadas con el clima dirigidas a la básica secundaria y una lección acerca de las estrategias para combatir la malaria y otras enfermedades tropicales en una era de cambio climático global planeada para la media. Nuestras lecciones de geografía fueron aplicadas en varios barrios muy pobres de NuevaYork. Los estudiantes también alcanzaron logros significativos en el desempeño de lectura estandarizada y las pruebas de matemáticas. Si bien no podemos decir que se “demostró” una relación de causalidad, las posibilidades son muy interesantes. En este contexto, es importante tener en cuenta que el nuevo Currículo Básico Común en los Estados Unidos se basa en investigación obsoleta. Como resultado, la implementación de clases experiementales del tipo descrito en este artículo pueden desanimar a los administradores escolares.

Palabras clave: neurociencia, razonamiento espacial, alfabetización, enseñanza de las matemáticas.

RESUMO

As últimas décadas do século 20 testemunharam uma revolução na pesquisa sobre o cérebro. Usando novas tecnologias de digitalização, pesquisadores descobriram que o raciocínio espacial humano usa um número de estruturas cerebrais separadas que trabalham de forma algo independente, muitas vezes simultaneamente. Além disso, essas estruturas e redes cerebrais se desenvolvem em ritmos diferentes em crianças diferentes, levando a significativas diferenças individuais no desempe-

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nho em sala de aula em tarefas espaciais, incluindo a leitura e vários tipos de raciocínio geométrico/matemático. Usando esta pesquisa como uma base, nós projetamos novos materiais educacionais para promover o raciocínio espacial. Neste trabalho, nós descrevemos um exemplo: uma seqüência de lições de geografia relacionadas a certa idade, incluindo um estudo de escola primária de mapas simples de animais africanos, diversas atividades de ensino médio sobre o clima, e uma lição de ensino superior sobre as estratégias para combater a malária e outras doenças tropicais em uma época de mudanças climáticas globais. Nossas aulas de geografia foram aplicadas em vários bairros muito pobres de Nova York. Os alunos dessas classes também tiveram ganhos significativos no desempenho em leitura padronizada e testes de matemática. Embora não possamos afirmar que "provou" um nexo de causalidade, as possibilidades são intrigantes. Neste contexto, é muito importante notar que o novo Common Core Curriculum nos Estados Unidos é baseada em pesquisa desatualizada. Como resultado, pode realmente desencorajar os administradores da escola de tentar aulas experimentais do tipo descrito neste artigo.

Palavras Chaves: Neurosciência, raciocínio espacial, alfabetização, educação matemática.

ABSTRACT

The last decades of the 20th century witnessed a revolution in brain research. Using new scanning technologies, researchers learned that human spatial reasoning uses a number of separate brain structures that work at least somewhat independently, often simultaneously. Moreover, these brain structures and networks develop at different rates in different children, leading to significant individual differences in classroom performance on spatial tasks, including reading and various kinds of geometric/mathematical reasoning. Using this research as a basis, we designed new educational materials to promote spatial reasoning. In this paper, we describe an example: an age-scaffolded sequence of geography lessons, including a primary-school study of simple maps of African animals, several middle-school climate activities, and a high-school lesson about strategies to combat malaria and other tropical diseases in a time of global climate change. Our geography lessons were used in several high-poverty neighborhoods in New York City. Students in those classes also had significant gains in performance on standardized reading and math tests. While we cannot claim to have "proved" a causal link, the possibilities are intriguing. In this context, it is very important to note that the new Common Core curriculum in the United States is based on outdated research. As a result, it might actually discourage school administrators from trying experimental lessons of the kind described in this paper.

Keywords: Neuroscience, spatial reasoning, literacy, mathematics education.

In a carefully written and exceptionally effective speech, a candidate for the office of Vice President in the United States said this to a crowded arena and a worldwide television audience:

> To confront the threat that Iran might seek to cut off nearly a fifth of world energy supplies ... or that terrorists might strike again at the Abqaiq facility in Saudi Arabia ... or that Venezuela might shut off its oil deliveries ... we Americans need to produce more of our own oil and gas.
>
> And take it from a gal who knows the North Slope of Alaska: We've got lots of both. (National Public Radio, September 3, 2008)

The statement hit its intended target: a widespread perception that the Democratic political party was responsible for high gasoline prices, because it seemed to favor governmental regulations that limited the ability of oil companies to search for new deposits of oil. Meanwhile, one of the favorite slogans of the Republican party was "get the government off our backs, and we can solve these problems."

The audience clearly saw this statement as a highlight of the speech – they responded with a chant of "drill, baby, drill." A carefully worded disclaimer was all but lost amid echoes of the chant as it swept across the room like a wave in a football stadium.

Like any comment about energy, environment, or economy, this statement is a complex and fascinating mixture of facts, perceptions, and beliefs about cause-and-effect. For that reason, it draws attention to a gap between what students are taught in typical American schools and the kind of knowledge and analytical skills that are needed by citizens in a democracy, in order to judge the validity of statements in political speeches and to make responsible voter decisions. On a factual level, a person cannot evaluate that statement without at least some knowledge of the geology of petroleum, the technology of exploration and production, and the quantities of oil that flow from country to country in the world. To interpret those numbers, in turn, one would need some idea of the quantity of oil that is used by the United States in a typical year.

In this paper, I am less concerned with this factual knowledge, per se, and more interested in how people acquire this kind of knowledge. Specifically, I will look briefly at the school subjects that could teach these facts and theories, but I will focus on the school subjects that claim to impart the skills ("literacies") needed to read and interpret text, maps, and other graphic representations in books, newspapers, television shows, and the internet.

This seemingly abstract exploration of "literacies" has a concrete immediacy in the United States, because of a current focus on "alignment" of educational materials and procedures with a framework that is generally called the Common Core Curriculum.

I will not try to frame a coherent discussion of the history and politics of the Common Core – that daunting task is far beyond the scope of a single journal article. Instead, I will examine the Common Core from the perspective of a geographer/educator who has also read some of the fascinating new research in neuroscience. In my current job, schools ask me to help with professional development of teachers. As part of that job, I try to design educational materials that make use of the brain's innate tendencies to acquire and process spatial information in multiple parallel ways, with significant individual differences among children and adults.

This paper is a report on that effort. It has six interlocking parts:

1. a description of the recent "Copernican revolution" in neuroscience, which was triggered by a dramatic change in how scientists can observe brain activity,

2. a summary of what we now know about how the human brain perceives visual images. The primary focus will be on how people get spatial information from maps. In this context, it is very important to note that gathering spatial information is not the same as gathering factual information about specific places,

3. a brief description of eight different modes of spatial reasoning that people seem to use in order to gather different kinds of information from a map,

4. a description of a fully scaffolded set of student activities that we designed to help students do particular kinds of spatial reasoning with maps of Africa,

5. an exploration of how these modes of spatial reasoning have implications for instruction in both mathematics and language arts (the United States curricular term for reading and related skills of text analysis and interpretation), and

6. a summarizing look the assumptions and procedures of the Common Core State Standards, with a focus on how they may interfere with effective instruction in geography, which in turn may compromise a major goal, a literate citizenry.

A REVOLUTION IN NEUROSCIENCE

Before the 1990s, the science of psychology had three major tools.

Animal studies involved inserting electrodes into animal brains or surgically removing specific brain structures or connections, followed by careful observation of behavior. Unfortunately, conclusions from animal studies may or may not apply to human beings. This is complicated by the fact that it is not possible to ask an animal a direct question and get a direct answer (at least not in a language that humans understand!) So why do research with animals? because it was considered acceptable to do things that would be called unethical if done with human subjects. Research with human subjects was restricted to non-invasive behavioral studies or after-the-fact lesion studies.

Behavioral studies asked subjects to perform specific acts of cognition under specific conditions. For example, people might be asked to remember a list of words or numbers as shown on a screen with different colors or fonts (with the experimenter occasionally trying to confound perception by using a blue color to display the word "red," or using a large font to display a small number). Careful statistical analysis of the responses could provide insights into the activity of the brain. The results were always at least somewhat ambiguous, however, partly because different individuals might perform differently even under the same conditions.

Lesion studies involved identifying individuals who had been injured in wars or industrial accidents, or who had suffered medical events such as strokes, and measuring what they could no longer do. These studies had the great disadvantage of imprecision, because it was not always possible to find subjects who had damage that was precisely limited to specific parts of the brain.

Then, in the 1990s, the research world changed. People invented brain-scanning technologies such as PET (positron emission tomography) and fMRI (functional magnetic resonance imaging). These brain "scanners" allowed researchers to observe an "intact" human brain while a subject was doing a specific act (or thinking about a specific topic or event). Originally developed to aid doctors and surgeons in their efforts to diagnose and correct certain medical conditions, these technologies quickly became valuable for other kinds of research. A few years later, these passive brain scanners were supplemented by active technologies such as TCMS (trans-cranial magnetic stimulation), which uses magnetic pulses to temporarily disable a particular part of the brain. Like PET and fMRI, TCMS was initially used for clinical purposes, to help mark areas for surgery. Later, researchers began using it to verify the importance of particular brain structures in particular kinds of reasoning

As "pure" research tools, these three brain-scanning technologies led to a flood of research activity. The next fifteen years saw a huge number of studies done in labs throughout the world. Thanks in part to the New York City subway system, which has "allowed" me to stand in a crowded train car for 12-18 quarter-hour blocks of otherwise useless time nearly every week for several years, I have personally reviewed more than 4,000 research studies dealing with spatial cognition. These studies were published in more than 240 journals, in geography, developmental psychology, neurobiology, architecture, vision science, linguistics, urban planning, and robot engineering, to name just a few of the groups of scholars who are interested in the topic. (And, I must add, my language facility is limited, and therefore I have had to focus on articles published in English. I have reviewed only a handful of articles in German, Portuguese, and Spanish, which I can read only haltingly with the frequent aid of an internet translator! Fortunately for people like me, the large Chinese, Dutch, French, and Italian research labs that do this kind of research routinely publish in English).

As a group, these studies provide a mass of often conflicting facts, insights, and opinions, but they are nearly unanimous about a few key points, aptly summarized by Neil Burgess in a 2008 review article:

> Spatial memory appears to be supported [in the brain] by multiple parallel representations, . . . In addition, it appears that [different] systems process different aspects of environmental layout (boundaries and local landmarks . . .) and do so using different learning rules.

In short, the emerging consensus is that the human brain constructs a subjectively unified spatial representation by using a number of separate brain structures. These perform different tasks and work at least somewhat independently, simultaneously, and in parallel (for a now somewhat dated review of this research as it applies to the task of landscape or map interpretation, see Gersmehl and Gersmehl, 2006, 2007). Moreover, these brain structures and networks develop at different rates in different children, leading to significant individual differences in classroom performance. These differences clearly affect the ability to read maps, graphs, mathematical symbols, and text – in short, nearly the entire range of symbolic systems that humans use to communicate information.

VISUAL PERCEPTION AND SPATIAL REASONING

The human visual system is enormously complex, by some accounts involving nearly half of the cognitive brain. A century of animal, behavioral, and lesion studies had provided a broad outline of its function. This understanding gained a lot of detail after the mid 1990s, when brain-scanning technologies allowed people to study brain reactions to a wide array of visual stimuli, from different colors, boundaries, and sizes to angles, textures, and complex symmetries.

Even though human eyes are located in the *front* of the head, the primary visual cortex of the human brain is located in the occipital lobe, in the *back* of the head. Here, the brain distinguishes between light and dark and forms a crude "map" of the visual field. Then, the visual "message" gets sent forward through a sequence of areas that seem to specialize in different facets of perception. The closest area organizes the scene by grouping similar colors and shapes into visual "regions."

The next area adds details by noting the orientation and fuzziness of *borders* between those areas. A third area assembles smaller fragments into larger entities in a visual *hierarchy*. All of this activity happens in the lower part of the head, behind the ears. Moreover, all of it is guided by "top-down" messages that proceed from front to back, using notions of meaning to guide perceptions. Meanwhile, a separate "stream" of information is moving forward higher on the side of the head, carrying messages about location and relative position with respect to other objects in the scene (Ungerleider et al. 1998).

These two streams of neural messages converge in an area near the hippocampus, where the "what" and "where" information gets put together in another kind of spatial "map" (Bohbot et al., 2004). From this area, messages go more-or-less unconsciously to at least five separate brain areas that examine the spatial information from different perspectives (Turk-Browne, 2008). An area on the right side looks at *associations* among spatial features – things that typically occur together in the same places, like bowls and spoons on a table (Aminoff et al., 2007; Caplan et al., 2009). Another area deeper inside on the right side of the brain looks at *spatial auras*, the zones of influence that viewers unconsciously put around themselves and other objects in the world (Weiss et al. 2003). A third area above and behind the left eyebrow is an essential part of a network for encoding and recalling *spatial sequences*, the order in which features in the world (or symbols on a map) are encountered or arranged (Histed and Miller, 2006). An area behind the left ear is engaged when people make *spatial comparisons*, mental estimates of differences in size, brightness, color intensity, numerosity, or density – all conditions that a cartographer might vary in order to communicate quantitative information about places on a map (Pinel et al., 2004; Rousselle and Noel, 2008). Finally, an area at the top front of the head is a key part of a broad neural network that deals with *spatial analogies* (Bunge et al., 2005). A spatial analogy is a way of thinking about two places that are located in similar positions in different settings – two cities in similar locations on different continents, two houses in similar positions in different towns, two slopes in similar positions in different watersheds, and so forth.

DIFFERENT MODES, WORKING IN PARALLEL AND SIMULTANEOUSLY

It is very important to note that these reasoning processes – perceiving and interpreting spatial regions, patterns, hierarchies, associations, sequences, auras, comparisons, and analogies – can happen in parallel and at roughly the same time. Moreover, the thinking processes are *not* well correlated. A student who performs well on a test of spatial association may not do as well on a test of spatial sequencing. Likewise, someone who is good at spatial comparisons may not be as comfortable with regionalizing, and so forth. As a result, different students may "see" different things when they look at the same map. In fact, one of the most risky things a teacher can do in a geography classroom is to ask students, "can you see the pattern on that map?" and then interpret their nods as indications that they have indeed all seen the same thing that the teacher thinks is being displayed.

The parallel nature of these brain processes has another implication for educators. When processes operate in parallel, it is not valid to propose a facile division of the modes of spatial reasoning into "lower-order" and "higher-order" thinking skills. For any given task, any one mode may serve as a preliminary step for another. For example, someone might note the similarity of several map patterns (e.g. of particular levels of household income or unemployment and crime rates in different parts of a city). That observation could lead to a valid hypothesis about their spatial association. On another occasion, prior knowledge of a causal association with a known feature can aid in the perception of a difficult-to-see map pattern. In a similar way, observation of a spatial influence can lead to better understanding of a spatial analogy, while for a different topic an analogy can help us understand a particular kind of influence. It is possible to make similar pairs of statements about nearly every conceivable pair of modes of reasoning. A careful teacher, therefore, may make use of the innate preferences of individual students by asking them to help other students grasp ideas that may be more difficult for them to see on their own. Eventually, of course, the goal is to structure educational experiences so that every student learns how to do all modes of reasoning more effectively. That is our goal in designing skill-oriented student activities for use in geography classrooms.

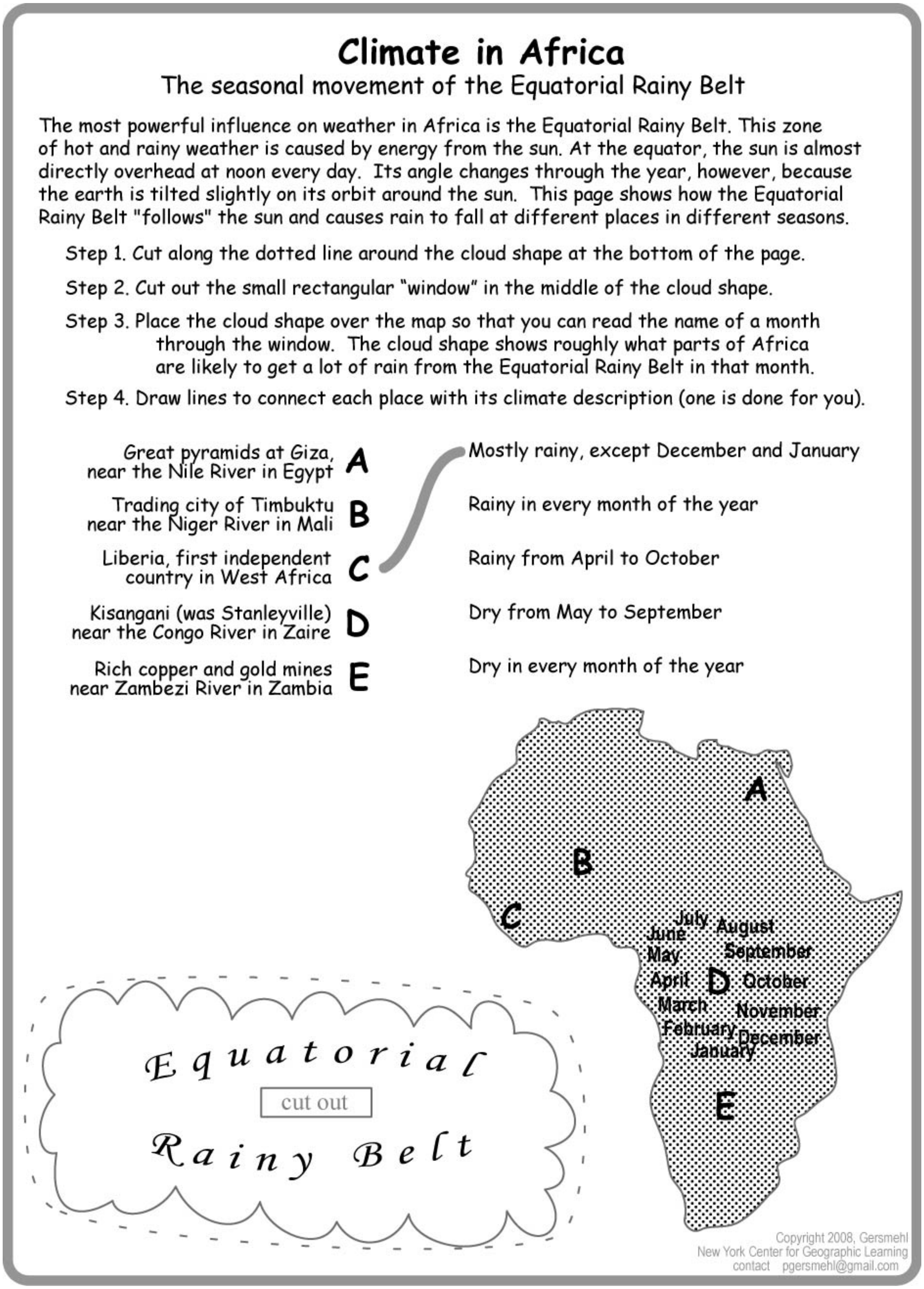
INSTRUCTIONAL MATERIALS TO TEACH SPATIAL REASONING

This section is a brief description of some instructional materials that we developed for use in several public schools in New York City, from grade 1 through 11. Some of the individual activities are similar to activities that have been used by good teachers for many decades. Where possible, we have simply adapted those time-tested activities so that they focus more sharply on the specific skills of geographic sequencing, geographic pattern recognition, regionalization, and other modes of spatial reasoning.

The sequence of activities starts in primary school with two very simple matching exercises. One of these involves the association of plants with the rainy and dry parts of Africa. Students see two outline maps, one with words like "rainy in every month," "sunny in every month year," and "rainy only in summer" written in appropriate places. The other map has words like "trees," "grass," and "desert" written. The activity involves attaching the words "true" or "false" to a number of statements about spatial associations – for example, "trees grow in places that are rainy in every month" or "grass grows in places that are usually sunny." This spatial-association activity is followed by a pattern-interpretation activity that involves matching very simple maps of animal ranges with brief "biographies" of important animals in Africa. Here is a sample biography: "I am like a big monkey. I can climb trees as well as walk on the ground. I like to live in forests that have really big trees. . . . Which map shows where I can live?

Both of these matching activities can follow or accompany a presentation to build visual vocabulary. In this presentation, students see pictures of features to associate with words like desert, grassland, gorilla, camel, etc. That presentation could be replaced by a trip to a zoo or some short videos, if viewing video is possible with the technology in the classroom. Either approach, in turn, can be used together with read-aloud stories about camels and other animals, a common part of the primary-school curriculum in many schools in the United States. What we have added is the map-matching activities, which reinforce the idea that particular animals live in particular places because they can move around in them and find the kind of food they like.

Each of these four primary-school activities has specific learner outcomes, but they are also part of a multi-grade sequence that builds background for a middle-school activity about the causes and consequences of equatorial and tropical weather. The core of that activity involves cutting a cloud out of white paper, cutting a small rectangular hole in the middle of the cloud, and positioning that hole over the names of the months of the year. These are written on a blank map of Africa in specific places, so that the cloud can indicate the major rainy part of the continent in that month (see Figure 1).



Climate in Africa

The seasonal movement of the Equatorial Rainy Belt

The most powerful influence on weather in Africa is the Equatorial Rainy Belt. This zone of hot and rainy weather is caused by energy from the sun. At the equator, the sun is almost directly overhead at noon every day. Its angle changes through the year, however, because the earth is tilted slightly on its orbit around the sun. This page shows how the Equatorial Rainy Belt "follows" the sun and causes rain to fall at different places in different seasons.

Step 1. Cut along the dotted line around the cloud shape at the bottom of the page.

Step 2. Cut out the small rectangular "window" in the middle of the cloud shape.

Step 3. Place the cloud shape over the map so that you can read the name of a month through the window. The cloud shape shows roughly what parts of Africa are likely to get a lot of rain from the Equatorial Rainy Belt in that month.

Step 4. Draw lines to connect each place with its climate description (one is done for you).

Great pyramids at Giza, near the Nile River in Egypt	A	Mostly rainy, except December and January
Trading city of Timbuktu near the Niger River in Mali	B	Rainy in every month of the year
Liberia, first independent country in West Africa	C	Rainy from April to October
Kisangani (was Stanleyville) near the Congo River in Zaire	D	Dry from May to September
Rich copper and gold mines near Zambezi River in Zambia	E	Dry in every month of the year

A teacher using this middle-school activity should ask students to reflect back on their primary-school look at maps of animal ranges. The middle-school activity, in turn, also lays a foundation for a junior-high activity about fires in tropical savanna environments. The savanna activity could use one of the fire-mapping websites as a source of up-to-the-minute information (e.g. http://firefly.geog.umd.edu/firemap/).

Still later in the curriculum, students do a high-school activity about climatic constraints on the geographic range of malaria mosquitoes. This, in turn, serves as a foundation for a more advanced investigation of the hypothesis that global climate change might cause malaria to expand into regions where people have less biological resistance.

An understanding of possible consequences of climate change may be the ultimate goal, but the foundations for inquiry are built much earlier in the curriculum. The range maps for malaria mosquitoes are similar to (albeit more detailed than) the range maps for fires in the junior-high activity and animals in the primary-school story-matching exercise. The design of all activities is informed by neuroscience research that strongly suggests that the development of competence in "seeing" map patterns involves a brain "rewiring" that is similar to the changes that occur as someone learns to read (see below). The sequencing of activities is based on the inference that there may be a window of opportunity in primary school when such development can proceed rapidly.

The early activity on map-pattern interpretation is therefore a key foundation for the later scientific investigation. To make that early activity most effective, however, it must also be scaffolded within the primary school to accommodate individual differences in reading speed and map-pattern comprehension. One way to do this is by providing one or more "right answers," thus turning a five-animal matching exercise into a four- or even three-animal problem.

Taken together, this set of activities is a good illustration of precisely the kind of multi-grade conceptual continuity that is sacrificed when teachers with limited disciplinary background assemble a "curriculum" for their classes by using keyword searches and downloading individual lessons from the internet. Good teachers can overcome those limits by imposing their own conceptual continuity in the selection and presentation of activities. For teachers with less background, however, the separate activities will probably lack the conceptual "rope" that students could use to tie ideas together and make their understanding more durable.

Now, let me stop for a brief "roadmap." This part of this article was basically a summary of a sequence of geography lessons. Previous parts had a review of the neuroscience that provided a conceptual foundation for some of the decisions that were made during the design of those activities. The story suddenly becomes much more complicated and interesting when we look more closely at how a young child's brain "rewires" itself, forming new neural connections and pruning others, in order to learn how to read or calculate quickly.

SPATIAL REASONING, READING, AND MATHEMATICAL UNDERSTANDING

Here is a capsule summary of current understanding of how a young learner acquires symbolic expertise. This information is summarized from a large number of research studies (representative examples include Fias et al., 2003; Temple et al., 2003; Thuy et al., 2004; Hubbard et al., 2005; Schlaggar and McCandliss, 2007; and Vinckier et al., 2007; for an in-depth review that is written in an accessible style, see Dehaene, 2009).

At first, the learner tries to decode individual letters and numbers by using a broad range of brain structures. Most of these are in the primary visual area in the occipital cortex (back of the head) and adjacent areas in the temporal and lower parietal lobes (the so-called ventral and dorsal visual processing streams that deal with what we are seeing and where it is located in the visual field and in the real world). Recognition of specific shapes and sequences as meaningful involves a measurable change in connections among neurons within several specific brain regions. In most people, a small area on the lower left side of the head eventually develops connections that are specialized for the recognition of letter shapes. Letters and letter-pairs are linked with sounds in another brain area just forward of that one. A third area still farther forward combines syllable sounds into words, and so forth. At each link along this chain, however, backward connections carry "top-down" messages about meaning that influence the interpretation of symbols.

Meanwhile, a roughly analogous sequence of structures on the lower right side of the brain is involved in other forms of visual pattern recognition – identification and naming of features in real life and on photos and video screens, development of vocabulary to associate with geometric shapes, and, very important for geographers, acquisition of ideas about symbolic representation of spatial relationships – in other words, maps of various kinds (Bergen et al., 2007; Carreiras et al., 2007; Pasnak et al., 2009).

Even more significant is this fact: in early childhood (and for adult illiterates), the general process of visual interpretation and the specific process of reading both make use of the *same* basic brain structures. Several years are required for the development of the specific neural connections that facilitate reading. In other words, both reading and pattern recognition use fairly large and overlapping areas at first, and then become more localized and separate as skills increase. It is therefore plausible to posit that classroom or takehome activities aimed at developing map-reading skills might also have spin-off effects on reading among young children. Given that most of the neuroscience research cited above is very new, done since the invention of non-intrusive brain-scanning technologies, it is not surprising to find very little research that examines these possible synergies. The small amount of research already done, however, does point in that direction. Studies in Arizona and Michigan showed that math and reading scores increased after a series of geography activities (Dorn et al., 2004; Hinde et al., 2007). Preliminary results from a study underway in Oregon shows that activities designed to promote spatial thinking have beneficial effects on other cognitive skills among blind and partially sighted subjects (A. Lobben, personal communication). And, most relevant for this article, the author was involved in a recent project to develop and test instructional materials for a number of kindergarten and first grade classrooms in Harlem, a low-income neighborhood in New York City.

In 2005, the author accepted a position as co-director of the New York Center for Geographic Learning. A year later, administrators of a Harlem school asked several people from the Center to work with teachers in 5 kindergarten and 4 first-grade classrooms. Their role was to suggest topics for classroom activities, provide maps and other manipulables, work individually with teachers to develop ideas for implementation, and occasionally observe classes.

Implementation was uneven, because the terms of the request specified that teachers could adapt or modify the lessons as they saw fit. Moreover, as in most other New York City schools, these teachers were under considerable pressure to ensure that students would be able to perform well on standardized math and ELA tests. Nevertheless, the results were interesting. Despite very high levels of poverty and single-parent families, and a lottery-based admission policy, these schools had reading scores that increased rapidly through the year and ended almost twice as high as the city average on end-of-year standardized tests.

It is important to underscore that this experience does NOT constitute scientific proof that geography lessons enhance reading skill. This was a limited-budget proof-of-concept project. Although students were chosen by lottery, there were no "control" classrooms for comparison. Moreover, the inclusion of two geography lessons each week was not the only difference between these classes and their "peers" elsewhere in the city. Scientific integrity therefore precludes any claim that the geography lessons were the "cause" of the dramatically higher reading and math scores. Nevertheless, people should not ignore the other side of the coin – the student performance in these classes clearly shows that devoting substantial time to geography lessons each week in first grade did NOT cause reading and math scores to go down. In short, we have observed the Hippocratic Oath – first of all, do no harm!

Other results of that "experiment," however, are worth noting. For example, a group led by Margaret Legates has adapted the Harlem lessons to fit educational standards in the small state of Delaware, 250 kilometers southwest of New York City. The lessons are now being used throughout the state, and they are required in several school districts. Teachers describe the results as very positive (Legates, personal communication). Meanwhile, the lesson developers have been invited to present the results of the Harlem work at ten professional conferences in seven states, and they have been asked to lead more than 30 day- to week-long teacher-training workshops in eight other states. Finally, some of the handouts and teacher guides that were prepared for teacher-training workshops have already been translated into Spanish, Chinese, Brazilian Portuguese, and Korean for use in teacher workshops.

As we review these events, it is important to remember that the design of these primary-school lessons was based on scientific research that was first reported in professional journals after 2000 (and subsequently replicated and extended in a body of research that now numbers over 4000 articles in more than 240 professional journals). As we noted in a presentation to the Spatial Intelligence Learning Consortium at Northwestern University in 2009: "we did not wait until all of the scientific issues had been settled, nor did we try to design a fully-controlled experiment that might take a decade to implement. We decided to use an invitation from a school as a platform for an attempt to aid the research process by designing lessons based on research and then simply observing the results."

In short, in real-world classrooms as well as in clinics and brain-scanning labs, the available evidence strongly suggests the possibility of synergistic effects between carefully designed early-grade geography lessons and student performance on standardized reading and math tests. This possibility is at least worth investigating, if not conclusively proved at this time. It follows that any state or national program of literacy and numeracy education that does not include primary-school activities dealing with geographic representation may be missing an important path toward greater mastery of both content and representational skill. Stated another way, current policy may be depriving students of opportunities to gain both knowledge *and* literacy, both present understanding *and* the means to gain further understanding. It is not surprising, therefore, that these policies may produce citizens who are less able to evaluate statements made by those aspiring to be their leaders!

Is it necessary? I consider Colombian context is different. In Colombia, Social studies teachers have to apply "Estandares en Ciencias Sociales" in their classes. The "Harlem experiment" and other curriculum projects did not take place in a vacuum. The United States has been embroiled in a multi-decade struggle to define the relative importance of national educational policy, state educational standards, and local educational initiatives. At the moment, the "winner" appears to be a strange hybrid called the Common Core State Standards. Described as fulfilling "a mandate from the states," the Common Core is actually a national effort to produce a single set of educational standards – currently 66 pages for English Language Arts and 93 pages for Mathematics. These are carefully described as "guidelines" for local initiative:

> By emphasizing required achievements, the Standards leave room for teachers, curriculum developers, and states to determine how those goals should be reached and what additional topics should be addressed. Thus, the Standards do not mandate such things as a particular writing process or the full range of metacognitive strategies that students may need to monitor and direct their thinking and learning. Teachers are thus free to provide students with whatever tools and knowledge their professional judgment and experience identify as most helpful for meeting the goals set out in the Standards. (Common Core State Standards Initiative, p4.)

Despite this careful wording, the goal of the CCSS is a greater degree of uniformity in educational practice. This sounds like a worthwhile goal, on first hearing, but it poses two large problems for disciplines such as economics, geography, music, or even science.

The first problem is encapsulated in the phrase "shelf space." Merchants know that a product, regardless of quality or price, is not likely to sell if buyers cannot find it "on the shelf" among the other alternatives. This principle applies to any product, from a cola drink in a grocery store to a political idea in an election. It also applies to any market, from a grocery store full of cans and bottles to an electronic stock exchange with computer-assisted trading.

In an educational setting, a discipline such as economics, geography, or music is likely to be squeezed out of the curriculum if none of the standards clearly describe their specific kind of knowledge or skill as a goal. Faced with a mandate to help students perform well on the tests that they have to take, teachers naturally respond by reducing the amount of time devoted to any topics that are not on those tests.

That problem is well known, and thousands of educators from many disciplines are engaged in various attempts to ensure that their topics become part of the standardized curriculum. I will leave that arena to those "combatants," in order to focus on what may be an even more serious problem. This problem is the fact that the standards rely on the current level of scientific understanding of the learning process. In fact, educational standards rely on a small handful of authors' and reviewers' current understanding of the learning process, which may lag behind actual research understanding. Despite that lag and resulting misunderstanding, the standards are usually worded in a way that requires teachers to follow specific ideas about how children learn.

Let me provide one extended example that is relevant for geography teachers. In October, 2011, the New York State Department of Education issued a Request for Proposals for curriculum writers to develop model lessons. These lessons will be offered on the internet to every school district, and the ideas in them may be used as a basis for state achievement tests. Moreover, scores on those tests can, in turn, be used "as one basis" for evaluating teachers and administrators, and those evaluations may be used to inform decisions about hiring, firing, and teacher pay.

In other words, the stakes are very high. For that reason, it is important to note that one major criterion for evaluating proposals is how they are "aligned to the New York State P-12 Common

Core Learning Standards for English Language Arts & Literacy" (NYSED, p.13, and restated many times throughout a 131-page Request for Proposals).

In short, proposed lessons *must* follow the standards, or they are not likely to get placed on the "shelf" of options available to teachers. This poses both a practical and a conceptual problem, which can be illustrated by looking at one very specific example. The Common Core Standards specify that lessons should help "students use proportional reasoning when they analyze scale drawings (7.G.1)" and "work with partitioning shapes (3.G.2)" as it "relates to visual fraction models" (PARCC, 2011).

These sound like laudable goals, clearly related to important geographical ideas – shape recognition, area partitioning, and scale drawings (i.e. maps). The problem is that the research that informs the sequence of ideas in the Common Core Standards is incomplete and at least partially obsolete. Recent behavioral and neuroscience research clearly suggests that mental scaling and symbol positioning in scale drawings are ideas that are easily grasped by very young children if presented with appropriate educational materials (Empson, 1999; Huttenlocher et al., 1999; Duffy et al., 2005; Jeong et al., 2007; Boyer et al., 2008). The Common Core Standards, however, do not specify those topics as part of the curriculum until Grade 3 and Grade 7. In the Harlem schools mentioned earlier, these ideas were featured in kindergarten and grade 1, in what proved to be a high-interest classroom- and playground-model activity.

Here is the important point: if the process of learning how to use map symbols and other mental representations of spatial relationships is similar to the process of learning how to read letter symbols in text, then there is a "window of opportunity" in primary school when it is easy to teach these skills (Jiang et al., 2007; van Dijck et al., 2009). Delaying them until Grade 7 may therefore lead to less efficient learning. And that, in turn, will make students (and adult citizens) less able to acquire information from maps and other geographic representations in books, newspapers, television, and the internet.

SUMMARY AND CONCLUSION

This paper had six sections, which made the following points:

1. Neuroscientists have recently developed some technologies for observing human brains as they perform specific acts of perception and cognition (and for verifying that specific brain "regions" are indeed essential for particular kinds of thinking) ,

2. Using those technologies, neuroscientists have identified specific areas of the brain that perform different aspects of the process of interpreting and encoding a visual image, such as a scene, photograph, or map (or letter, number, or drawing),

3. That research has several conclusions. Human brains use several different modes of spatial reasoning to gather and organize spatial information, e.g. from a map. Each mode uses a distinct brain network. Different modes can operate simultaneously. There are notable individual differences in children's abilities to do different kinds of spatial reasoning. All children can learn to do all modes better.

4. We used that research to guide the design of geography lessons for kindergarten and first grade. These lessons were used, with varying degrees of fidelity, in 9 public-school classrooms in a high-poverty area of New York City. Reading and mathematics scores went up dramatically in those classrooms.

5. Neuroscience shows that learning how to read and do math begins by using generalized brain networks. These networks overlap with areas used in processing colors, shapes, sizes, and numerosities on maps. Later in the process of learning how to read, the brain essentially "rewires" itself so that smaller areas become specialized for specific processes, such decoding printed symbols quickly.

6. The Common Core Curriculum in the United States is a national-state effort to specify particular topics to be taught and assessed at specific grade levels. The framework, however, relies on research that is incomplete and sometimes out of date. For example, the process of encoding the relative location of a symbol on a map is a seventh-grade objective in the CCSS, even though research shows that the skill may be more appropriately taught in kindergarten and first grade.

How are these six conclusions relevant for the political campaign described on the first page of this paper? According to a recent National Academy of Science report, "learning to think spatially is a form of learning how to learn" (Downs and Souza 2006). If subjects that focus on spatial reasoning are omitted from the curriculum, or delayed until much later than current research might recommend, we should not be surprised if citizens are less able to acquire relevant information from maps and other geographic representations. In this specific case, easily obtained maps clearly show that Alaska's geologic structures are capable of holding between 30 and 40 gigabarrels of petroleum. That sounds like a huge amount, but for an economy that uses more than 7 gigabarrels of oil every year, it represents four to six years of supply (and some of it has been used already). That is hardly the kind of resource that should be held up to a crowd chanting "drill, baby, drill," as if drilling in Alaska could solve the energy problem.

That was indeed the message included in the subsequent disclaimer, but it was not the message heard by the American electorate that night. The failures of the United States educational system are among the reasons for a disconnect between school knowledge and citizenship skill. That conceptual disconnect, in turn, has implications for future world security. In short, we must base our educational decisions on the best available research. To do that, we must create policies that are flexible enough to make use of new research in a timely manner.

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Artículo recibido 20 - 09 - 11. Aprobado 25 - 11 – 11.