Spatial Thinking About Maps

Development of Concepts and Skills Across the Early Years

Report prepared by
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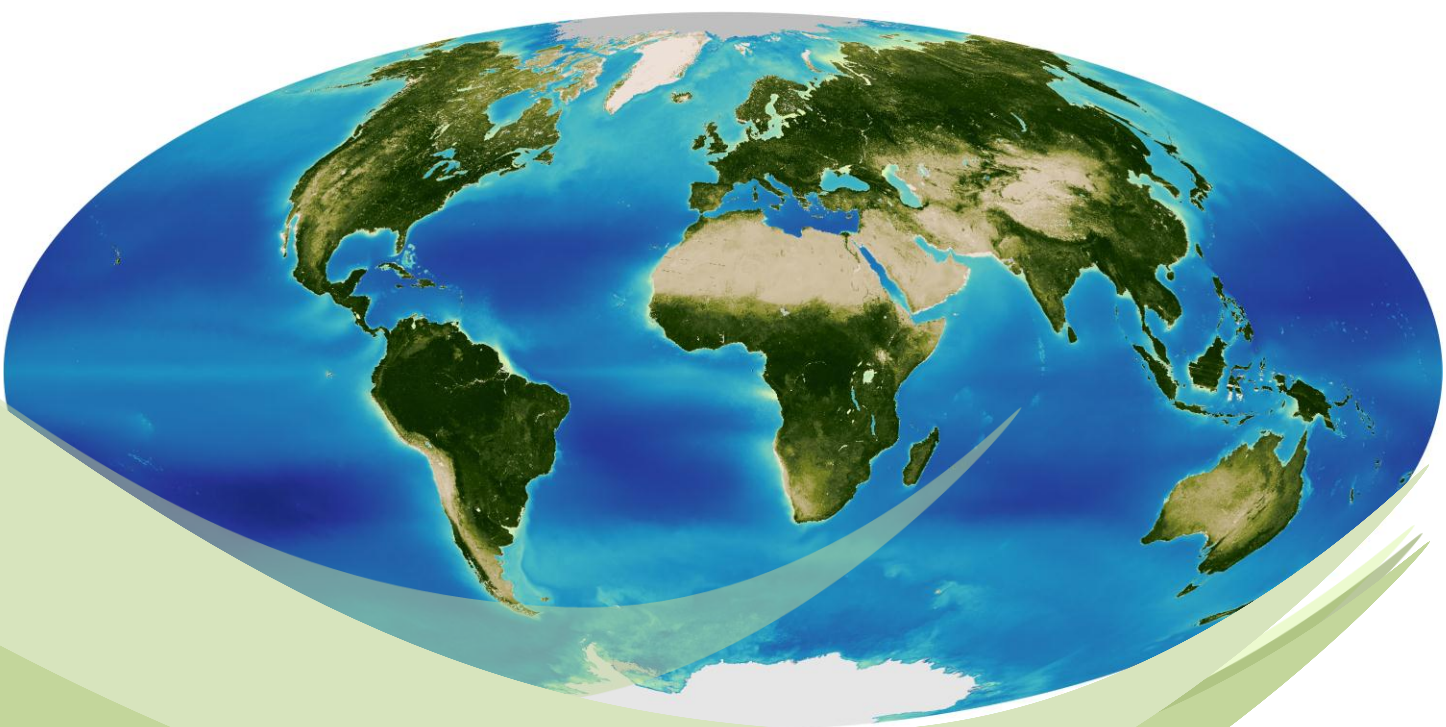

This report was prepared for National Geographic Education Programs as part of their mission to design and improve educational resources provided to educators and families.

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Cover Photo: A spatial representation depicting chlorophyll concentrations in the ocean and terrestrial vegetation. Representations such as these model data in ways that tell us something about how the Earth is changing over time. This NASA Earth Observatory image was produced by Jesse Allen, using data provided courtesy of the Ocean Color web team.

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Highlights

Spatial thinking is arguably one of the most important ways of thinking for students to develop as they learn geography, earth and environmental sciences. Spatial thinking involves knowing and understanding spatial concepts and relations, how we represent those concepts and relations in different ways, and also how we can reason with spatial information (NRC, 2006). A student who has acquired robust spatial thinking skills is at an advantage in our increasingly global and technological society. Spatial thinking is also positively correlated with success in math and science. Thus, providing quality instructional resources for learning how to think spatially during the formative school years is critical. It is even more important that such resources are not simply "flashy" software programs or fun and games, but instead are learning experiences designed with research on spatial concept development in mind. This document highlights the findings from the spatial thinking research report and provides recommendations for K-5 map education programs.

The review includes a summary of over 80 articles, book chapters, and books from the most prominent researchers in spatial thinking in geography and earth sciences, especially those focused on the development of mapping concepts and skills. This includes work by Mark Blades, Jim Blaut, Bob and Sarah Bednarz, Roger Downs, Phil and Carol Gersmehl, Reginald Golledge, Mike Goodchild, Mary Hegarty, Don Janelle, Kim Kastens, Lynn Liben, Nora Newcombe, David Stea, and their various colleagues over the years. We also included the recent National Research Council spatial thinking report, *Learning to Think Spatially* (NRC, 2006), and the UCSB websites http://www.spatial.ucsb.edu/ and www.teachspatial.org as key resources in our review.

Major findings and curricular recommendations include:

Grades PreK through 1 (ages 3 to 6)

Developing Spatial Concepts

- **Identity and Location:** Young children can begin identifying places on maps, landscape features on maps and aerial photographs, and can locate familiar places on maps. Children this age also use landmarks as a way to identify where places or items are located on a map.
- **Magnitude:** Children innately can understand magnitude of objects (bigger, smaller), but might confuse the scale of an object with the number of objects (numerosity).
- **Relative Distance and Direction:** Children this age can understand relative distance, such as *near*, *far*, *next to*, and can began using relative direction on maps, such as navigating mazes. However, children this age struggle with knowing which way to "hold a map" and easily get confused if it is not aligned to the real world.
- **Symbols-** At this age, symbols should represent an object or place in the real world and be a recognizable icon to the child. Abstract, unrelated symbols are not understood well at this age.

Curricular Recommendations

Children in early elementary learn through sensory experiences and do best with tactile, hands-on, active mapping activities. Children should be given opportunities to practice with maps of familiar places (classrooms, homes, schools, neighborhoods), and should also be given opportunities to make maps, real and imaginary. Maps should also be big in size to allow children to explore them with their whole bodies (as opposed to atlas maps). At this age, pictorial and possibly panoramic views are common ways that children represent their views of the world.

Grades 2 through 4 (ages 7 to 9)

Developing Spatial Concepts

- **Identify and Location:** Children at this age level are much more accurate at locating places and landscape features on a map, but still perform better with familiar locales as opposed to foreign locales. Map alignment issues improve, but students inconsistently use landmarks to verify locations.
- **Distance and Direction:** This age is a transition period between topological concepts of distance to metric measurements. By the end of 4th grade, some children will readily use metric distances, but many will still need guidance. Children are still using landmarks and relative direction, but some are learning cardinal directions.
- **Symbols:** Children at this age are transitioning between iconic real-world symbols to abstract symbols; however, they still make significant errors and will need explicit guidance on what symbols mean.
- **Reference Frames:** Children at this age are being introduced to grid systems (coordinate system) to begin learning absolute location. This corresponds with the same concepts introduced into math classes.
- **Hierarchies:** The concept of hierarchy (or nesting) is not well established innately with this age group, but can be introduced and developed with close guidance.

Curricular Recommendations

By this age, children begin exploring a broader world beyond the familiar and begin using birds-eye views of maps, but will still have a combination of pictorial and panoramic views. Activities should be as active and hands-on, allowing children to manipulate maps when possible. This is a prime age to introduce more complex spatial concepts, but teachers will need to provide explicit support in doing so as many of these concepts are not learned innately by this age. Students should be given the opportunity to produce their own maps at this age and use maps and models that allow active exploration (e.g. 3-D topo maps, landscape models).

Grades 5 and 6 and beyond (ages 10 and older)

Developing Spatial Concepts

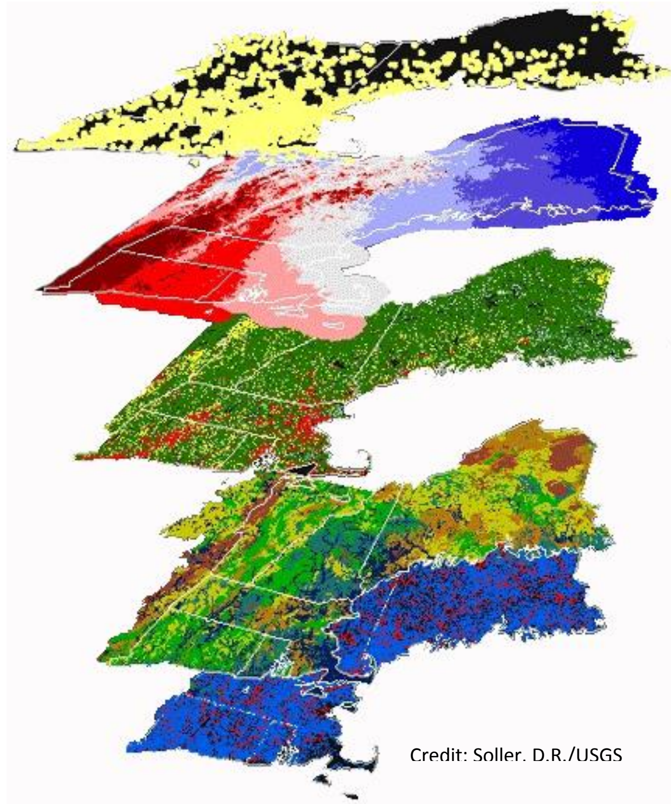
- **Identity, Location, Distance, and Direction:** Children in upper elementary grades do not readily use map scales, metric distances, cardinal directions, etc. to help them determine locations, so before mapping tasks, these children will need to be primed to use all the resources available to them to determine locations, and should be encouraged to self-explain decisions, which might also cue them into thinking more about landmarks, distances, and directions**.**
- **Symbols**: By this age, students readily use abstract symbols and understand that symbols do not always "look like" the referent.
- **Overlay and Complex Spatial Concepts**: About half of all 6th grade students incidentally understand the concept of overlay without formal instruction. If students have mastered the basic spatial concepts of location, distance, direction, boundaries, regions, etc., they can then move onto more complex spatial concepts such as distribution, patterns, overlays, and projection.

Curricular Recommendations

Mapping activities at this age can include different projections and viewing angles, and children will use measured distances, cardinal directions, and abstract symbols with support. Students at this age will use multiple map formats (reference maps, thematic maps, digital maps) at multiple scales. This is a good age to introduce more complex spatial concepts such as projection and overlay.

Introduction

Spatial thinking is arguably one of the most important ways of thinking for students to develop as they learn geography and earth and environmental sciences. Spatial thinking involves knowing and understanding spatial concepts and relations, how we represent those concepts and relations in different ways, and also how we can reason with spatial information (NRC, 2006). A student who has acquired robust spatial thinking skills is at an advantage in our increasingly global and technological society. Spatial thinking is also positively correlated with success in math and science (see Battersby, Golledge, & Marsh, 2006). Thus, providing quality instructional resources for learning how to think spatially during the formative school years is critical. It is even more important that such resources are not simply "flashy" software programs or fun and games, but instead are learning experiences designed with research on spatial concept development in mind. This report synthesizes spatial thinking research with respect to mapping concepts and skills as a first step toward making improvements in instructional resources for use in Grades K-5.


Credit: Soller, D.R./USGS

Review Process

Our investigation of spatial thinking revealed abundant research on different spatial thinking concepts, and as we read, we were able to identify overarching trends in the way learners of different ages come to understand those spatial concepts. The literature was so rich and diverse, that our initial task in the review process was to set parameters on literature to be included. These parameters helped us make the task more manageable, but more importantly, focused our search on the most relevant resources for informing the redesign of National Geographic Education Program's mapping instructional resources for Grades K-5. Spatial thinking can occur at many scales, from the nano- and micro-scale (i.e., structures of atoms) to the larger figural, environmental, and geographic scales; our review covered research between the figural and geographic scales, but only research related to mapping concepts and skills.

Our review includes over 80 articles, book chapters, and books from the most prominent researchers in spatial thinking in geography and earth sciences, especially those focused on the development of mapping concepts and skills. This includes work by Mark Blades, Jim Blaut, Bob and Sarah Bednarz, Roger Downs, Phil and Carol Gersmehl, Reginald Golledge, Mike

Goodchild, Mary Hegarty, Don Janelle, Kim Kastens, Lynn Liben, Nora Newcombe, David Stea, and their various colleagues over the years. We also included the recent National Research Council spatial thinking report, *Learning to Think Spatially* (NRC, 2006), and the UCSB websites www.teachspatial.org and http://www.spatial.ucsb.edu as key resources in our review. Lastly, we consulted work by three proponents of spatial thinking with young children—Lucy Sprague Mitchell, David Sobel, and Maria Montessori—and although this work was mostly anecdotal, it complimented the research studies we reviewed. We sought out seminal articles on spatial development, even if the articles were published decades ago. A great deal of the developmental work on spatial thinking began in the 1970's and continues to the present day, so we selected to read as many important pieces of work produced during this time period. Many of the articles we read were published in peer-reviewed geography education and cognitive psychology journals. For a complete list of our sources, please refer to the **Reference and Credit** section.

While we present the majority of research findings in the **Findings** section, we felt it necessary to point out several notable issues and ideas that emerged during our review. These warranted additional elaboration and also help set the context for reviewing and understanding the specific findings described later in the report. They include:

- In general much of the **theoretical perspectives** used by researchers are originally derived from Piaget's work (or starkly in contrast to Piaget's work) so almost all the research is presented using a cognitivist/ constructivist theoretical perspective.
- In terms of **conceptual frameworks**, there is no clear consensus about the best organization of spatial concepts. The NRC report, as well as work by Golledge and others, appear to present a generally uncontested way of identifying and organizing concepts. For that reason we chose to use their conceptual framework as the organization structure to present our findings. However, other spatial hierarchies have been developed and warrant a look. These are included in the following **Frameworks** section.
- There is a **debate** among spatial thinking researchers about the emergence and capabilities of young children, especially ages 3 to 6. This debate represents two different beliefs about spatial thinking abilities of young children and will be particularly important to consider when designing educational resources for Grades K-2.
- Spatial thinking is a domain with a long history of **sex differences**, usually favoring males. Many studies we reviewed included sex as a variable and found some, although slight, sex differences. We will summarize some key conclusions about sex differences in this introduction section, but will not elaborate more on these findings as they are inconsistent and usually only slightly significant or not significant at all.

Credit: Forest Service/USDA

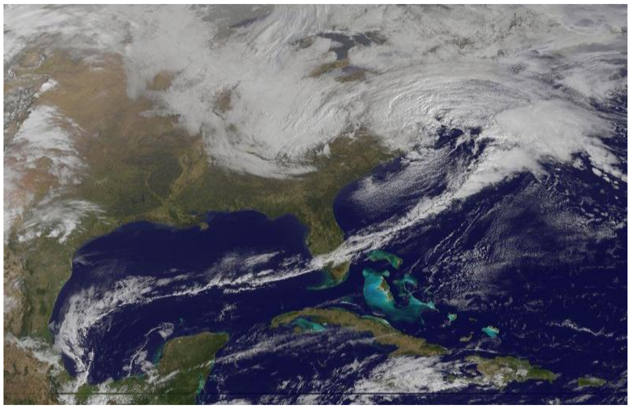
- Many researchers in spatial thinking have focused on how the **brain** works during spatial thinking tasks. While we did not review this area of research extensively, some findings on spatial thinking at different scales, from table top tasks (e.g., making a map) to navigational tasks (e.g., using a map to find a location), have implications for designing lessons and activities for the classroom.

Theoretical Perspectives

Several of the spatial thinking researchers—Downs, Liben, Kastens, among others—adopted a Piagetian framework for organization and development of spatial concepts. Downs, Liben, and Daggs (1988) say that an "advantage of Piagetian theory for geographic education lies in its emphasis on three sets of ideas—representation, space, and logic—which are central to the comprehension and production of maps" (p.684). This statement, although written decades before the NRC report, *Learning to Think Spatially*, is similar to the way the NRC committee organized their ideas about spatial thinking.

More specifically Piaget proposed a progression of spatial concepts, beginning with topological concepts between the ages of two to seven, followed by the emergence of projective and Euclidian concepts after the age of seven. This progression—topological, projective, Euclidian—will be prominent in the Findings section because of the centrality of Piaget's ideas to the spatial research we read. Examples of the concepts include (Kastens & Libens, 2010; Libens, 2008):

- Topological: ability to understand…on, in, inside, in the middle of, over, by, with, close to, between, next to, around, and beside.
- Projective: ability to understand…in front of, behind, past, right, on the right, on the side of, left or right of, straight, down the hill, and up the hill.
- Euclidean: ability to think abstractly using a frame of reference (such as a coordinate system), and then measure distance, direction, and angle.



An image from NOAA's GOES-13 satellite on March 6, 2013 shows a winter storm hitting the U.S. mid-Atlantic region. Credit: NOAA-NASA.

It is also notable that when researchers did not adopt a Piagetian framework, they typically contextualized their work is contrast Piaget's work, often finding that children can perform more advanced tasks than what Piaget found in his research. The emphasis on Piaget and the cognitivist/constructivist perspective likely reflects the time period in which much of the spatial thinking research was initiated—the 1970's-1990's. We did not read a single research article that took the situative or sociocultural perspective of learning spatial concepts, although recent research on GIS training might adopt this perspective—we cannot say. However, in general this field has primarily focused on cognitive development of spatial concepts, with a few exceptions.

Conceptual Frameworks

Many geography education researchers have attempted to develop conceptual frameworks organizing the vast array of concepts and skills that ultimately relate to spatial thinking. These conceptual frameworks were invaluable in helping us organize our ideas as we read, and in reality, there is quite a lot of overlap between conceptual frameworks used by different researchers. The NRC report, *Learning to Think Spatially,* adopted a conceptual framework based on work by Golledge (1995, 2002, et al., 2008), which has also been elaborated by Jo and Bednarz (2009). This conceptual framework seems particularly useful when focused on spatial primitives and simple spatial relations, because those are the spatial concepts taught at the K-5 level. We chose to organize our **Findings** and **Curriculum Recommendations** using the Golledge et al./Jo and Bednarz framework (Spatial Primitives, Simple Spatial Relationships, Complex Spatial Relationships) as this framework is situated within the broader categories of Concepts of Space, Representations, and Reasoning used by NRC (2006). Refer to the **Frameworks** section for an overview of the different conceptual frameworks by researchers and how these frameworks overlap. There have been other frameworks or hierarchies proposed and those have been included in Frameworks section.

The Debate

During the 1980's an interesting debate emerged among geography spatial thinking researchers. The work by Blaut, Stea, and DeLoache represent one side of the debate, while the work by Downs, Liben, and Kastens represent the other side of the debate. The debate primarily concerns the spatial abilities, especially with respect to maps, of preschool and early school children, roughly ages 3 to 6 years old.

On the one side of the debate are researchers—namely Blaut, Stea, DeLoache, Newcombe, and their colleagues—who have conducted research to show that young children (preschool age or younger) have mapping abilities not originally recognized by Piaget (see Uttal, 2000, for a review and Todd, 2010, who also found similar results). Blaut and colleagues (e.g., Blaut et al., 2003) claim that their research shows that spatial mapping abilities, to some extent, are a universal acquisition made by very young children regardless of instruction. From their research they conclude that spatial abilities are a 'cultural universal' that emerge even prior to formal instruction and that preschool children demonstrate relatively sophisticated spatial abilities even though they have never been formally taught spatial concepts and skills. The quote below is an example argument from this side of the debate:

> *Children's map—like toy landscapes (made with all sorts of objects that can stand for landscape features) are crude and temporary, but they do depict more or less veridical landscapes that are viewed from roughly overhead in play and are representational at a small scale—hence, are map-like…We suggest that geographical, macro-environmental behavior—including mapping—does not pre-require any cognitive understanding of formal geometric principles in order to be effectuated. (Blaut, Stea, Spencer, & Blades, 2003, p. 166 and p.177)*

On the other side of the debate Downs, Liben, and Kastens conclude, more or less, that prior to the ages of 7 or 8 years old, most children have very limited mapping abilities because they have only mastered topological spatial concepts and not projective or Euclidian concepts. Their work is strongly rooted in the original work by Piaget and Inhelder. Piaget and Inhelder claimed that topological spatial concepts are the easiest to learn and thus, children in the early years only have access to these concepts when reasoning about maps. Projective and Euclidian concepts begin to emerge in early elementary (simultaneously) but are not mastered until upper elementary (around 9 years old) if they are mastered at all. An example description of this side of the debate is quoted below:

> *Piaget and Inhelder argued that children understand topological space before projective and Euclidian spaces. Understanding of projective and Euclidian spaces emerges in parallel at approximately the same developmental age, but the Euclidian spatial concept takes longer to be fully comprehended (Kastens & Ishikawa, 2006, p.55). Skilled map use is not an ability that develops naturally and inevitably in all children, like walking or talking. Instead, it is a complex ability that must be taught and practiced if it is to be fully developed. (Liben & Downs, 1989 as cited in Kastens & Liben, 2007, p. 46-47).*

While we did not read every article or book written with respect to this debate, we are able to draw some conclusions about what it means for revising mapping curriculum in Grades K-5. The following are our conclusions:

- The research shows that young children (ages 3 to 6) appear to naturally acquire topological spatial concepts to some degree, regardless of cultural group or background experience with maps, but even if they are acquired at a young age there are still some children (sometimes almost half in these research studies) that struggle with topological concepts.
- The research shows that projective and Euclidian concepts are very difficult for students to master and that even adults struggle with these concepts, especially Euclidian concepts.
- There is some debate about projective spatial concept development and when projective concepts begins to emerge is children's reasoning; Blaut, Stea, and DeLoache say as early as 3 or 4 years old while Downs and Liben argue it is more like 7 to 8 years old. Regardless, even if younger students show projective spatial concepts emerging in their reasoning about maps, the students' mastery of those concepts is limited. In any given classroom, many to most students will not have access to projective spatial reasoning unless provided very good instructional resources on these concepts.

TAKE HOME MESSAGE

Any given curriculum cannot assume that children have mastered any or all of these concepts by a given age. A set of instructional resources at K-2 would do well to focus on topological concepts and basic projective concepts. Resources Grades 3-4 should begin with topological concepts, but focus on helping students make progress on basic projective and Euclidian concepts. Resources at Grades 5-6 should begin with basic topological, projective and Euclidian concepts, but focus mostly on advancing students' understanding of projective and Euclidian space.

Sex Differences

For many decades now, people generally believe that males are superior to females in spatial reasoning, and these is research to support this conclusion, especially in terms of sex differences on mental rotation tasks (e.g., “the average American man has an ability to perform mental rotation of a three-dimensional object that exceeds that of the average American woman by half a standard deviation or more” (Linn & Peterson, 1985; Voyer, Voyer, & Bryden, 1995 as reported in Newcombe, 2007, p. 1). From the research it appears that males generally perform better on paper-pencil spatial tasks, and that males and females perform in different ways when engaged in environmental wayfinding tasks. While a lot of research has focused on establishing the biological cause for these differences, none of the theories hold up well. For example, some researchers argue that, “Man the Hunter” explanation does not justify male superiority on spatial abilities because “Woman the Gatherer” also needs these abilities to navigate terrain searching for food (Newcombe, 2007). Others may argue that “Man the Hunter” does help us better understand spatial sex differences because the different tasks required by men and women in hunter-gatherer societies.

Additionally, even if there is a biological connection it does not mean that intervention cannot be used to correct deficits. Newcombe (2007) points out that people often assume, incorrectly, that biologically caused differences are not malleable, but humans have found ways to circumvent our biological inheritance. Most people assume differences that emerge early in development—like the differences in spatial ability—must be biologically caused, but Newcombe (2007) notes that biologically caused conditions can come late in life and environmentally caused differences can come early in life.

In terms of the research we reviewed, sex differences on spatial tasks were limited, and often insignificant. The following are some general conclusions from our review:

- Males tend to perform better on paper-pencil spatial tasks compared to women (Newcombe, 2007), and paper-pencil tasks are the most common way researchers have measured spatial abilities (Montello et al., 1999). There are many more paper-pencil spatial tasks in which there are no differences between the sexes compared to the paper-pencil tasks in which there are differences.
- Studies that do not find sex differences generally do not report sex equality on spatial tasks, possibly skewing what gets published or what gets attention when read (Halpern, 1992; McArthur & Wellner, 1996).
- With respect to wayfinding tasks, females generally report higher levels of anxiety and less confidence in their sense of direction compared to males, who report higher levels of confidence (Montello et al., 1999).
- Males tend to engage in “survey strategy” maintaining a sense of self-location in relation to metric distances, cardinal directions, etc., whereas females tend to engage in a “route strategy” paying attention to key landmarks (Montello et al., 1999). However there is a considerable overlap between the distribution of males and females, meaning that many females engage with route strategies and many males engage with survey strategies, so both strategies need to be taught in instructional resources.

- Sex difference on mental rotation and map reading were not observed in elementary-school children from low-income backgrounds even though they were found in children from middle- and high-income groups. (Levine et al., in press; Newcombe, 2007, p.3). This means that experiences at home and school may influence spatial capabilities and, in turn, be responsible for some of the sex differences that emerge in middle- and high-income groups.
- Intervention helps both men and women, even though it does not appear (as of yet) to eliminate the differences (Terlecki & Newcombe, 2005). In general, spatial abilities of both males and females are poor, so both sexes need intervention regardless if one sex does slightly better than the other.
- In a comprehensive study looking at sex differences across a range of Piagetian tasks researchers found, "The majority of performance assessments did not demonstrate a significant difference between males and females. Males significantly outperformed females on 8 of the 22 spatial structure tasks. However, as with other gender studies, similarities between male and female performances far outweighed any differences" (McArthur & Wellner, 1996, p.1065).
- In one map reading and wayfinding study, males tended to be more accurate measuring angles while women tended to be more accurate at distances, but statistical significance was not found (Golledge, Doherty, & Bell, 1995).

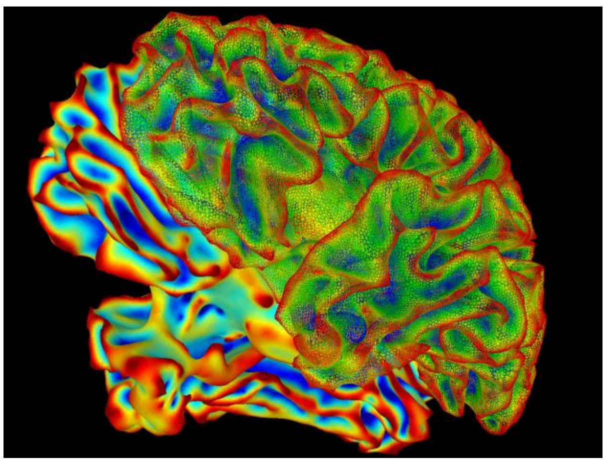
Neurological/Brain Research

We would be remiss if we did not mention the studies of neurological functions and spatial thinking that emerged during our review of research. While these studies do not intend to inform classroom practice, the results from the studies can help our understanding of spatial thinking at different scales and on different types of tasks. Most notably is the work done by Hegarty and colleagues using brain scans during spatial thinking tasks and the review of neurological studies by Gersmehl and Gersmehl (2006) that have informed the development of their proposed modes of spatial thinking.

Hegarty, Montello, Richardson, Ishikawa, and Lovelace (2006) studied the brain's response during spatial thinking tasks at different scales to determine whether there was a relationship between ability to perform small-scale (i.e. table-top) spatial tasks to the ability to perform real-world spatial tasks. They found that the ability to perform table-top tasks is only somewhat related (e.g., using the same parts of the brain) to the ability to perform navigational, real-world tasks. People also perform spatial tasks differently when learning from direct experience, as opposed to learning from visual media or table-top tasks.

In their review of over 900 research studies, the Gersmehls have developed ten modes of spatial thinking linked to neuroscientific evidence. The ten modes identified are 1) describing conditions; 2) tracing spatial connections; 3) making a spatial comparison; 4) inferring a spatial aura; 5) delimiting a region; 6) fitting a place into a spatial hierarchy, 7) graphing a spatial transition, 8) identifying a spatial analog, 9) discerning spatial patterns, and 10) assessing spatial association.

These modes of spatial thinking have been used in several curriculum development projects and resources, such as Gersmehl's Teaching Geography (2008) and AAG's GeoStart Teachers Guide (www.aag.org/galleries/education-files/GeoStartTeachersGuide.pdf). Importantly, educators need to know that doing small-scale, table-top activities may use different parts of the brain and different modes of thinking when compared to real-world spatial activities, such as navigating a terrain. Educators should not assume that reasoning on spatial tasks is transferrable to different scales and settings.



Credit: National Institute of Mental Health

Limitations of the Review

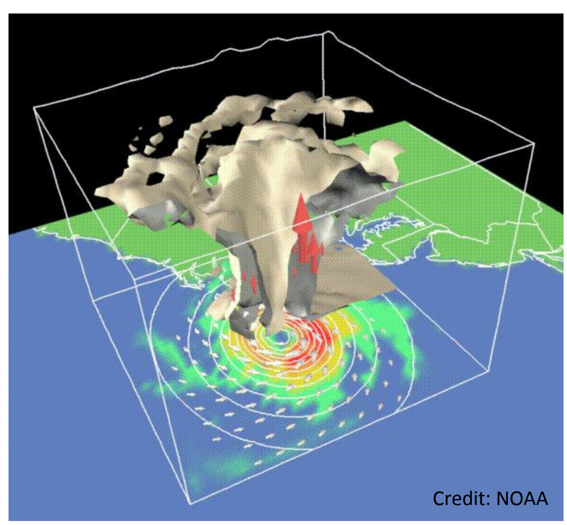
The most notable limitation we found in reviewing the research is the lack of systematic, long-term research across many grades looking at specific spatial thinking concepts or skills (such as the work done on learning progressions). There have been calls for a research agenda in spatial thinking (see Baker et al., 2012), but there are currently no published longitudinal studies. Most studies have focused exclusively on very young children (e.g., only infants, toddlers, or early childhood children) or on one grade level (e.g., 3rd graders), which limits what we can say about the longitudinal development of spatial thinking from pre-K through Grade 12. Furthermore, much of the research has focused on incidental learning of spatial concepts (naïve or common sense learning) rather than learning with skilled, formal instruction (Marsh, Golledge, & Battersby, 2007. This lack of research on intervention with high quality instructional materials limits our understanding of the spatial thinking potential students may have given a skilled, knowledgeable teacher and well-designed curricula being used in the classroom. Our review was also limited by parameters we set when conducting our literature search. This is not an exhaustive review; there is much more research available on spatial thinking. This work was not included due to project time constraints and also because of judgments made in selecting what articles might be most informative for K-5 map curriculum development and design. We chose the seminal articles between 1970 and the present day that could best inform design of materials related to map skills. Other limitations include:

- The search focused on research with children ages 3-12. There is a great deal of research on high school, college and adults learning and spatial thinking processes, but it was not included in our review.
- The search primarily focused on spatial thinking as it relates to mapping and navigation.
- The search focused on geography education research and research from related fields, including cognitive psychology, but almost all articles had a strong mapping component as the basis for research.
- The research needed to be original or at least cite original research, such as a summary of spatial thinking research. Anecdotal evidence received only limited consideration in this review.

Preview of the Report

The remainder of this report is broken down into five additional sections and a separate annotated bibliography document. We briefly describe each below:

- **Frameworks**: In the next section we review key frameworks developed by geography spatial thinking researchers. We have developed a table to show how these frameworks overlap. The frameworks show major concepts students must master in order to learn spatial thinking. When designing or redesigning curriculum, the concepts addressed in the curriculum should match well to at least one of the frameworks (if not more than one).
- **Findings:** We organize the specific findings by the overarching conceptual framework shared by Golledge et al. (2008) and Jo and Bednarz (2009). This framework divides spatial concepts into spatial primitives (e.g., location), simple spatial relations (e.g., distance, direction) and complex spatial-relations (e.g., distribution, dispersion). For each of these spatial concepts, we summarize key findings for accomplishments and challenges for age bands preK-1, 2-4, and 5-6 so that curriculum design can focus on what students have mastered or not mastered within a given grade band.
- **Curriculum Recommendations:** We organize curriculum recommendations using general instructional strategies that emerged from the research literature. Note that most of the research we read did not study curriculum interventions, thus, the recommendations in this section were made based on researchers' experiences and 'best guess' for what may be important tasks to include in curriculum for different ages students.
- **Definitions:** This glossary represents a cumulative effort to record any instance in which researchers explicitly defined a specific spatial term. Each definition is linked to an article or book. We have included all instances in which we saw explicit definitions
for key terms related to the project. There are many terms defined by more than one researcher, as well as many relevant terms never defined in a single article.
- **References:** The final section in this document is a list of references we read and used to arrive at the findings and curriculum recommendations we present. Note that several websites have a plethora of additional resources and we consulted these websites throughout our review.
- **Annotated Bibliography:** We made annotations for the resources we consulted, with each annotation consisting of a 1-2 page summary, including key findings, definitions, and interesting quotes from the reference. The annotated bibliography is a stand-alone document, excluded from this report due to its length.


Credit: NOAA

Frameworks

Table 1. Spatial Concepts Frameworks

Learning to Think Spatially, NRC, 2006	Building on work by Golledge et al., 1995, 2002, 2008; Adapted by Jo & Bednarz, 2009	Gersmehl & Gersmehl, 2006; 2007	Janelle & Goodchild, 2011	Cognitive Psychology (general reference)*(see Bednarz & Lee, 2011; Golledge, Doherty, & Bell, 1995)*
Concepts of Space • Primitives of identify • Spatial relations Tools of Representation • Internal • External Processes of Reasoning • Extracting spatial structures • Performing spatial transformation • Drawing functional Inferences	Spatial Primitives • Identity/Name • Location • Magnitude • Time/Duration Simple Spatial Relationships • Distance • Direction • Connectivity & linkage • Movement • Transition • Boundaries • Region • Shape • Reference Frame • Arrangement • Adjacency • Enclosure Complex Relationships • Distribution • Pattern • Dispersion/ Clustering • Density • Diffusion • Dominance • Hierarchy/Network • Association • Overlay/Layer • Gradient/Profile/Relief • Scale • Projection • Buffer	Conditions Connections Comparison Aura Region Hierarchy Transition Analog Pattern Spatial Association	Location Distance Neighborhood and Region Networks Overlays Scale Spatial Heterogeneity Spatial Dependence	Visualization • ability to mentally manipulate, rotate, twist or invert two- or three-dimensional visual stimuli Orientation • ability to imagine how a configuration would appear if viewed from a different orientation or perspective. Spatial Relations • ability to estimate or reproduce distances, angles, linkages and connectivities; to develop spatial hierarchies in which nearest-neighbor effects are prominent; to remember sequence and order as in cues along a route; to segment or chunk routes into appropriately sized units that facilitate memorization and recall; to associate distributions or patterns in space; and to classify and cluster information into meaningful spatial units such as regions.

Table 2: NRC Framework.
This table is a synthesis of work by NRC (2006), Golledge et al. (1995-2008), and Jo and Bednarz, 2009. We used this to organize our findings, but acknowledge other frameworks exist.

Concepts of Space	Tools of Representation	Spatial Reasoning
Spatial Primitives • **Identity/Name** • **Location** • **Magnitude** • Time/Duration Simple Spatial Relationships • **Distance** • **Direction** • Connectivity & linkage • Movement • Transition • Boundaries • Region • Shape • **Reference Frame** • Arrangement • Adjacency • Enclosure Complex Relationships • Distribution • Pattern • Dispersion/Clustering • Density • Diffusion • Dominance • **Hierarchy** • Network • Association • **Overlay/Layer** • Gradient/Profile/Relief • ***Scale** • ***Projection** • Buffer • ****Navigation** **Scale and Projection have been included as concepts, although they can also be considered a Tool for Representation (for example, Anderson & Leinhardt, 2002). **Navigation was added for our purposes.*	**TYPES of [external] Representation** or Spatial Visualizations (Jo and Bednarz, 2009; NRC, 2006): • Map • Diagram • Chart • Graph • Photo ELEMENTS of Representation: • **Symbol/Sign Array** • Dimension • **Perspective** • **Viewing Angle**	Extracting Spatial Structures Performing Spatial Transformations Drawing Functional Inferences (NRC, 2006)

Findings

Concepts of Space

Spatial Primitives			
Key Concepts	**Grades PreK-1 (ages 3-6)**	**Grades 2-4 (ages 7-9)**	**Grades 5-6 (and beyond) (ages 10-12)**
Identity/Name* *This concept has also been classified as "non-spatial" (Jo & Bednarz, 2009).	Regardless of cultural background it appears that 4-6 year old children can consistently identify at least two or more landscape features on an aerial photograph (e.g., a tree, road, house). (Note: Aerial map is at a scale of 1:2,000 up to 1:5,000) (Blaut & Stea, 1971; Sowden et al., 1996). Landscape feature identification improves if aerial photograph is of similar landscape to the student's locale (Blaut et al., 2003, Blaut et al., 1998) and if the aerial photograph is in color compared to black-white (Blaut et al., 2003). *Challenges—Research shows that while young children (under age 5) are able to identify landscape features, they are often limited by lack of vocabulary or verbal skills to describe what they are seeing or understand from aerial photographs or other map types (Spencer & Darvizeh, 1981; Zwaan, 2004). It has been found that children at this age have a limited understanding of what constitutes a map (holistic) and the objects in the map (componential), so while they may identify some things in a photograph or map, they are inconsistent in their overall performance (Downs, Liben Daggs, 1988).*	Seven year olds improve in the number and accuracy of landscape identification from aerial photographs (Blaut & Stea, 1971) and this gets even more reliable and accurate as children approach the age of nine. Spatial interpretations from aerial photograph seems to be fully formed by the age of nine as 6th graders showed no improvement beyond performance of 4th graders (Blaut & Stea, 1971) *Challenges—Children at this age may struggle with identification—holistic and componential—of environments they are unfamiliar with. While students tend to still be able to identify some features in foreign environments, their performance is not as good compared to working with maps of familiar locales.*	This age group readily and accurately identifies what aerial photographs depict—both holistic and componential (Blaut & Stea, 1971).

Location	In kindergarten children are beginning to understand abstract, plan-view maps of small, familiar environments and some general understanding of location, especially when landmarks are in close proximity (Liben, 2008). Given this understanding, children ages 3 to 5 are able to use simple maps of simple (and contrived) environments to locate themselves or a hidden object (like a toy hidden in a sand box or toy hidden in a sparse room). Success using maps to locate themselves or hidden objects depends a great deal on whether the map is given to the child already aligned (Bluestein & Acredolo, 1979; Huttenlocher, Newcombe, & Vasileya, 1999; Liben & Downs, 1993; Stea, Kerkman, Pinon, Middlebrook, & Rice, 2004;). In fact, children age 5 and older can typically find the hidden object even if map is not aligned to room, but younger than five requires alignment unless they have guidance from an adult (Bluestein & Acredolo, 1979; Blades & Spencer, 1986). Landmarks are especially helpful to children to locate themselves or hidden objects on a map, especially when given an unaligned map (Blades & Spencer, 1990). Blades & Spencer, (1990) found that even 4-year-old children (technically 4.5 year olds) could locate hidden objects reliably with an unaligned map and object hidden near prominent landmark. Children this age do not see the need to mentally rotate an unaligned map when they can instead rely on prominent landmarks (Presson, 1982; Blades & Spencer, 1990). ***Continued on next page…***	Fourth graders can use topological and projective spatial concepts to locate real-world objects and then locate/place these on a map, but they continue to struggle with how to accurately use key landmarks in helping them figure out where they themselves or objects are located on a map—this is when placed in a natural and/or more complex setting (Kastens & Liben, 2010). 4th graders performance on location mapping tasks significantly improves if children are asked to self-explain location decisions. 4th graders were asked to place stickers on a map to represent locations in a park and the children who were asked to self-explain made far fewer errors in their sticker placement for locations (Kastens & Liben, 2007). There is gradual improvement from age 7 to age 9 in location concepts, but both ages performed poorly when compared to adults who perform near perfect (Bell, as cited by Golledge, Battersby, & Marsh, 2008). *Challenges—While map alignment issues begin to disappear in this age group, children still struggle a lot with location tasks in natural and more complex settings. In general they struggle with encoding things from their environment in order to make location decisions—such as taking in the distance & direction of landmarks, etc.—to determine location. For example, they may realize they are located at the corner of a building but locate themselves at the wrong corner because they didn't use other key landmarks or cardinal directions to help them determine the correct corner.*	This age group is ready to make progress on learning projective and Euclidian concepts that will greatly assist them in determining location. While they do not readily use metric distances and cardinal directions (see below), they are primed to learn and be able to use these concepts in locating themselves or objects in different settings. *Challenges—Like the younger age group this age group is still going to struggle with using landmarks and other spatial concepts that would assist them in accurately locating themselves and objects in the environment. They do not spontaneously use map scales, distances, cardinal directions, etc. to help them determine locations, so before mapping tasks, these children will need to be primed to use all the resources available to them to determine locations, and should be encouraged to self-explain decisions, which might also cue them into thinking more about landmarks, distances, directions, etc.*

Location ***continued***	Success on these hidden object tasks improves greatly if child is given the map to use while locating, as opposed to studying the map first, then walking in a room to locate the object, which requires memory of the map (e.g., Blaut et al., 2003). Note that all these studies used very contrived, simple situations to tests their hypotheses (like a square room with minimal furniture). *Challenges—Children at this age may struggle with the following issues:* • *Locating themselves/object in an environment where map is unaligned.* • *Knowing how to identify and use prominent landmark in natural or more complex settings to make accurate locations on a map (seem to be able to use landmarks in simple, contrived settings).* • *Locate themselves/object 180 degrees from their actual location when given a map that is flipped 180 degrees.*		
Magnitude *(see "scale" for more)*	Magnitude knowledge appears to be an innate skill (understanding that certain objects or areas are larger or smaller than others), as opposed to counting, and typically use surface area for the basis of judgment (Rousselle, Palmers, & Noel, 2004; Mix, 1999; Brannon & Van de Walle, 2002). *Challenges—Students might confuse magnitude (scale of objects) with numerosity (number of objects) (Golledge et al., 2008 citing Starkey & Cooper, 1980; Antell & Keating, 1983; and Strauss & Curtis, 1981)*		

Simple Spatial Relationships			
Key Concepts	**Grades PreK-1 (ages 3-6)**	**Grades 2-4 (ages 7-9)**	**Grades 5-6 (and beyond) (ages 10-12)**
Distance, Measurement	Four and five year old children have a basic understanding of distance using topological descriptors (such as “near to”, “next to” and “between”) (Liben, 2008) *Challenges—While children at this age have access top topological spatial concepts for distance, they do not spontaneously use this knowledge to help with spatial tasks unless prompted to do so, possibly due to verbal limitations at this age (Blades et al., 1995)*	Between 2nd and 4th grade children are developing projective and Euclidian concepts, but mostly have access to topological concepts for distance and can readily use these concepts. By fourth grade children can use topological and projective spatial concepts to describe distances between objects (Kastens & Liben, 2010) *Challenges—Even by 4th grade children do not readily use Euclidian concepts and metric distances to describe distance, although some may be able to do so with prompting and guidance from adults.*	Beginning around the age of 9 or 10 children are ready to begin using metric/Euclidian measurement to make sense of distance (Liben, 2008), although many students will not do so unless prompted or assisted. Students at this age realize that distance is something that can be accurately measured. *Challenges—Children at this age will need guidance and prompting to apply a measurement system to distance or they will default to topological descriptors for distance.* *As location get further and further away from students' lived world, the accuracy of distance estimate becomes much less. This is also true for older children and adults (Golledge & Stimson, 1997; Tretter et al., 2006).*
Direction	By the ages of 5 and 6 children can use a map to make directional decisions in a maze to find goal objects, such as making decisions about turns at “T” intersections (Blades & Spencer, 1987; Rutland, Custance, & Campbell, 1993). This skill at navigating mazes appears to emerge during 4 year olds, as ½ of the kids are successful compared to almost no success among 3 year olds. It is not until ages 5 or 6 that most kids become successful at this type of task. ***Continued on next page...***	Children at this age can accurately make decisions about directlon/turns in contrived settings, like a maze. They have not yet developed an understanding of cardinal directions, until possibly 4th grade, so determining directions in a complex, natural settings would depend on topological descriptors and landmarks, and not an understanding of Euclidian space. ***Continued on next page...***	At this age level the alignment of the map to the real world does not appear to affect children's decisions about orientation and direction being similarly accurate with aligned and unaligned maps (Liben & Downs, 1993). The 180 problem is usually non-existent in this age of children. The children are ready to learn and use cardinal directions to more accurately determine, describe and communicate directions. *Challenges—Even though they may be ready to use cardinal directions, they will need guidance and prompting to do so.*

Direction *continued*	*Challenges—Barriers to learning direction are often associated with map alignment:* • *K and 1 graders struggle with the 180° problem but this starts to go away in grade 2. The 180° problem basically means that when maps are unaligned to the real world, the 2nd most common choice for direction is the 180° opposite of the correct answer. (Liben & Downs, 1993), so a lot of kids at this age don't think to "turn the map".* • *In studies where an adult stands in a classroom and points in a direction students struggle to identify the direction being point to when the direction is oblique to a nearby wall as opposed to parallel. When a direction was parallel, all students in grades K, 1, and 2 performed better, especially when map was aligned to room (Liben & Downs, 1993).*	*Challenges—Directions are not readily accessed on tasks, and children default to focusing on prominent landmarks. When fourth graders were asked to walk around a park to locate flags and then mark on a map where the flags were located, the children did not appear to use direction to help determine their location, but focused on landmarks instead (Liben & Kastens, 2010).* *Also, 2nd and some 3rd graders may still struggle with the 180 problem described for younger children. They may also struggle with the identifying direction is the direction being pointed out is oblique to nearby walls, as opposed to parallel.*	
Frames of Reference	Children at this age continue to use an egocentric frame of reference and topological spatial concepts.	Around the age of 9, children begin using frames of reference (such as grid systems) and it is appropriate to introduce the use of coordinate grids (Euclidian spatial concepts) to find or describe a location (Bell, 2000; Liben, 2008). Likewise, the Math Standards recommend teaching grids, shapes and references by the third grade. *Challenges—By fourth grade children still "have not fully mastered the technique of strategically focusing their attention on those aspects of the environment that are useful for locating positions on a particular map. Amid the overwhelming profusion of things to look at, participants sometime attended to features that were not useful or (as discussed below) neglected features that would have been useful" (Liben & Kastens, 2010, p. 334).*	By 10 children are ready to use frames of reference (such as grid systems) and it is appropriate to introduce the use of coordinate grids (Euclidian spatial concepts) to find or describe a location (Bell, 2000; Liben, 2008). Likewise, the Math Standards recommend teaching grids, shapes and references by the third grade.

Complex Spatial Relationships			
Key Concepts	**Grades PreK-1 (ages 3-6)**	**Grades 2-4 (ages 7-9)**	**Grades 5-6 (and beyond) (ages 10-12)**
Hierarchy/Overlay	Too complex for this age.	The concept of hierarchy or nesting objects is difficult for students at this age to grasp (Wiegand & Stiell, 1997 as cited by Lowes, 2008). Lowes, 2008, found that 60-80% of 3rd graders showed no evidence of the concept of hierarchy or nesting in their free-hand world maps.	In grade 6, only about half of students use the concept of overlay, and only half of the students who use overlay, use it successfully; by high school, students perform significantly better on overlay tasks. 6th grade students also struggle with overlay operators (AND, OR, and NOT), but perform best when using AND. (Battersby, Golledge, & Marsh, 2006). The results indicate that map overlay may be too complex for upper elementary without explicit instruction. In other words, students may be capable of more successful use of overlay in the 6th grade, but this concept does not develop intuitively until high school.
Scale	Can handle familiar environments better than large-scale, distant environments (Liben, 2008), but do not have a systematic concept of scale at this age. Three to five year olds still have difficulty interpreting and using scale relations and can handle smaller spaces (such as a classroom map) much better than large-scale spaces (see Uttal, 2000 for a review). *Challenges—Young children often confuse scale on maps, identifying the mapped area incorrectly (e.g., saying "houses" to name something as large as a city). Students also sometimes say that roads and buildings on a map are not large enough to be roads or buildings because cars can't fit on them, or buildings on maps seem smaller than they are in real-life ("that can't be my dad's office because his office is sooo big!").*		

Projection	Projection, which is considered a spatial concept and also a tool of representation in this report, needs to be discussed separately from the Findings table because we have little to no grade level data on projections for early elementary. However, research has shown common misconceptions people have about projections themselves or about the world as a result of projection types which is an important consideration to curriculum developers. Projections introduce distortion to the area, distance, direction, angle, and shapes as they translate a three-dimensional object (Earth) into a two-dimensional representation (a map; see Battersby & Janelle, 2009 for a discussion on projection). The most notable misconception is that the Mercator projection gives people a false perception that areas closer to the poles are larger than they really are because it drastically distorts area at higher latitudes (Battersby & Janelle, 2009 citing Saarinen, 1999; Monmonier, 2004; Uttal, 2000). However, Battersby & Janelle (2009) found that the distortions in Mercator projections are not strongly correlated to distortions in college students' mental maps of the world.		
Navigation* *Navigation includes multiple spatial concepts so we haven't figured out where this goes in the framework yet.	Four year olds, regardless of cultural background, can successfully identify a route between two objects on an aerial photograph (Blaut et al., 1998). This means that they can identify "roads" and use manipulatives to "drive" or "walk" a route between the two locations on the aerial photograph or a tracing of the aerial photograph (Blaut & Stea, 1971; Blaut et al., 2003). Most of these studies, however, only had a little more than half of students successful at the tasks. Some students at this age can navigate a maze successfully Blades & Spencer, 1987; Rutland, Custance, & Campbell, 1993).	Landmark knowledge and route strategy for navigating is likely the ideal focus for navigation at this age level. Helping children at this age readily identify key landmarks and use them accurately would be an important accomplishment. For 4th graders, introducing Euclidian spatial concepts would be necessary to help them begin engaging with survey strategies for navigation (see more in column to the right).	There are two basic navigation strategies in the research literature and children at this age level likely engage in both—the "survey" strategy that relies on cardinal directions and metric measurements, and the "route strategy" that relies mostly on key landmarks. Females tend to use the route strategies slightly more than males, but the findings on this are inconsistent (McArthur & Wellner, 1996; Montello et al., 1999). Montello (1998) proposes that survey knowledge is more advanced than route knowledge (agree upon by Golledge, Doherty, & Bell, 1995), so helping children at this age level engage with both is an important achievement. Much of the navigational tasks experiments (beyond reading a map to actually using the map) have been done with adult populations (see Golledge, Doherty, & Bell, 1997; Lobben, 2007). However, Lobben (2007) found that self-location (i.e. the ability to use environmental clues to locate oneself on a map) was the most influential predictor of navigational map reading. Thus, activities that promote self-location awareness at this age might be beneficial to developing navigational map reading ability.

Tools of Representation

Elements of Representations

Key Concepts	Grades PreK-1 (ages 3-6)	Grades 2-4 (ages 7-9)	Grades 5-6 (and beyond) (ages 10-12)
Symbols and Symbolization	Understanding that maps use symbols to represent referents in the world is difficult for young children. Some children may understand that highly iconic symbols represent an object or place in the real world, but it depends on how recognizable the icon is to the child. Abstract, unrelated symbols are not understood well at this age level. Even though 5 to 6 year olds show they understand a mapmaker's intent when choosing a symbol to represent a referent, they still focus on aesthetic qualities that "match" referent (Myers & Liben, 2008). For example, if given the choice between red or green symbols to represent fire trucks, the red will be more "matched" in the child's mind, even if told that the green is a symbol for fire trucks. *Challenges—Students can understand highly iconic symbols but may exhibit the following barriers with anything else:* • *Confuse symbols with real-world referent, based on things like color (i.e., conflate symbolic and referential qualities) (Liben, 2008; Liben, 2009)* • *Focus on color similarities and get thrown off when color does not match their ideas for the referent.* • *Focus on size or scale issues and get thrown if symbol does not match their ideas about the size of the referent.*	By nine years old children are starting to understand symbols better, but many 7 and 8 year olds still focus on aesthetic qualities—like color—when looking at map symbols. Iconic symbols make sense to the 7 and 8 years old (like a pine tree representing a park or forest), but abstract symbols are still difficult until a child reaches about 9 years of age. (Golledge, Battersby, & Marsh, 2008; Liben 2008; Liben, 2009; Myers & Liben, 2008) *Challenges—Students continue to face the same challenges as the younger children, although fewer students at this age make errors like the 5 and 6 year olds (Meyer & Liben, 2008; Liben, 2008). They continue to struggle with any abstract symbols and do better with iconic symbols until about the age of nine. Performance on real-world and abstract symbols is statistically different between grade 3 and grade 6 students (Golledge, Battersby, & Marsh, 2008).*	Nine to 10 year olds consistently show that they understand symbols do not always 'look like' the referent, but can stand for the referent. They have a much better grasp of the "stand for" relationships and rarely get sidetracked by aesthetic qualities, like color. (Liben, 2008; Liben, 2009; Myers & Liben 2008) Sixth graders perform equally well on tasks that use abstract symbols (points, lines, and polygons) as they do on tasks that use real-world symbols (e.g. giraffes, roads, area of park) indicating that abstract and real-world symbols can be used at this grade level (Golledge, Battersby, & Marsh, 2008). *Challenges—Some students may still get sidetracked by color and other aesthetic issues, such as always thinking 'blue' means water because it often does on maps. To prevent struggles, abstract symbols should be included in map keys and reviewed before a mapping activity begins to remind students of the nature of symbols in mapmaking.*

<table>
<tr>
<td>Perspective-Taking</td>
<td>Piaget’s work showed that children under seven can sometimes, although rarely, make sense of a location from another vantage point (see his Three Mountain Problem). This typically can happen if the child is very familiar with the environment, such as thinking about what the classroom looks like from the teacher’s desk. However, perspective taking and vantage point are not well developed at this age.

Challenges—Children at this age struggle with tasks that require vantage point because they have yet to develop projective concepts (Liben, 2008). While Newcombe & Frick 2010 reviewed studies finding that children younger than seven can take the perspective of another, when they replicated Piaget’s tasks, the children could not do it.</td>
<td>While children at this age are sometimes more successful at perspective-taking tasks. Newcombe & Fricke, 2010 discussed that children younger than 5th grade tend to make egocentric errors when trying to complete perspective taking tasks. They are more successful than younger children, but still inconsistent, in their success on these tasks. Basically Newcombe & Frick conclude that there is still at lot of egocentrism even at this grade level when it comes to perspective-taking.

Challenges—Children at this age may exhibit similar challenges as younger children until they reach middle childhood.</td>
<td>Children age 10 and older tend to do well on perspective-taking tasks and can imagine a scene from another vantage point.</td>
</tr>
<tr>
<td>Viewing Angle</td>
<td colspan="2">Some children at this age can recognize that when looking at a map, they are looking at a different angle than what they usually see. Usually this angle is orthogonal, or the bird’s eye view. However, many kids still struggle with viewing angle, and this becomes especially tricky when trying to identify landscape features from an unfamiliar angle. (Kastens & Liben, 2010; Liben, 2008; Liben, 2009). At least half of kids at this age—in a variety of cultural groups—can correctly identify landscape features from aerial photographs indicating they have some understanding of what these features—roads, homes, trees, etc.—look like from an orthogonal viewing angle, but it is uncertaning how much they understanding

Challenges—Students that this age may not recognize landscape features from the bird’s eye view because the features do not appear as the child usually sees them (Kastens & Liben, 2010; Preston & Herman, 1974 as cited in Maxim, 1997). In fact some features may appear as altogether different objects (tennis courts look at doors). This becomes especially tricky when conflated with issues of scale because kids may not believe a road is a “road” because it’s not large enough to fit two cars.</td>
<td></td>
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Curriculum Recommendations

The research literature on spatial thinking has almost exclusively focused on incidental learning of spatial concepts and processes of reasoning, with very few, if any, research focused on instructional intervention through teaching strategies or well-design curricula. The "Findings" table in this review attempts to piece together a big picture view of results from numerous research studies on spatial thinking across many decades, but in the process of creating this tool, in became apparent that recommendations for curriculum design and implementation are not always closely connected to research studies in many cases. Therefore, we have attempted to draw upon the research where we can to form recommendations for curriculum, but we also included non-empirical sources to develop our recommendations.

In our review of spatial thinking, as it relates to the development of map skills, we consulted two notable sources for curriculum development (Sobel, 1998; Sprague Mitchell, 2001). These two sources are not peer-reviewed research articles, but rather are books written by authors with years of experience working with kids and maps. The first book by Lucy Sprague Mitchell, *Young Geographers*, was initially published in 1934, but has been reprinted four times. This book has had an enduring impact on maps skills instruction and her recommendations for curriculum design and teaching are still in line with findings from the latest research on spatial thinking. The second book by David Sobel, *Mapmaking with Children*, is based upon work with elementary children and mapmaking, and provides sound advice for curriculum development for children ages five through twelve.

We will briefly discuss the key ideas from both of these sources, along with some recommendations from Dr. Maria Montessori's work. Combined, these three sources provide helpful suggestions for designing mapping curriculum. Finally, we have included our own grade level recommendations, based on the work of Golledge, Marsh, and Battersby (2008) along with the other research we read. This table represents the best consensus on the ideal time to introduce spatial concepts.

Mitchell's Young Geographers

Lucy Sprague Mitchell was a progressive educator that advocated for hands-on experiential learning particularly when teaching geography and using maps. Through her experience working with elementary kids, she found that experiential learning with large and tactile maps was the best way to introduce children to maps in early elementary ("The smaller the children, the larger the map should be", p. 30). Her curricular recommendations are sound for even today's social studies classrooms (and science classrooms as well); the evidence for these recommendations

Credit: Lewis Mendez/USGS

coming predominantly from years of anecdotal evidence from working with children and maps. For the purposes of this report, we have included an adapted table found on pages 10-12 of Young Geographers that we believe is useful in thinking about map instructional materials. Mitchell notes five specific geographic relations that children needed to understand before using reference maps or relief maps; those are:

- Space relations in far-away and large-scale situations – both horizontal and vertical.
- Relation of drainage to elevation.
- Relation of soil to elevation.
- Relation of human work to environment.
- Map projections or distortions of the Earth's surface due to picturing a spherical upon a flat surface (p. 30).

In her work with children Mitchell recommended the following for maps skills instruction:

- "Teachers must know the stage their children are in and provide tools and data (experiences or source material) for the next discovery" (p. 28).
- "Children must be given the opportunity to work out elementary relationships before they are jumped into the use of materials which are based on these relationships" (p. 29).
- Airplane views are the easiest maps because they are "only extensions or variations of the familiar instead of being expressed in difficult symbols" and can be used as transition maps before students use symbolic maps (p. 30).
- "Maps must be kept functioning and for six- and seven-year-olds this usually means they must be played upon. Children like to take imaginary trips on a map…" (p. 31).
- Early elementary children also enjoy making "demonstration maps", or maps of their own creation, that are "added to from time to time as experiences accumulate…It is a statement of discoveries rather than a tool for investigations…A teacher should be careful not to cramp the art-play maps by insisting upon too great accuracy. At times, beauty or general impression is more precious than accuracy" (p. 31).
- Horizontal orientation (such as two-dimensional maps) typically comes before vertical orientation (such as understand elevation). Under the age of ten, aim for free experimentation with relief rather than accuracy of measurements (p. 32)
- After these rough, often inaccurate maps, of early elementary, it would be appropriate to progress to the use of relief maps (plastic molds) that allow students to investigate relationships (e.g., relief and drainage). Maps thus become tools to study relationships (p. 33-34).
- Children become interested in projections around the age of 10, but as early as 8. Mitchell suggests giving students a globe and an orange. They are asked to describe a specific, marked spot on the orange (or ball). Then children begin a series of measurements and Mitchell suggests timely discussions on sun angles striking Earth's surface, seasons, etc. with older kids. After the students have measured the marked spot, they are then challenged to translate the spherical shape and measurements to a two-dimensional paper map. Full activity is described in detail, pp. 35-41. The activity is hands-on, student-centered, and inquiry-based.
- Image symbols should precede abstract symbols (p. 47).

Table 3: Sprague Mitchell's Stages

Stages Approximate Age Zones	Interest Drives. What children observe in their environment	Orientation	Tools and children's methods of expression
3^{rd} Stage 3 years to early 4^{th} year	Environment widens to domestic still with self as center. Interest in moving things begins. Also in growing things.	Orientation in room and building becomes more elaborate.	Words elaborated. Toys as symbols of own experiences. Domestic play with own experiences recalled. Often superimposed upon moving inanimate objects. Traces of representation in block building and crayons.
4^{th} Stage 4 and 5 years	Widened interest in external moving objects, such as autos, animals, boats, trains. Relationships largely in terms of sense and motor expression; e.g., a train moves, whistles, is hot, etc.	General sense of direction on streets from home to school or other familiar places.	Images in crayons and clay. Dramatic play extends to moving objects often put into domestic setting. Symbols for image recalls often have little representative value. Cooperative play begins.
5^{th} Stage 5 and 6 years	Moving objects begin to function. Relationships begin to include functional; e.g., train related to track, station, freight, etc.	Familiar places crudely placed in space relations. Street-environment and house environment. Rough block-building maps.	Dramatic play much elaborated. Representative symbols more important. Cooperative play elaborates.
6^{th} Stage 7 and 8 years	Beginning to leave the "here and now." Distant and long-ago still has to be closely connected with the here and now. Interest in skills and techniques begin.	Rough maps with crayons. Orientation begins in relation to distant and long ago.	Symbols of general ideas begin. Still closely tied up with direct images. Books. Source material written and in map or chart form.
7^{th} Stage 9 and 10 years	Great impulse towards the distant and long-ago. Interest in techniques in full force. Interest in adventure, in incalculable element.	Ability to think of geographic abstractions; e.g., projection, sphere and equator.	Symbols can be expressed in abstract form with actual image recall.
8^{th} Stage 11 years	Interest in social thinking, in form and pattern.	Ability to work on relationship expressed through abstractions.	Organized play and organized group activities.

Table adapted from Mitchell, 2001, pp. 10-12, to include her notes on ages 3 – 12+. Stage 1 and 2 (age 3 and earlier) are omitted, along with her notes on curriculum implications, which are discussed within the text.

Mitchell's book describes other activities that are laboratory-based, allowing children to experiment with relief maps and models. She concludes with a plea to make "this great interest count [the natural curiosity of children to investigate the world] in genuine educational terms and to consider geography in its many aspects as a serious laboratory study demanding source materials and tools, to let our young geographer investigate and map the world they live in" (p. 57).

Mitchell clearly believes that early elementary maps skills instruction should be hands-on using creative play with large floor maps. Symbols should be created by students using real images initially before introducing abstract images (such as a picture of a town rather than using a dot). Instruction should begin with the familiar (home, school, neighborhood) and then progressing to the less familiar once students understand basic spatial relations.

Sobel's Mapmaking

Mitchell's views of elementary mapping are echoed by David Sobel's work in Mapmaking with Children. However, while Mitchell worked most closely with in urban Manhatten, Sobel's work has been largely with students in England, Costa Rica, and parts of New England. However, like Mitchell, Sobel asserts that, "We do a disservice to children when we jump in too quickly at a prematurely abstract level in map reading and mapmaking. It's important to have children begin mapmaking the way they begin drawing; maps and drawings are representations of things that are emotionally important to children…children's maps represent their experiences of beauty, secrecy, adventure, and comfort" (p. 5).

Sobel advocates for a "small world" approach and does not support the use of abstract, far-away or long away curriculum frameworks (such as the Five Themes). He likens this approach to teaching the solar system in elementary science. By adopting this large-scale, faraway approach to teaching "Learning is copying someone else's shapes and consuming someone else's facts; learning isn't about drawing your own maps and finding things for yourself" (p. 7). Sobel advocates for using both the local, small-scale approach to learning geography and mapping, along with some traditional large-scale content, and at times, these two things should merge. Through his research across multiple cultures, Sobel has found patterns in children's map development, despite culture or environment. These two patterns emerge with two aspects of the maps: 1) scope (the size and range of the child's world), and 2) perspective (the angel in which the maps is drawn by the child). For example, children around the age of 5 tend to draw pictorial views of their home or neighborhood. By age 11, many children might be drawing aerial maps of their towns. Sometimes children's maps combine both the aerial view of the neighborhood or town, but preserve the pictorial view of the buildings. However, by age 11 or 12, children can begin dealing well with abstract information and using maps to navigate or make geographic inferences. Sobel proposes curriculum recommendations very similar to Mitchell (although the books were written 65 years apart):

- Maps for children should be big – currently atlases use small maps of big places. It should be big maps of small places.
- Children should be allowed to use three-dimensional material to make model maps rather than only draw two-dimensional paper maps.
- Consider the "Expanding Horizon" perspective in developing curriculum.
- In early elementary, use pictorial and panoramic views of the world.
- Allow children to naturally advance their mapmaking and map reading skills by choosing smaller places of focus when the children are not ready for a larger-scale curriculum.

Sobel advocates for the Expanding Horizons approach using the curricular progression in the table on the following page (adapted from diagram on Sobel, 1998, p. 45).

Both Mitchell's and Sobel's work is helpful in guiding curricular decision-making and when compared to the research, it is really not so different from what research studies have found. Early elementary children have an egocentric perspective that is focused on the familiar (e.g., home, school, community). By upper elementary, students have moved away from this perspective and can think more abstractly about symbols and relationships. Most research, in agreement with Sobel and Mitchell, feel that 12-year-olds are ready to be challenged with all types of maps at all scales. However, the development progression from age 5 to 12 should be thoughtfully considered in curriculum design.

While traditionally geography teaching has always started with memorizing continents, oceans, and place names, perhaps an inquiry-based approach exploring and constructing local maps is the best place to start. This is not to suggest that students cannot learn place names; rather, teachers need to be aware that students might only be memorizing the faraway places and will not have a good conception of those places until much later in elementary or even middle or high school grades.

Table 4: Sobel's Expanding Horizons

Age	Scope	Method of Representation
5 and 6 years	Home and School	Models and Tool Maps to Pictures and Murals
7 and 8 years	Neighborhood	Pictures and Murals to Panoramic Views and Sketches
9 and 10 years	Community and Watershed	Panoramic and Sketches to Baseline and Offset Mapping
11 and 12 years	Bioregion, Nation, and Beyond	Baseline and Offset Mapping to Surveying, Contour Maps, and Aerial Views*

*Note: This is drawing aerial views; not interpreting these views. Adapted from diagram on Sobel, 1998, p. 45.

Montessori's Approach

We liked to make a special note regarding the Montessori approach to mapping activities. While we did not read research on this approach, we found that Mitchell's recommendations for early elementary mapping activities are echoed by Maria Montessori's work as well; young children need active, hands-on, tactile activities that let them explore maps using their senses. As children grow through elementary school, they begin exploring the world with more sophisticated knowledge and reasoning skills (Montessori, 1969). However, it is important to point out that the Montessori Method disagrees with Mitchell and Sobel's ideas about focusing on familiar locations in early elementary (mapping homes, classrooms, schools and neighborhoods); rather, Montessori classrooms have students using world and country maps at very early ages (ages 3-6). These maps are puzzle maps that allow students to learn about shapes, piecing shapes together, and identify of other places in the world, but it is unclear what additional spatial concepts students are learning as they use puzzle maps

Recommendations from Research

Below and on the following pages we provide two different Tables to organize the research-based curriculum recommendations. The first Table, produced by Golledge, Marsh, and Battersby (2008), organizes spatial concepts by the appropriate grade level at which they should be taught. Table 1 provides good suggestions for the level of sophistication in topics that should be included in curriculum materials based on research by Golledge and his colleagues. Table 5 is a list we produced from our literature review when researchers made explicitly curriculum recommendations. We did not attempt to hypothesize what curriculum might look like given research results, but instead focused on when the researchers made direct reference to the design of materials. Note that none of these researchers report on their own curriculum intervention studies, just simply their "best guess" at what curriculum should include based on studies of incidental learning. It is clear from the research that making spatial concepts explicit in lessons and formally taught in K-12 is needed (Marsh, Golledge, & Battersby, 2007, p. 710).

Table 5: Spatial Thinking Concepts by Grade

	Geospatial concept	**Grade**					
		K	**1**	**2**	**3**	**4**	**5**
Primitives	Identity/Name	X	X	X	X	X	X
	Location (Relative)	X	X	X	X	X	X
	Magnitude	X	X	X	X	X	X
Simple Spatial	Distance (Relative)		X	X	X	X	X
	Direction (Relative)		X	X	X	X	X
	Shape		X	X	X	X	X
	Symbol (Real-World)		X	X	X	X	X
	Boundary			X	X	X	X
	Connection			X	X	X	X
	Reference Frame/Coordinate Grid				X	X	X
	Distance (Metric Measurement)				X	X	X
	Direction (Cardinal Directions)				X	X	X
Complex Spatial	Network				X	X	X
	Hierarchy				X	X	X
	Distribution				X	X	X
	Pattern				X	X	X
	Symbol (Abstract)					X	X
	Map Projection						X
	Scale						X

Adapted from Golledge, Marsh, and Battersby, 2008, p.96.

Table 6: Recommendations From Literature

Pre-Teach & Model the Use of Maps in the Field	Avoid making assumptions that once concepts are taught during generic classroom-based lessons that students are then prepared to apply the concepts in the field. Even introducing concepts at the beginning of the field task may not be enough support. Student struggle most with connecting the map and the landscape, as opposed to simply understanding a map on paper, so the teacher will need to pre-teach, review, remind, model, etc., as students use maps in the field (Kastens & Liben, 2010; Liben, 1997). Explain and model the process of identifying "viable" landmarks, features that exist both in the real world and on the map (Kastens & Liben, 2010, p.337). "In the field, using examples, demonstrate the inadequacy of using representational correspondence alone to determine one's position in a complex terrain...emphasize that two or more pieces of spatial information are generally needed to pinpoint a location on the surface of the earth" (Kastens & Liben, 2010, p.337). "Despite classroom lessons on map scale and compass rose, students may need help connecting these features to the viewed environment. Model the use of map scale and compass rose in the field. Consider structuring questions that can be answered only by use of these features" (Kastens & Liben, 2010, p.337).
Help Students Connect Maps to the Real World	Emphasize map-to-world links because this can improve both representational and field mapping tasks (Liben et al., 2002)" (Liben, 2009, p. 314). "Link maps to the real world, not just to other representations": "Thus, practice in understanding the representation-reality link is critical if children are to learn authentic map skills. Practice may be particularly helpful in situations in which children encounter novel environments" (Liben, 2008, p. 28). While preschool children get something out of watching spatial tasks on television (such as Curious George navigating a maze) they learn much, much more when there is social interaction or real-world action involved instead of just observing in on TV (Newcombe & Fricke, 2010). Classrooms rarely include activities where students produce maps or modify maps or activities where students practice map comprehension in which the student performs an action in the real world using information from the map). "Instead, materials emphasize representational correspondence tasks (in which the student compares two different spatial representations, typically without looking at the real space) and meta-representational tasks (in which the student articulates his or her theoretical understanding of the relationship between map and place). Although these latter two categories of mastery are necessary, we believe that they are incomplete. Students must also learn to connect what they see around them to what is on a map" (Liben, Kastens, Stevenson, 2002, p286-287). *Using Technology:* "A key component of the curriculum is software that gives users eye-level views (videotaped scenes) as they "walk" through a park by clicking on arrow buttons" (page 28)…"Educational curricula like these, which are designed to help children understand the relation between visual experience in novel environments and maps of those environments, can play an important role in map education" (Liben, 2008, p.29). Include activities that have kids observe their environment with the teacher asking questions about what the kids see, especially pointing out unique physical characteristics of the environment (Maxim, 1997).

Give Students Experience with Lots of Types of Maps	"Aim for diversity in maps and map functions"- "expose children to a wide variety of maps. These may include maps that use different symbol systems (different colors, abstractions, or even different modalities, as in tactile maps for visually impaired map users); maps in different projections…maps that are centered in different parts of the world…maps that are designed for different purposes…and thematic maps" (Liben, 2008, p.28). In geography curriculum materials, most questions that use maps and promote spatial thinking can be found in page margins activities or supplemental sections of the textbooks, rather than features prominently in the main text or end of section exams. Teachers can utilize these supplemental sections more to promote spatial thinking among students (Jo & Bednarz, 2009). "Present students with views of the world from a variety of perspectives such as from the poles, from the Pacific, or from the Southern Hemispheres and expose students to as many different kinds of maps as possible" (Rice, 1990, p.393). "Maps can be culturally confining and reinforce the ethnocentricism that is native to all of us when we limit students' exposure to one or two perspectives of the world (Phipps, 1989)."…"Some of the most effective maps to help students develop pivotal orientation can be found in a collection entitled, Look at the World: The Fortune Atlas for World Strategy…Two other maps should be mentioned; McArthur's "Universal Corrective Map of the World," an Australian perspective of the world and Levine's "Turnabout Map," a view of the Western Hemisphere from a South American perspective" (Rice, 1990, p.395-396). "Finally different perspectives of the earth can also be gleaned by exposing students to as many different types of maps and views as possible. Landsat views, aerial and satellite photographs, weather maps, topographic maps, historical maps, geologic maps, and census maps are just a few of the options available" (Rice, 1990, p.396-397). Compare Mercator projection, Peters projection, and the World Turned Upside Down (McCall, 2003). Introduce students to a variety of maps, especially maps that have obvious biases and distortions and maps that are from other perspectives and not Western culture centered. In addition show different types maps of the same area to discuss the cartographer's purpose and reason for different maps (road/political, topographic, etc.) (Brophy & Alleman, 2007; Jacobs, 2010; McCall, 2011; Natoli, 1988; Segall, 2003).
Teach Students to be Critical Consumers of Maps	Promote critical thinking about maps, helping students learn how to question the accuracy and intentions of maps, as opposed to view maps as the ultimate source of authority (McCall, 2011; Segall, 2003; Sharma & Elbow, 2000). Show different types of map of same area and discuss cartographer's intent and the strengths and weaknesses of each type of map (political v topo v aerial) (Segall, 2003). Make students aware of cartographers' biases and distortions" (Rice, 1990, p. 393). Calculate landmass size of different projected maps and talk about map distortions (Segall, 2003). Include critical questioning about map creation (why does your map look different from the other kid's map when you mapped the same area?) (Segall, 2003). Watch for place name bias (Euro or Anglocentric, gender or age, exotic, upscale bias, problem bias- using too many problems, headlines, or personal favorites); In other words, show the world as it is (Gersmehl, 2005).

Promote Reflection and Self-Explanation when Engaging with Maps	Have students reflect on the reasoning and decision-making when producing, reading, or using maps (Kastens & Liben, 2007). Require that students give verbal description and self-explanations of positional cues because this can trigger their thinking about position judgments (Kastens & Liben, 2010). Discuss why the physical environment looks the way it does, moving beyond observation and description to talk about the "why" (Maxim, 1997). Have student construct maps collaboratively and use discussion to reason about their decision-making when choosing certain elements on the maps (scale, grid systems, symbols; Leinhardt, Stainton, & Bausmith, 1998).
Focus on Understanding Symbolization	Symbols require abstract thinking. Point symbols are often misinterpreted as representing the area of a city rather than the population size. Some cities have smaller areas and are more densely populated, but a larger point on the map leaves readers with the impression that the city is "bigger" in area. Pictorial symbols (they discuss using a cow) often confuse elementary readers because they represent "one cow" or "one oil derrick" rather than a region of cattle grazing or oil production (Bednarz, Acheson, & Bednarz, 2006). Color often leads readers to misinterpret regions. For example, the green used for low elevation is often believed to coincide with forests/grasslands. Color is also confused with temperature and emotion (Bednarz, Acheson, & Bednarz, 2006).
Literacy Connections	Adults' discussion of spatial issues during picture-book reading improved the children's success on spatial tasks (Szechter & Liben, 2004). Books and stories with spatial thinking components (like Zoom) could open the door for teaching spatial concepts (Blades, Sowden, & Spencer, 1995; Newcombe & Frick, 2010). Vocabulary development of objects, shapes, and other spatial terms is key early on (Newcombe & Frick, 2010). Read books where people/characters "walk" through their environment. Then map their journey (Maxim, 1997).
Incorporate Spatial Talk in Everyday Talk & Play	Incorporate spatial terms and talking in the course of everyday activities, whenever it seems appropriate to talk and discuss these explicitly (Blades, Sowden, & Spencer, 1995). Using blocks when playing with children naturally leads to more use of spatial language around children (Ferrara, Golinkoff, Hirsh-Pasek, Newcombe, & Shallcrosse, 2010 as cited by Newcombe & Frick, 2010).
Familiar to Unfamiliar	Start activities with maps of familiar environments like the classroom or the school grounds (Maxim, 1997). Include activities where elementary children create and then analyze their own self-made maps (of familiar places) before they engage with activities where they are using maps developed by other people (Brophy & Alleman, 2007; McCall, 2001, McCall 2003; Seefeldt, 2005).

Manipulatives & Games at Younger Ages	Use toy-play to construct 3-D worlds and liken these to maps; use blocks or other objects and toys to represent referents in the real-world and talk about how the objects are being used to represent referents (Blaut, 1997; Maxim 1997) Finding hidden objects using a classroom treasure map: first hiding object according to a location specified, then other students finding objects using a map (Newcombe & Frick, 2010). Use activities where students play with real objects and symbolic representations of those objects (activities to "help them discover the relationships between actual physical features and the symbols used to represent them"; Maxim, 1997, p. 207). Use blocks and other objects to construct 3-D worlds and talk about how blocks represent real-life objects. Use probing questions with block models to help kids see the correspondence to a real world similar to block models (how could you get car to grocery store if that road were closed; Maxim, 1997).
Assessment	Anticipate substantial student-to-student variation in accuracy (Kasten & Liben, 2010, p. 337). Do not make assumptions about students' basic representational and spatial understanding before jumping into a spatial task. " (basically kids may draw from special experience rather than generalized concepts and this could give a teacher a false sense that the kid knows more about maps than they do; Liben, 2008).
Other	• Imaginary maps are ok to use, but only sometimes (avoid overuse; Gersmehl, 2005). • Limit use of longest, highest, deepest (exceptional features; Gersmehl, 2005). • Activities should include construction of maps (by the end of 4th grade, per Geography for Life; Bednarz, Acheson, & Bednarz, 2006). • Integrate mapping across subject areas and include geospatial technologies (Bednarz, Acheson, & Bednarz, 2006). • Pages 101-120 of Gersmehl (2005) is a list of curricular recommendations by primary, middle, and high school levels broken down by the 8 distinct modes of thinking, plus location, conditions, connections, and spatio-temporal thinking. There are too many recommendations to list here, but this is a potential resource for National Geographic as they design or revise lessons.

Glossary

Definitions of Spatial Thinking & Related Terms

Spatial Thinking: To think spatially entails knowing about (1) space—for example, different ways of calculating distance (e.g., in miles, in travel time, in travel cost), the basis of coordinate systems, (e.g., Cartesian versus polar coordinates), and the nature of spaces (e.g., in terms of the number of dimensions [two versus three]); (2) representation—for example, the relationships among views (e.g., plans versus elevations of buildings, orthogonal versus perspective maps), the effect of projections (e.g., Mercator versus equal-area map projections), and the principles of graphic design (e.g., the role of legibility, visual contrast, and figure-ground organization in the readability of graphs and maps); and (3) reasoning—for example, the different ways of thinking about short distances (e.g., as the crow flies versus route distance in a rectangular street grid), the ability to extrapolate and interpolate (e.g., projecting a functional relationship on a graph into the future, estimating the slope of a hillside from a map of contour lines), and making decisions (e.g., given traffic reports on a radio, selecting a detour) (NRC, 1997, p.3).

Spatial Thinking: Encompassing three major elements: first, knowing about concepts of space (such as units of measurement, coordinate systems, dimensions of space); second, knowing how to produce and interrelate spatial representations (for example, depicting the same objects from different viewpoints and understand how these are related); and third, having skill in spatial reasoning (for example, calculating a shortest distance as the crow flies and as a route distance in a rectangular street grid)(Liben, 2008).

Spatial Thinking: A constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning, as outlined by the NRC (p. 25)…in this paper these elements are terms spatial concepts, spatial representations, and spatial reasoning, respectively (W & I, 2011, p.305).

Spatial Thinking: An ability to visualize and interpret location, distance, direction, relationships, movement, and change in space (Sinton, 2012, p. 733).

Knowledge OF space: Accumulation of facts about the spatial arrangement and interactions comprising human-environment relations (Golledge, 2002, p. 1 as cited in Unwin, 2011, p.8).

Knowledge ABOUT space: Recognition and elaboration of the relations among geographic primitives and advanced concepts derived from these primitives (such as arrangement, organization, distribution, pattern, shape, hierarchy, distance, direction, orientation, regionalization, categorization, reference frame, geographic association and so on) and their formal linking into theories and generalizations (from Golledge, 2002, p. 1 as cited in Unwin, 2011, p.8).

Spatial Literacy: An individual's abilities or attitudes to think spatially in an appropriate way. (W&I, 2001, p.306)…"The NRC [1, p.4] points out that spatially literate students have the following characteristic:

- They have the habit of mind of thinking spatially.
- They practice spatial thinking in an informed way.
- They adopt a critical stance to spatial thinking.

Spatial Literacy: The ability to think and act in any context that requires the recognition that location in space is important (Unwin, 2011, p.7).

Spatial Abilities: Cognitive skills fundamental to spatial thinking being composed of spatial visualization, spatial orientation, and spatial relation

(W&I, 2011, p. 306, possibly borrowed from Golledge & Stimson, 1997).

Spatial Relations: Abilities to recognize spatial distributions and spatial patterns, to connect locations, to associate and correlate spatially-distributed phenomena, to comprehend and use spatial hierarchies, to regionalize, to orientate to real-world frames of reference, to imagine maps from verbal descriptions, to sketch map, to compare maps, and to overlay and dissolve maps (Gollege and Stimson, 1997, cited by Bednarz & Lee, 2011).

Spatial Relations: The ability to estimate or reproduce distances, angles, linkages and connectivities; to develop spatial hierarchies in which nearest-neighbor effects are prominent; to remember sequence and order as in cues along a route; to segment or chunk routes into appropriately sized units that facilitate memo- rization and recall; to associate distributions or patterns in space; andto classify and cluster information into meaningful spatial units such as regions (Golledge, Dougherty, & Bell, 1995).

Definitions for Map & Related Terms

Map: Representation of the surface of the earth-a smaller and simpler model that can be used in place of the earth itself (Anderson & Leinhardt, 2002, p. 288).

Map: A map must have a scale (for communicating distances), and a set of abstract signs (for communicating the semantic meaning of landscape features). But the scale, project, and sign array do not have to be explicitly defined, i.e., translated into written words, in the map itself. If all of the signs are pictorial or iconic, as many of them are on conventional maps, there is no need of a legend (dictionary), and the properties of scale and projection can be inferred, at least roughly, from the image (Blaut & Stea, 1971, p. 388).

Map: A representation, usually on a flat surface, as of the features of an area of the earth or a portion of the heavens, showing them in their respective forms, sizes, and relationships according to some convention of representation (Random House, 1997, p.1173; cited in Liben, 2008, p. 21).

Real map: External, physical artifacts that represent some portion of the world—studied to identify processes entailed when graphic representations are used to acquire, record, communicate about, or reason with symbolic and spatial information (Liben, 2009, p. 310).

Functions of Mapping: The transmission and receipt, in any medium, of information about distance, direction, and landscape feature or site, information of the sort contained in a “cognitive map” (Blaut & Stea, 1971, p. 387).

Graphicacy: The ability to understand and use a map or graphy (Oxford English Dictionary, cited in W&I, 2011, p. 306).

Representation: Include internal representations and external representations. This article used “representation” to refer to external representations likes maps. (Anderson & Leinhardt, 2002, p. 284, not a direct quote).

Spatial Representations: Include paper/ink hard copy format maps, on-screen visualizations (images and graphics), RS imagery, etc. (Golledge, 2002).

Euclidian, Projective, Topological Terms

Euclidian Spatial Concepts: Contain metric information, such as distance, direction, and angle, coordinated in a fixed fame of reference (Kastens & Ishikawa, 2006, p.55).

Euclidian Spatial Concepts: Child's ability to conceptualize space with an abstract system (such as coordinate grid of horizontal and vertical lines) that then allows the child to measure distance and angle across the map. (Liben, 2008, p. 23; from Piaget & Inhelder 1956).

Euclidean Space: Emphasizes the quantitative measurement of proportions and distance. Development of Euclidean structures allows for the subsequent rise of measurement structures necessary for graphing and construction of data tables (Berg & Phillips, 1994). (McArthur & Wellner, 1996, 1068).

Projective Spatial Concepts: Understanding of spatial relations tied to a specific viewpoint and differentiation of various viewpoints (Kastens & Ishikawa, 2006, p.55). (Examples: in front of, behind, past, right, on the right, on the side of, left or right of, straight, down the hill, up the hill. (Kastens & Liben, 2010)

Projective Spatial Structures: Coordination of perspectives and allow one to realize that the appearance (i.e., size, shape, distance, and angularity) of objects is a function of the spatial position from which they are seen. (McArthur & Wellner, 1996, 1068).

Topological Spatial Concepts: Involve only qualitative relationships such as separation, order, and continuity (e.g., "next to," "between," "inside/outside")(Kastens & Ishikawa, 2006, p.55). Examples: on, in, inside, in the middle of, over, by, with, close to, between, next to, around, beside, etc. (Kastens & Liben, 2010)

Topological Space: Involves spatial continuity, boundaries, order of placement, separation, and proximity. It is the most general and inclusive system and is first in ontogenic order of appearance (Flavell, 1963). With topologic space, the only properties described are those that will not change if the space is stretched/distorted (McArthur & Wellner, 1996,1068).

Other Terms (Listed Alphabetically)

Choropleth Map: Map that colors entire counties, states, or other political units according to their value.

Frames of Reference: Providing structures that allow absolute or relative locations to be identified (Golledge, 2002).

Geometric Correspondences: Liben and Downs (1993) identify three kinds of geometric correspondences:

- Viewing distance (scale relations)
- Viewing azimuth (orientation)
- Viewing angle (rotational angle, orthogonal or oblique).

Geospatial: Golledge et al. [9, p.286] pointed out that geospatial refers to environmental or geographic scales [10], comprising areas that cannot usually be perceived from a single vantage point on Earth (W&I,, 2011, p.306).

Landmark: Discrete objects or scenes (patterns of objects against a background) that are stored in memory and recognized when perceived. They do not in themselves contain spatial information, other than the local spatial information implied by recognizable pattern (Montello, 1998, paraphrased p. 144).

Landmark Knowledge: Knowledge of distinctive objects or scenes stored in memory (Montello, 1998, p.143).

Orientation: Ability to picture spatially arrayed elements from different perspectives (Bednarz & Lee, 2011).

Orientation/Perspective: Spatial orientation involves comprehension of visual stimulus patterns from different view- points or the ability to imagine how a configuration would appear if viewed from a different orientation or perspective. NOTE: highly correlated with perspective (Golledge, Dougherty, & Bell, 1995).

Reference Map: A map that shows the locations of a variety of things within an area.

Route: Sequences or "chains" of landmarks linked by experienced paths or movement connecting them (Montello, 1998, p. 144).

Route Knowledge: Knowledge of travel paths connecting landmarks (Montello, 1998, p.143).

Route Knowledge: Sequence of features and/or actions that describe a path between two known points (MacEachren, 1992, p.247).

Simple Classroom Map: 1) a planimetric map, 2) using black-and-white line drawing techniques, 3) with a minimum of abstract (or arbitrary) symbols, and 4) an absences of verbal labels (at least in the case of kindergarten and grade 1 classes)(Downs, Liben, Daggs, 1988, p. 691).

Spatial Analysis: Set of spatially based analytical tools that explicitly focus on comprehending the spatial component of geo-referenced data (Golledge, 2002, p. 7).

Survey Knowledge: Emphasizes spatial relations among places and features (MacEachren, 1992, p.247).

Survey Knowledge: Is configurational knowledge of the locations and extents of features in some part of the environment that is not limited to particular travel paths (Montello, 1998, p.143)

Thematic Map: A map that shows the pattern of a specific thing in a large area.

Visualization: Spatial visualization is the ability to mentally manipulate, rotate, twist or invert two- or three-dimensional pictorially presented visual stimuli. This ability involves recognition, reten- tion, and recall of two- or three-dimensional structures in which change among the internal parts is depicted. It may also refer to an object manipulated in three-dimensional space (Golledge, Dougherty, & Bell, 1995).

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University of California-Santa Barbara Center for Spatial Studies:
www.spatial.ucsb.edu

UCSB Resources for Spatial Teaching and Learning:
www.teachspatial.org

Spatial Intelligence and Learning Center (SILC):
www.spatiallearning.org

Spatial Literacy in Teaching (SPLINT):
www.le.ac.uk/geography/splint/index.html

University of Oregon Spatial Map and Cognition Research Lab:
www.geography.uoregon/edu/geocog/

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