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How Children acquire Spatial Thinking

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Some comments on content

- What is spatial thinking, what makes it special and worth pursuing
- Other notions that relate to it
- Most influential spatial development theories
- … and a recent one all of which deal with preschoolers, marginally with primary education students but none of them with secondary education ones
- Spatial thought (and its components) development throughout the curriculum

Spatial Thinking; Definition

The understanding of space, of spatial concepts, and of spatial phenomena, the knowledge of interrelations and interactions among them but also the relation and action between humans and the environment constitute a significant cognitive ability; **spatial thinking**.

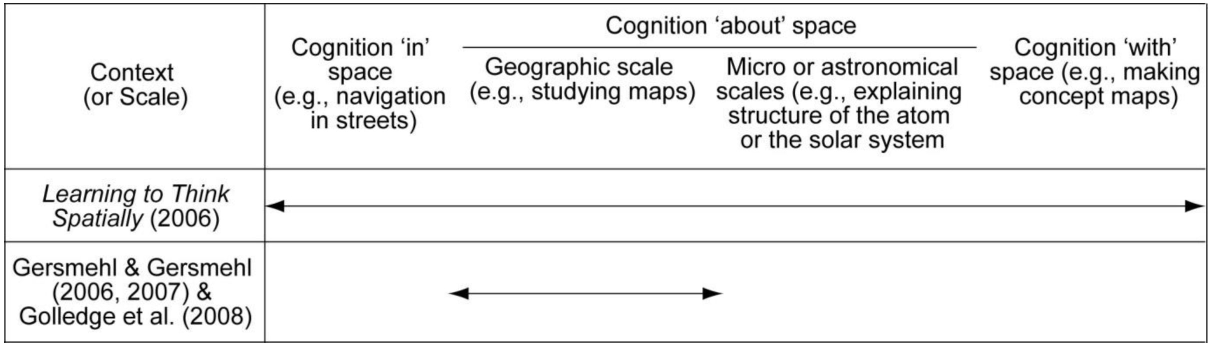
Why Geospatial Thinking?

- Ability with profound and rewarding effects on numerous aspects of everyday life and **STEM** disciplines, also highly relevant to social sciences and humanities - from giving and following directions, interpreting maps and diagrams, to understanding correlation of social phenomena in space and time.

- Replaced, however, in education for a long period of time by other forms of thinking (verbal, metaphorical, hypothetical, and mathematical).

Spatial Thinking; The importance of scale

Which space?



Scales of spatial thinking concepts used in the literature, from Lee and Bednarz, 2012

Spatial Thinking; The importance of scale

Montello's typology (1993)

- **Figural space**; perceived in all its properties, without requiring locomotion by humans
- **Vista space**; which includes the human body, relatively as large or larger than the human body and comprises a room or a town square
- **Environmental space**; larger than the human body, comprising semantic information, variable and hardly perceptible without moving into it, comprises of buildings, neighborhoods, cities and, finally,
- **Geographical space**; much larger of the human body and cannot be understood directly even by human movement. Conversely, it can be perceived through representations, such as maps or schematic models.

Spatial Thinking; Related Notions

- **Spatial sense** can be defined as an **intuition about shapes and the relationships among shapes**. Individuals with spatial sense have a feel for the geometric aspects of their surroundings and the shapes formed by objects in the environment (van de Walle, 2003).

- **Space perception** is defined as the perception of the properties and relationships of objects in space especially with respect to **direction, size, distance, and orientation** (Merriam - Webster Dictionary, 2014).

Spatial Thinking; Related Notions

- **Spatial ability** is the ability to:
  - understand and remember the **spatial relationships** among objects
  - manipulate **images in space**
  - **visualize** how separate parts of complex physical systems **interrelate** (The Johns Hopkins University Center for Talented Youth, 2013)

Spatial Thinking; Related Notions

- Spatial abilities include the following (Golledge, 1992):
  - **thinking geometrically**;
  - **imaging complex spatial relations at various scales**;
  - **recognizing spatial patterns** in distributions of functions, places and interactions at a variety of different scales;
  - **interpreting macro-spatial relations** such as star patterns;
  - **giving and comprehending directional and distance estimates** as required by navigation, or the path integration and short-cutting procedures used in way finding;
  - **understanding network structures** used in planning, design and engineering; and
  - **identifying key characteristics of location and association of phenomena in space**.

Spatial Thinking; Related Notions

- Spatial thinking includes **cognitive skills** related to:
  - **map reading and making,**
  - processes involving **representation, scale transformation, production and recall of symbolic (non-verbal) information, recognition and understanding of spatial projections, coordinate systems, synthesis of geometric configurations, formulation of verbal instructions,** and
  - **navigation and orientation based on observation and instruments handling**.
- Finally, the distinction between **knowledge of space** and **knowledge about spaces** is significant; *knowledge of space is phenomenal, knowledge about spaces is intellectual* (Eliot, 2000)
- Piaget also argues that **interaction in space**, not perception of space is a fundamental building block for the acquisition of **spatial knowledge** in (Golledge & Stimson, 1997, p. 191).

Spatial Thinking; Related Notions

- Spatial skills:

1. Disembedding
2. Spatial visualization
3. Mental rotation
4. Spatial perception
5. Perspective taking

The formation of spatial perception and knowledge

Three approaches to spatial development

1. Piaget's account
2. Nativist approaches
3. Vygotsky's theory

Piagetian spatial development

Piaget's premise: infants born without knowledge of space or of the things in space.

A series of experiments by Piaget and his colleagues (1956, 1958, 1960) on how children perceive space, thereby forming spatial perception and knowledge:

- spatial awareness from infancy beginning from near/far objects,
- distinguish various simple relationships between objects, which are of topological nature,
- topological ideas are very general (proximity, order, separation and closure) and can be described through the features of various types of geometry.

Piaget’s stages of spatial perception

- 4 stages to a child’s development;
  1. the sensorimotor stage (0-2 years),
  2. the pre-operational stage (2-7 years),
  3. the concrete operational stage (7-12 years), and
  4. the formal operational stage (12-18 years).

Piaget’s stages of spatial perception

- During the concrete operational stage:
  - **Classification:** name and identify sets of objects and form hierarchies;
  - **Conservation:** understand that, although an object’s appearance changes, it still stays the same in quantity.
  - **Decentering:** take into account multiple aspects of a problem to solve it
  - **Reversibility:** understand that numbers or objects can be changed and returned to their original state.
  - **Seration:** sort objects in an order according to size, shape, or any other characteristic.
  - **Transitivity:** mentally sort objects and recognize relationships among various things in a serial order.

Piaget's stages of spatial perception

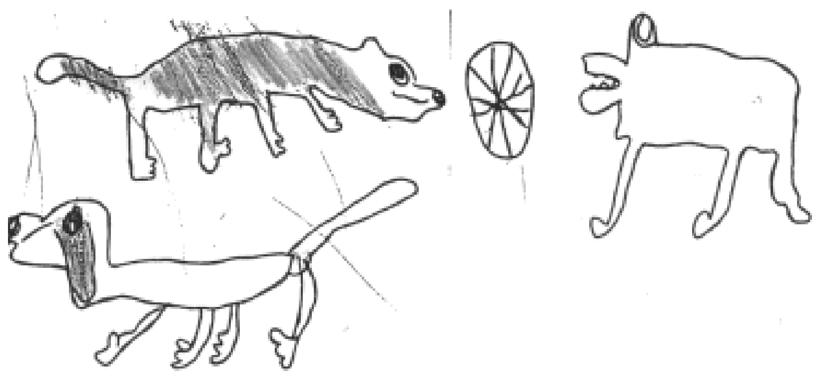
Spatial knowledge during the concrete operational stage:

- perception of space is upgraded and **logical space** becomes experienced however still confined to the **perceived world**,
- estimate distances, dimensions, weights, and volumes due to reversibility,
- build a **clear, stable, unified and detailed space**; associate things with space,
- topological and Euclidean relations are significantly improved; long distances are assessed accurately,
- gradually understand and represent the objects from different angles and incorporate the idea of perspective, and
- horizontal and vertical relationships (projective geometry).

Piaget’s stages of spatial perception

Empirical Evidence on the last two arguments

a) Perspective (7year-old)

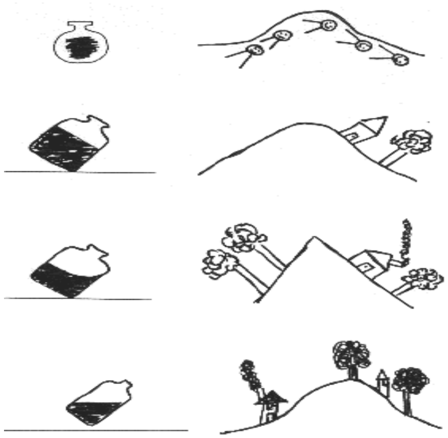


Dogs playing soccer; picture taken from (McNally, 1975)

Piaget's stages of spatial perception

Empirical Evidence on the last two arguments

b) Projective geometry (4-10year-olds)



Water in a tilted vase/ people on a hill; picture taken from (McNally, 1975)

Piaget’s stages of spatial perception

- During the formal operational stage:
  - "reasoning using a **hypothesis** and testing it in a certain way”; involves hypothetical situations and is often required in **science and mathematics**.
  - **abstract thought**, **metacognition** (thinking about thinking) and **problem-solving** are also abilities acquired during this stage.

Piaget's stages of spatial perception

Spatial knowledge during the formal operational stage

- During adolescence (from the 12^{th} to the 18^{th} year), children are at the stage of formal reasoning; the perception of space is growing. Specifically, through perception, all elements in both the area surrounding the children and the global area (in its all dimensions) are interpreted.
- **Space** in the mind of the teenager receives a new dimension and from sensorimotor and practical, **becomes reasonable, uniform and clear**.
- Children become able to understand and handle abstract and general concepts and relations, or even mathematical, which are studied per se, as abstract and independent.

Piagetian spatial development

Where Piaget was wrong

1. Many spatial achievements are reached late in childhood.
2. Adults perform spatial tasks accurately.

Seem contradictory? Yes(!), true, nonetheless.

Nativism

Nativist premise: understanding of space innate in infants.

- Empirical evidence to support the view:
  1. Early ability to perform spatial analysis even by blind children (no visual input used)
  2. Understanding space is a (geometric) modular ability
  3. Maturation of the brain can only help aspects of spatial development that were not accounted for by innateness.
- Nativism suffers from lack of interest in environmental input and developmental change; its focus on the origins of cognitive competence have proven quite monolithic.

Vygotsky's influence

Vygotskyan views of : 1) Guided participation, 2) Situation specificity and 3) Symbolic systems have influenced research in spatial competence.

1. Guided participation; children better understand the world through adults/older peers guidance.
2. Situation specificity; cognitive effort is adapted to and specific of particular situations.
3. Symbolic systems; dealing with maps or diagrams involves how humans interact with their cultural environment. No direct experience is need, such systems serve as **amplifiers of individual intelligence**.

Counterargument : emphasis on adult instruction and on cultural transmission, leaving aside individual cognitive efforts.

Development

Question of:

Age/ Maturity?

Gender?

Experience?

Instruction?

Some words on gender

Spatial thinking has a long history of sex differences favoring males.

However, if we review research conducted, findings indicate that any sex differences are insignificant, or inconsistent.

More details on this: Mohan, A. & Mohan, L. (2013) Spatial Thinking About Maps Development of Concepts and Skills Across the Early Years

A novel theory of spatial development

A blended approach to spatial development; Newcombe and Huttenlocher account (2000).

- Interactonist (mind and body may affect each other)
- Starting point for spatial cognitive development lays in infancy
- Importance of cultural transmission evolved by past generations

Premise: **adults have metric representations but there judgments are not perfectly accurate**.

Spatial Development; Two axes

1. Location or spatial coding
    i. How we remember the location of things
    ii. How this ability develops

2. Spatial representation
    i. Think about and act on locative information
    ii. How these abilities develop

1. Location

Spatial Coding

1. Externally Referenced → Spatial relations to landmarks
   i. Cue Learning → Coincident landmarks
   ii. Place Learning → Distance and direction
2. Viewer Referenced → With respect to the (moving) self
   i. Response Learning → Pattern of muscular movements
   ii. Dead Reckoning → Updated information on distance and direction

The sensorimotor stage; empirical evidence

Egocentric to allocentric shift

6month-olds → 11 month-olds → 16 months-olds

Cue learning: 11 month-olds

and earlier depending on the landmark

Movement marks a qualitative shift; external referenced coding and dead reckoning

The pre-operational stage; some empirical evidence

- Acredolo (1977): 3-, 4- and 5year-olds search for a prize (located under a bucket) either to the left or right side of the room.
- Results:
  - 5year-olds consistently look for the prize in either side,
  - 4year-olds had to be reminded that they had moved to keep looking, and
  - 3year-olds had not kept looking even after being reminded that they had moved.
- Explanations:
  - Preschoolers differ from infants in understanding the social nature of many cognitive tasks.
  - 5year-olds as opposed to 3year-olds have a good idea about the kind of game rule

2. Spatial Representation

- Evidence that it evolves in the second year of life
- Ability to perform four kinds of tasks;

1. perspective-taking,
2. distance comparison,
3. route planning,
4. establish areas of search for lost objects,

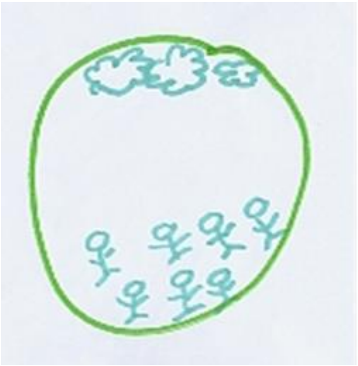
dates back to 3 and 4 years.

The pre-operational stage; some empirical evidence

- Vosniadou & Brewer (1990): Draw the Earth, people and sky and give answers to questions such as: “Where do people live?”
- Subjects: 5-year olds

Flat Earth

Dual representations of the Earth



Hollow Earth

Spatial thinking development and the curriculum

A pedagogical framework for Geometry; the van Hiele Model of the Development of Geometric Thought [1959] (van Hiele-Geldof & van Hiele, 1984)

- Covers **geometric thought development from 5year-olds to adults**.
- Identifies **5 levels** of geometric understanding.

van Hiele's model of the development of geometric thought

1. Visualization; recognize and name shapes based on global, visual characteristics of the shape.
2. Analysis; able to consider all shapes within a class and recognize properties of classes of shapes.
3. Informal deduction; develop relationships between and among these properties.
4. Formal deduction; construct proofs; understand the interaction of necessary and sufficient conditions; make distinctions between a statement and its converse.
5. Rigor; understand non-Euclidean geometries and different systems can be compared; geometry is seen in the abstract.

van Hiele's model of the development of geometric thought

- The learner progresses sequentially from level 1 to 5, throughout the years of their academic endeavor.
- **Not** all learners make it to level 5, though because few of them are exposed to it through the formal curricula.
- This last level has received little attention and analysis by researchers, since the majority of high school geometry curricula end at level 4 (Crowley, 1987).

van Hiele's model of the development of geometric thought

The properties of the model identified by van Hiele himself are:

- Sequential; the levels come one after the other; the learner should have mastered the previous level to proceed to the next.
- Advancement; progress form one level to another comes not from age rather from (successful) teaching methods.
- Intrinsic and extrinsic; inherent concepts of one level become study concepts of the next.
- Linguistics; students master concept names gradually; a square is also a rectangle and a parallelogram as the students move from one level to the next.
- Mismatch; occurs when teaching methods belong to superior level than of the student's.

(Geo)spatial concepts and educational needs

Golledge et al. (2008a) and (2008b) have proposed a geospatial task ontology as an effort to match geospatial concepts with geographic educational needs

- The ontology consists of **45 geospatial concepts** organized in **five categories**, from basic concepts called primitives to complex ones, which are 4th order derivatives.
- Grossner (2008) and Golledge himself added several other concepts to the initial list reaching their number to **126**, while keeping the **original categorization**, to accommodate the complexity and diversity of the geospatial domain.

(Geo)spatial concepts and educational needs

I Primitives	II Simple (1st Order Derivatives)	III Difficult (2nd Order Derivatives)	IV Complicated (3rd Order Derivatives)	V Complex (4th Order Derivatives)
Identity	Area (math)	Adjacency/ Contiguity	Buffer	Activity Space
Location	Arrangement/ Placement	Alignment	Chirality	Areal Association
Magnitude	Behavior	Analogy	Chaos	Central Space
Space-Time	Class/ Group/ Category	Angle	Connectivity	Distance Decay
	Closeness/ Nearness	Area	Corridor	Distortion/ Deformation
	Connection	Center/ Centre	Dissolve	Enclave
	Density	Centrality	Gradient/ Slope	Great Circle
	Direction/ Orientation	Centroid	Heterogeneity/ Diversity	Interpolation
	Distance	Change	Hierarchy	Projection
	Distribution	Classification/ Categorization	Map	Social Area
	Duration/ Continuance	Cluster/ Bunch/ Clump	Mean Areal Center	Spatial Aggregation
	Edge/ Boundary/ Border/ Bound	Coordinate	Navigation	Spatial Association
	Existence	Dimension	Network	Spatial Autocorrelation
	Farness/ Remoteness	Enclosure	Overlay	Spatial Dependency
	Frequency	Grid	Profile	Spatial Sampling
	Length	Growth	Representation	Subjective Space
	Line	Isolated	Scale	Virtual Reality
	Link/ Nexus	Isotropic/ Anisotropic	Shortest or Least cost Path/ Time	
	Numerosity	Linkage	Surface	
	Order/ Ordination	Linked	Topology	
	Perimeter/ Circumference	Motion/ Movement		
	Proximity/ Propinquity	Neighborhood/ Vicinity		
	Sequence	Pattern		
	Shape	Polygon		
	Situation/ Site	Reference Frame		
	Size/ Quantity	Region/ Zone		
		Rotation		
		Spread/ Diffusion/ Dispersion		
		Symbolization		

Golledge initial and revised list of geospatial concepts

(Geo)spatial concepts and educational needs

- A child should first understand simple spatial concepts before proceeding to more complex ones, because complex concepts result from the combination of several simpler ones. ⇨

- For every level of complexity several tasks have been proposed that would help children to better understand the concepts of each level (only for the initial list).

(Geo)spatial concepts and educational needs

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	Numerosity	Linkage	Surface	
	Order/ Ordination	Linked	Topology	
	Perimeter/ Circumference	Motion/ Movement		
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	Shape	Polygon		
	Situation/ Site	Reference Frame		
	Size/ Quantity	Region/ Zone		
		Rotation		
		Spread/ Diffusion/ Dispersion		
		Symbolization		

Golledge initial and revised list of geospatial concepts

(Geo)spatial concepts and educational needs

- Some examples of tasks associated to concepts at different levels:
  - Primitives; **Location**: Recognizing that objects are found or located at specific places (e.g., home, school, shopping, gas station)
  - Simple concepts; **Edge/boundary**: Awareness of containment within a boundary (e.g., city; school yard; shopping mall)
  - Difficult concepts; **Center**: Determining (by estimation, measurement, or common acceptance) the middle of a spatial set (such as “the center of the city”)
  - Complicated concepts; **Connectivity**: Building or recognizing a static or dynamic area surrounding a node (e.g., newspaper circulation; marketplace)
  - Complex concepts; **Social Area**: Recognizing or constructing regions based on social characteristics of people (e.g., families versus singles)

Geo(spatial) concepts understanding and learning

- Empirical evidence: studies and experiments indicate that the ontology can be used as a reference frame for the development of the Geography curriculum.

Tier	Geospatial concept	Grade												
		K	1	2	3	4	5	6	7	8	9	10	11	12
Primitive	Spatial Primitives	X	X	X	X	X	X	X	X	X	X	X	X	X
Simple	Relative Distance/Direction	X	X	X	X	X	X	X	X	X	X	X	X	X
	Shape		X	X	X	X	X	X	X	X	X	X	X	X
	Place-based Symbol		X	X	X	X	X	X	X	X	X	X	X	X
Difficult	Boundary			X	X	X	X	X	X	X	X	X	X	X
	Connection			X	X	X	X	X	X	X	X	X	X	X
	Distribution				X	X	X	X	X	X	X	X	X	X
	Pattern				X	X	X	X	X	X	X	X	X	X
	Reference Frame				X	X	X	X	X	X	X	X	X	X
	Coordinate/Grid				X	X	X	X	X	X	X	X	X	X
	Zone					X	X	X	X	X	X	X	X	X
Complicated	Map						X	X	X	X	X	X	X	X
	Legend						X	X	X	X	X	X	X	X
	Map Projection						X	X	X	X	X	X	X	X
	Slope/Gradient							X	X	X	X	X	X	X
	Scale							X	X	X	X	X	X	X
	Surface								X	X	X	X	X	X
	Hierarchy										X	X	X	X
	Overlay										X	X	X	X
Complex	Interpolation											X	X	X
	Global Warming												X	X
	Spatial Association												X	X

Connection of geospatial concepts to education levels from Golledge, Marsh, & Battersby, 2008a

Geo(spatial) concepts understanding and learning
Concluding remarks and comments

- Concepts of the same level of complexity in the Golledge ontology cannot be grasped by children at the same time.

Tier	Geospatial concept	Grade												
		K	1	2	3	4	5	6	7	8	9	10	11	12
Primitive	Spatial Primitives	X	X	X	X	X	X	X	X	X	X	X	X	X
Simple	Relative Distance/Direction	X	X	X	X	X	X	X	X	X	X	X	X	X
	Shape		X	X	X	X	X	X	X	X	X	X	X	X
	Place-based Symbol		X	X	X	X	X	X	X	X	X	X	X	X
Difficult	Boundary			X	X	X	X	X	X	X	X	X	X	X
	Connection			X	X	X	X	X	X	X	X	X	X	X
	Distribution				X	X	X	X	X	X	X	X	X	X
	Pattern				X	X	X	X	X	X	X	X	X	X
	Reference Frame				X	X	X	X	X	X	X	X	X	X
	Coordinate/Grid				X	X	X	X	X	X	X	X	X	X
	Zone					X	X	X	X	X	X	X	X	X
Complicated	Map						X	X	X	X	X	X	X	X
	Legend						X	X	X	X	X	X	X	X
	Map Projection						X	X	X	X	X	X	X	X
	Slope/Gradient							X	X	X	X	X	X	X
	Scale							X	X	X	X	X	X	X
	Surface								X	X	X	X	X	X
	Hierarchy										X	X	X	X
	Overlay										X	X	X	X
Complex	Interpolation											X	X	X
	Global Warming												X	X
	Spatial Association												X	X

Geo(spatial) concepts understanding and learning
Concluding remarks and comments

- The revised list contains 126 concepts is more detailed than the initial one;
- Concepts somehow overlap such as: closeness/nearness, farness/remoteness and proximity/propinquity categorized as 1^{st} order derivatives; all relative to distance; the first is the spatial property resulting from a relative small distance, the second the property of being remote, and the last the property of being close together (WordNet).

Geo(spatial) concepts understanding and learning
Concluding remarks and comments

- The cases of connection and link/nexus, belonging to 1st order derivatives, of linked, and linkage, belonging to 2nd order derivatives, and of connectivity, a 3rd order derivative present difficulty in justifying the inclusion of all these strongly related terms in the list. It would seem more logical to include only connection as a 1st order derivative and everything else is logically entailed –and taught/ learnt- as one progresses.

- Link/nexus is defined as the means of connection between things linked in series, while connection as the state of being connected, linked as connected by a link and linkage as an associative relation, a kind of connection, finally, connectivity is defined as the property of being connected or the degree to which something has connections (all definitions from WordNet).

Geo(spatial) concepts understanding and learning Concluding remarks and comments

- As an overall conclusion, one could say that contrary to *simple* and *difficult* level concepts (1^{st} and 2^{nd} order derivatives) which become all best understood by the age of 10 and need less time to become so, *complicated* and *complex* level concepts (3^{rd} and 4^{th} order derivatives) need more time to become fully understood and they all do so from the age of 10.
- What is important to bear in mind is that spatial knowledge can be acquired by humans from the early stages of their education. In the beginning, the child is exposed to geospatial primitives and gradually progresses into more complex concepts along the way.

Maps and other representations

- Representations serve as an effective reasoning tool and trigger complex reasoning processes and abilities (National Research Council, 2006).

- Representations, which include maps, models, diagrams, and graphs help in making the most abstract concepts understandable, and additionally helps grounding their communication skills (Mathewson, 1999).

- Science and technology are developed through exchange of information and data presented as diagrams, illustrations, maps, schematics, which summarize information and contribute to their understanding by the wider public (ibid).

Maps and other representations

- Symbolic representations of spatial location serve the transmission of information among people, ensuring the need to explore each site they visit. (Newcombe & Huttenlocher, 2000).

- Uttal (2000) found out that using maps and thinking about them can help children to understand abstract concepts of space and to gain systematic thinking about spatial relations with which they have not come into direct contact. In addition, the “exposure” to maps can help children to think the numerous spatial relationships that may exist among locations.

Maps and other representations

Representations are all around us:

- Letters of the alphabet
- The sound of the word “mother”
- A red traffic light
- Gestures in sign languages
- …

For spatial thinking development however, maps constitute the core representational means.

Maps and other representations

Map; what is it

- Children have a conceptual prototype for map, which is the world atlas
- Children call maps a small range of representations, which expands by age.

as proven empirically by Downs et al. (1988)

Since maps can encompass nowadays almost any type of visual representation, children through formal education should enrich and expand the map concept.

Maps and other representations

Map; scale and children

- Downs and Liben (1987) have proven that scale is important to children (3- to 6year-olds)
  - Only 50% of the children participating in the experiment answered that a map of the city of Philadelphia is actually a map.
- According to Vasilev et al. (1990) national scale (e.g. a map of France) is more typical for map than city scale (e.g. a map of Grenoble) when it comes to children.

Maps and other representations

Map; representational tool

- The "stand for" relation in graphic systems is delayed although the ability to acquire symbols is present even in 2year-olds.
- The relation is surely present after 3 years of age.
- Lack of empirical work when it comes to earlier years.
- Maybe with guidance, the representation correspondence becomes more obvious to children from early age.

Maps and other representations

Map; alignment

- Physical vs mental rotation
  - Physical alignment; once the need is understood, children can succeed in the task by the age of 5. Younger ones could physically rotate it but it seems difficult to perform the task.
  - Mental rotation; is acquired more difficultly. Even 8year-olds may have difficulties. But it is important to bear in mind that even adults struggle to provide the right answers in directional questions with misaligned maps.

Maps and other representations

Map; navigation

- Maps with low level of complexity and no demands on alignment or scaling are used by 4year-olds for navigation in a simple situation.
- However planning routes is more demanding than following ones already indicated. Empirical evidence shows that 6years-olds can perform a task of following a route.
- Even adults have difficulties in route planning when there are multiple factors (terrain, traffic load, road quality).

Maps and other representations

Map; knowledge acquisition

- Very little is known about how children use maps to learn from them!
- More empirical evidence is needed in the field.

Maps and other representations

Lucy Sprague Mitchell, an educator, with elementary children proposed the following steps for instructing map skills (1934):

- Know the child's stage
- Get to know elementary relations before use appropriate materials
- Bird's eye views are easier than symbolic maps
- 6, 7years-old need to play upon maps
- Early elementary children like to make their own maps
- 2d comes before 3d representation; that is why terrain models should be taught after 10 years, and relief maps should be then used as tools
- Projection becomes of interest between the age of 8 and 10
- Iconic symbols should be taught before abstract ones.

Spatial Thinking; Fundamental Issues

Questions

1. How to draw conclusions about spatial coding of children when knowing that even adults' spatial judgments have distortions?
2. Is space absolute or relative?
3. How to distinguish "where" from "what" information?
4. Can people with sufficient experience of an environment form spatial representations that are independent of perspective?

Conclusions

- The geospatial domain presents an excellent opportunity towards achieving a meaningful connection between theoretical, higher-level concepts (e.g., geographical phenomena and processes) and tools of representation (e.g., maps and terrain models) and their application in everyday life such as locating one's home or following directions to an unknown place using their mobile phones or web-based applications (reasoning processes).

- Since geospatial thinking varies according to age, background knowledge, education, etc., a major challenge is to analyze the needs and characteristics of students and develop the appropriate knowledge components that will help them enhance their geospatial skills.

Conclusions

- No consistent and significant research on how children in adolescence develop spatial thinking, only that they have learnt from early ages to deploy strategies to perform spatial tasks.

- Geospatial concepts cross-cut the curriculum which make it more difficult to identify how spatial thinking notions are dealt with in formal education.

- To support spatial thinking in the classroom, it should be incorporated into the general education system including educational practices, curricula, teaching support materials, and assessments.

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