



**GI Learner**

**Creating a learning line on spatial thinking**

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# **LITERATURE REVIEW ON SPATIAL THINKING**

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# 1 BACKGROUND

Geo-ICT is part of the digital economy identified by the European Commission as being vital for innovation, growth, jobs and European competitiveness. As a rapidly growing business sector, there is a clear and growing demand for Geo-ICT know-how (DONERT, 2015).

The use of GI tools to support spatial thinking has become integral to everyday life. Through media agencies that use online interactive mapping and near ubiquitously available tools like GPS and car navigation systems, the general public has started to become aware of some of the potential of spatial data.

Space and location make spatial thinking a distinct, basic and essential skill that can and should be learned in school education, alongside other skills like language, mathematics and science. The goal of GI-Learner is to integrate spatial literacy, spatial thinking and GIScience into schools. BEDNARZ & VAN DER SCHEE (2006) made three recommendations for the successful introduction and integration of GIScience in schools. These were to:

- address key internal issues related to GIS implementation: teacher training, availability of user friendly software, ICT equipment in schools.
- use a community of learners approach and
- institutionalize GIScience into curricula, making sure that it is aligned with significant general learning goals like graphicacy, critical thinking and citizenship skills.

In terms of the first two recommendations considerable progress has already been made, for example there have been more training opportunities for teachers as the EduGIS Academy (<http://www.edugis.pl/en/>), iGuess (<http://www.iguess.eu>), I-Use (<http://www.i-use.eu>) and SPACIT (<http://www.spatialcitizenship.org>) projects. Schools nowadays generally have better ICT equipment, pupils are asked bring their own devices, data is more freely available and Web-based platforms have reduced costs. The digital-earth.eu network launched 'Centres of Excellence' in 15 European countries (<http://www.digital-earth-edu.net>). The Geo For All initiative has developed a network of Open Source Geospatial Labs around the world and has also focused its attention on school education (<http://geoforall.org/>). These initiatives have helped build capacity for a community of practitioners, in Europe and beyond, by collecting and disseminating good practice examples and organizing sessions with teachers. However, there are still needs for much more training, additional learning and teaching materials, good practice examples and a comprehensive and well-structured compilation of digital-earth tools.

The institutionalization of geo-technology and geo-media into curricula still remains a goal in almost all countries. It has by and large not been achieved, despite the development of:

- benchmarks (HERODOT 2009; LINDNER-FALLY & ZWARTJES 2012), intended to give a rationale and recommendations on the implementation to teacher trainers, teachers and headmasters, but also to policy and decision makers
- competence models (SCHULZE et al., 2012, 2013, 2015, GRYL et al., 2013),
- teacher guidance (ZWARTJES, 2014) whereby teachers can select suitable tools to use, based on curricula, abilities of their students and their own capabilities and
- European innovative projects like iGuess, SPACIT, EduGIS Academy, I-Use etc.

GI-Learner aims to respond to this by the development of a GIScience learning line for secondary schools, so that integration of spatial thinking can take place. This implies translating the spatial

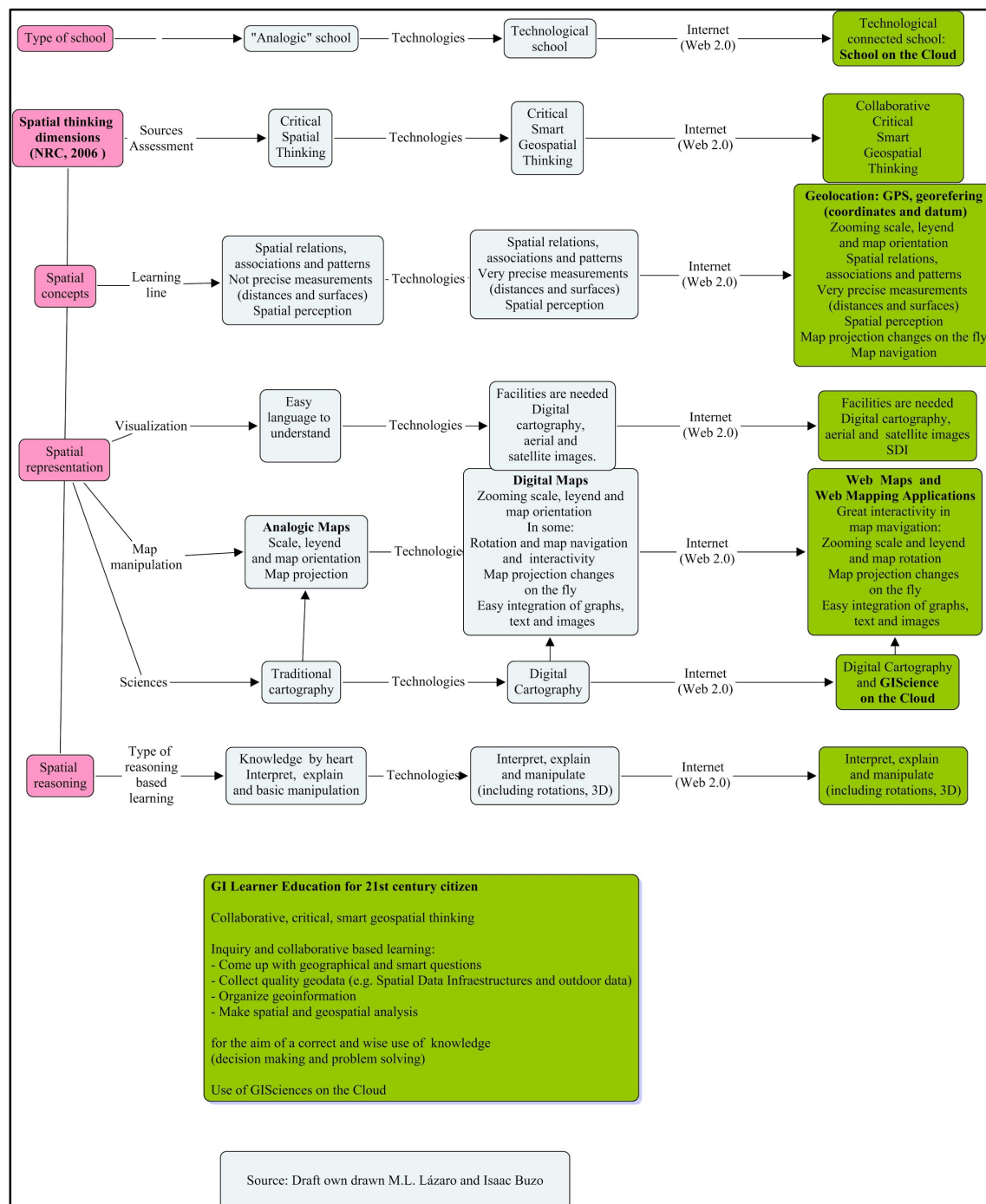
and other competences, taking into account age and capabilities of students, into real learning objectives that will increase spatial thinking education activities and help produce the workforce we need now and for the future and geospatially literate citizens.

The present work responds to the spatial thinking literature and how it turns into geospatial thinking. It will develop a state of art taking into account a psychological point of view, as well as different spatial approaches that we implement on those stages:

- Spatial thinking
- Critical thinking
- Using GIS and making smart questions for a geospatial critical thinking.

All of this will help us to create a learning line showing the importance of geospatial smart thinking.

The GI Learner project will develop teaching and learning material for this aim, as well as an evaluation on learning outcomes of the students who use these materials. The following conceptual map develops the main points of this work:



Source: Spatial Thinking dimensions and related terms based on NRC, 2006 and other authors.  
Own drawn M.L. Lázaro and I. Buzo

## 2 GI-LEARNER PROJECT

GI-Learner (<http://www.gilearner.eu>) is a project supported by Key Action 2 of the Erasmus Plus education program. It is a three-year project, with seven partners from five European countries. GI-Learner aims to help teachers implement learning lines for spatial thinking in secondary schools, using GIScience. In order to do this, the project:

- summarizes the most important literature on learning lines and spatial thinking
- scans curricula in partner countries to identify opportunities to introduce spatial thinking and GIScience
- defines geospatial thinking competencies
- develops an evaluative test on an online tool to analyse the impact of the learning lines on geospatial thinking and
- creates initial draft learning lines translating them into learning objectives, teaching and learning materials for the whole curriculum (K7 to K12)

It is envisaged that by the end of the first year of the project, pupils from age groups K7 and K10 of the partner schools will pilot the materials and give their feedback. The diagnostic tool will also be developed, tested, assessed and revised. GI-Learner learning outcomes will then be re-written into a final version and published. Further materials for learning lines will then be developed for year groups K8, K11 and K9, K12 respectively in the second and third years of the project. Finally, a publication with guidelines for suggested inclusion into the national curricula will be produced.

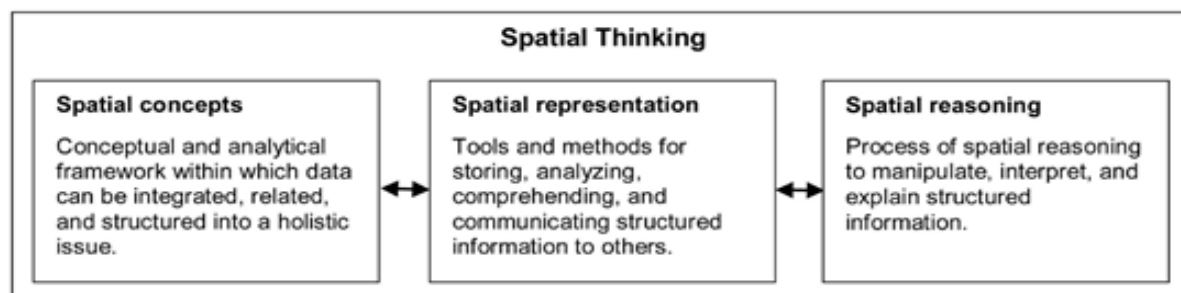
As part of the project, GI-Learner will create a tool to help learners evaluate their own spatial thinking ability, as advocated by CHARCHAROS et al. (2015). The purpose and content of this tool could be adapted to meet the specific needs in terms of participant target group their age, gender, ethnicity or other aspects. The geospatial abilities to be examined can be selected, whether geospatial thinking ability is to be evaluated in a holistic or partial way.

### 3 WHAT IS SPATIAL THINKING

Spatial thinking is integral to everyday life. With the use of online mapping tools, GPS and car navigation the general public has become aware of the possibilities of spatial data. And the different concepts of space make spatial thinking a distinct form of thinking, which helps students to visualize relationships between and among spatial phenomena (STOLTMAN & DE CHANO, 2003). It is a basic and essential skill that can and should be learned, besides other skills like language, mathematics and science.

The Theory of Multiple Intelligences (GARDNER, 1983, 2006) distinguishes spatial intelligence as one of the nine intelligences. Although spatial intelligence provides the ability to solve spatial problems, in Gardner's model it is mainly related to arts subjects. Geography, as a science, mainly focuses on spatial analysis and deals with spatial thinking and the stages of the Kolb's experiential learning model (1984): plan, do, observe and think.

One key publication is the NATIONAL RESEARCH COUNCIL (NRC 2006) report: *'Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum'*. It defines spatial thinking as three lines: knowledge, tools and skills, and habits of mind, "a collection of cognitive skills comprised of knowing concepts of space, using tools of representation and reasoning processes". It is exactly the links among these three that gives spatial thinking its power of versatility and applicability



(Figure 1).

Figure. 1. *Spatial Thinking dimensions and related terms according to NRC, 2006. Drawn by: Michel & Hof (2013)*

LEE and BEDNARZ (2006) describe spatial thinking as a constructive combination of three mutually reinforcing components: the nature of space, the methods of representing spatial information, and the processes of spatial reasoning. Spatial thinking is the catalyst to improve understanding of subjects across the curriculum and as a way of thinking that crosses disciplinary boundaries (BEDNARZ, 2005).

GOODCHILD (2006) argues that spatial thinking is one of the fundamental forms of intelligence needed to function in modern society, it is a basic and essential skill whose development should be part of everyone's education, like learning a language, numeracy and mathematics. Students need to know the building blocks of spatial thinking. It includes models, graphics, charts, photographs, 3D modelling, video and other multimedia tools. Geographers apply spatial intelligence to education. There have been many attempts to analyse, organise, classify and define them. The remainder of this section examines some of the key literature.

The COMMITTEE ON SUPPORT FOR THINKING SPATIALLY (2006) suggest spatial thinking involves breaking the process down into three component tasks: extracting spatial structures, performing

spatial transformations, and drawing functional inferences. They explicitly stated that “Spatial thinking uses representations to help us remember, understand, reason, and communicate about the properties of and relations between objects represented in space”. Their report defines spatial thinking as the ability to understand spatial relationships, the knowledge of how geographic space is represented, and the ability to reason and make key decisions about spatial concepts. They suggest these skills are essential as they cut across many school subjects. The challenge is to integrate it into learning in all appropriate content areas. HESPANHA et al. (2009) look at examples of spatial thinking from a social sciences perspective. They discuss insights and strategies that emerged from a series of NSF workshops in the USA. They discuss the importance in creating an environment for learning to think spatially, where a learner-centred approach builds knowledge and teachers creates environments for knowledge construction. They suggest this is based on prior knowledge and skills as well as individual differences to make the concepts appear more relevant and accessible. They recommend a number of strategies for assessing content knowledge, spatial concepts and skills.

The real world and its spatial representation helps us to understand cadastral charts, Common Agricultural Policy maps and use location-based services (LBS) as well as other civic spatial engagement practices (collecting and diffusing geospatial data and participation in the analysis) which are necessary skills for citizens (HAKLAY, 2012). Thus the Spatial Thinking approach is not only based on Geographical Information Education (GI Education) and labs but also on using human, applied and social geography to solve spatial problems, and for this critical cartography and spatial citizenship skills are necessary. A solid foundation in spatial literacy will provide students with the crucial scientific and social questions of the 21st century (TSOU and YANOW, 2010).

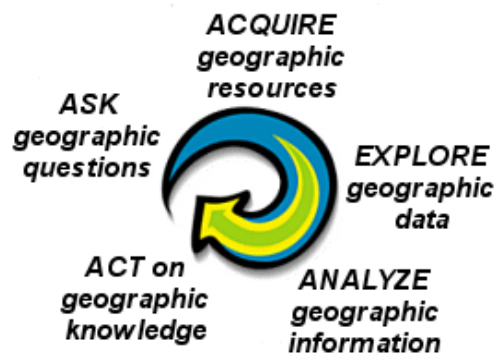
Spatial thinking has been a common element in all Earth system sciences, such as Geography, Geology and Environmental Sciences. It is also prevalent in other disciplines, such as Business, Marketing, Science and some areas of Mathematics. Spatial thinking is also a catalyst to improve the understanding of subjects across the curriculum and as a way of thinking that crosses disciplinary boundaries (DONERT, 2015). Geospatial technologies can be used to ask or help answer different sorts of spatial question, develop spatial skills and improve the ability to reason spatially. This can be related to many different study areas in schools.

Developing the spatial thinking capabilities of students helps foster geographic skills, knowledge and understanding. KERSKI (2008) summarizes it as the ability to study the characteristics and the interconnected processes of nature and human impact in time and at appropriate scale. TSOU & YANOW (2010) consider how spatial perspectives assist students in discovering the value of geographic knowledge and develop their ability to explore and visualize real-world, critical problems such as global climate change, natural disaster recovery and responses, and watershed conservation. They suggest that with a solid spatial foundation, students will be better prepared to consider the crucial scientific and social questions of the 21<sup>st</sup> century.

Spatial thinking strengthens students' abilities to conduct scientific inquiry, engage in problem solving, and think spatially. Students need to know the building blocks of spatial thinking. These, according to SCHULTZ et al. (2008), may either be expressed in general spatial terms such as symmetry, isomorphism, reflection, orientation, rotation, and function, or those based on a particular discipline, such as relative versus absolute distance, small versus large scale, and distance decay in geography. To this end, the NATIONAL ACADEMY OF SCIENCES (2006) proposed five skill sets, asking geographic questions, acquiring geographic information; organizing



geographic information; analysing geographic information; and answering geographic questions (Figure 2).



*Figure 2: Geographic Inquiry: Thinking Geographically (ESRI, 2003)*

## 4 BACKGROUND OF SPATIAL THINKING

Research by child psychologists confirm that areas of the brain are devoted to different kinds of spatial thinking and that these seem to develop in very early childhood and that these tend to accumulate through life. As NEWCOMBE and FRICK (2010) state, spatial intelligence has evolutionary and adaptive importance. Any mobile organism must be able to navigate in its world to survive and must represent the spatial environment in order to do so. So spatial orientation and knowledge about the environment around is known as a primary space use (ROBSON, 2012). The development process of spatial competences can be noticed from very early childhood and it continues into school age (BULLENS et al., 2010).

ROBSON (2012) identifies three main stages of the spatial competence development, related to the way we represent spatial location:

- *egocentric representation*: in relation to ourselves, and our own position;
- *landmark representation*: in relation to landmarks in the environment;
- *allocentric representation*: by use of an abstract frame of reference, including use of maps, or coordinates,

As infants we understand a space in egocentric way, putting ourselves in the centre. However, research shows that even babies aged three to four months understand the concepts of above, below, left and right (QUINN et al., 2011). When babies start to explore the world by crawling, they also activate process of cognitive mapping, developing mental maps of the spatial environment around them. By the age of eighteen months children commonly use landmark representation. They are able to use characteristic points in the surrounding to reorient themselves (BULLENS et al., 2010), even if that means necessity to link few mental maps developed earlier.

As researchers claim the allocentric representation of spatial location can be seen among children of one-year-old. By the age of 4 children are able to use simple maps to find their way around. They interpret different symbols representing specific objects in the real world (roads, rivers, etc.). They also start to use coordinates, for example on a simple grid (ROBSON, 2012).

Changes in the representation of spatial location are strongly related to so called secondary spatial use – construction of the maps. As mentioned by ROBSON (2012), children start with simple schematic drawings where things are seen from the side rather than from above, through the mixing both plan (objects seen from above and from the side), finally to the most complex approach including abstract representation of objects with clearly defined spatial relations. Children follow this developmental path as they become more aware with understanding of two important issues – first, that a map is only a representation of a real world, and secondly, how layers shown on a map are related to real world. Research show that children aged 3 appreciate the relations between maps or models and the real world (NEWCOMBE, FRICK, 2010).

Spatial behaviours look very different during infancy, childhood, and adulthood – there can be little debate about that among psychologists (LIBEN, 2006). However, and what is particularly interesting, is that there is relatively little agreement about whether the age-linked differences in observed behaviours signify qualitative differences in the way that space is represented and thought about, or do they only signify quantitative changes in other cognitive skills or structures

(e.g., changes in speed of processing). Therefore, probably, different models of spatial competences development can be proposed.

GERSMIEHL and GERSMEHL (2006, 2007, 2011) examined the neuroscience research that deals with distinct modes of spatial thinking' described in research about adult spatial cognition. Their papers were based on a detailed review of neuroscience research observing how areas of the brain are related to the kinds of "thinking" that appear to be done. They conclude that several brain regions appear to be devoted to doing specific kinds of thinking about locations and spatial relationships. They advised that "durable learning of geographic information is more likely to occur when lessons are explicitly designed to "force" students to perform a spatial task, that is, to use one or more of the distinct modes of spatial thinking that appear to be at least partially "hard-wired" into the human brain." They confirmed that students would greatly benefit if spatial thinking skills was more prominently placed in the school curriculum including in early years education.

After their study (Table 1) on different modes of spatial thinking GERSMEHL and GERSMEHL (2011) concluded that "Students who are proficient with one kind of spatial thinking, such as spatial association, are often less able to do other kinds of spatial reasoning, and vice versa. In general, females tend to score better on tests that involve spatial associations, whereas males seem to do better with tasks that involve spatial sequencing or mental rotation".

*Table 1: Modes of Spatial Thinking (Gersmehl and Gersmehl, 2011)*

**Location** — Where is this place?

a. Conditions (Site) - What is at this place?

b. Connections (Situation) - How is this place linked to other places?

**Eight aspects of Spatial Thinking** (an example of a concrete activity)

**1. Spatial comparison** - How are places similar or different? How can we compare them fairly? Can we compare places by examining maps? (e.g. arrange models of the continents in order of size, location of desks in the classroom, verbal comparisons of rooms in the school)

**2. Spatial influence** (Aura) - What effect(s) does a feature have on nearby areas? The ability to recognize what is "near space" and "far space" for a specific purpose. (e.g. a game that required the use of the words next to, near, close to and far from)

**3. Spatial groups** (Region) - What nearby places are similar to each other and can be grouped together? it is possible to draw a line around them on a map or on a satellite image. (e.g. divide the classroom into regions with similar features – desk areas, play areas, reading areas, and so forth; draw pictures of the scenes they had seen on a trip and put the pictures into groups– places where people live, places where people shop, places where people worship, places where people go to have fun, and other places; work with land use maps)

**4. Spatial transition** - Is the change between places abrupt, gradual, or irregular? (slopes, gradients, sequences). (e.g. to ask students if they know of a place where it is hard to walk or pull a wagon because the land goes uphill, to recognize places with different rainfall)

**5. Spatial hierarchy** - Where does this place fit in a hierarchy of nested areas? (e.g. A political map provides an easy-to-understand example: municipality, province or county and country).

**6. Spatial analogies** - What distant places have similar situations and therefore may have

similar conditions? The importance of similarity of position, however, extends beyond mapping. (e.g. to “put your book in the same position on your desk as my book is on my desk.”)

**7. Spatial patterns** - Are there clusters, strings, rings, waves, other non-random arrangements of features? The human brain has been described as a “pattern-seeking machine. (e.g. describe and analyse the spatial patterns of real-world phenomena such as earthquakes, malls, or settlements). The analysis of spatial patterns is an end in itself. On the contrary, it usually serves as a prelude to the last of our modes of spatial reasoning, the analysis of spatial associations.-

**8. Spatial associations** (correlations) - Do features tend to occur together (have similar spatial patterns)? It tries to understand causal relationships. (e.g. asked to make lists of “things that are usually found together in the same room, like toothbrushes and toothpaste, or books and comfortable chairs”; make a map of their classroom, we asked students to try to name things that go together in the same part of the room, like desks and chairs.

**Spatio-temporal thinking** - How do spatial features change through time?  
 Change - change in conditions (e.g. climate, military control, land use, etc.) at a place over time  
 Movement - change in position of something (e.g., train, hurricane, border, etc.) over time  
 Diffusion - change in extent of something (e.g., disease, urban area) over time.

Research on spatial thinking has been compared by ISHIKAWA (2016), see Table 2.

Table 2: Comparison with other studies’ geospatial concepts (Ishikawa, 2016)

Gersmehl and Gersmehl (2007)	Janelle and Goodchild (2011)	Kuhn (2012)	Golledge, Marsh, and Battersby (2008a)
Location	Location	Location	Location
Aura	Network	Network	Link, (network)
Region	Neighborhood and region	Neighborhood	Buffer
Hierarchy			Area, cluster, (social region)
Transition			Central place, (hierarchical order)
Pattern			Change, growth
Association	Spatial dependence/ heterogeneity		Arrangement, distribution
	Objects and fields	Object, field	Interpolation, (similarity, correlation)
	Distance		Identity, space–time
	Scale	Granularity	Distance, proximity
		Event	Scale
		Accuracy	Identity, (occurrences)
		Meaning	(Data and representation)
		Value	(Time–space context)
Comparison			(Values)
Analogy			(Comparisons)
	Overlays		(Similarity)
			(Map comparisons)

Another overview of spatial concept frameworks can be found in SOLEM et al. (2014) in Table 3.

Table 3: Spatial Concepts Frameworks (Mohan, Mohan & Uttal, mentioned in Solem et al., 2014)

Learning to Think Spatially, NRC 2006	Building on work by Golledge et al. 1995, 2002, 2008a; Adapted by Jo and Bednarz 2009	Gersmehl and Gersmehl 2009, 2007, 2006	Janelle and Goodchild 2011	Cognitive Psychology (general reference; see Bednarz and Lee 2011; Golledge, Doherty, and Bell 1995)
<b>Concepts of Space</b> Primitives of identity Spatial relations  <b>Tools of Representation</b> Internal External  <b>Processes of Reasoning</b> Extracting spatial structures Performing spatial transformation Drawing functional inferences	<b>Spatial Primitives</b> Identity/Name Location Magnitude Time/Duration  <b>Simple Spatial Relationships</b> Distance Direction Connectivity and linkage Movement Transition Boundaries Region Shape Reference Frame Arrangement Adjacency Enclosure  <b>Complex Relationships</b> Distribution Pattern Dispersion/ Clustering Density Diffusion Dominance Hierarchy/Network Association Overlay/Layer Gradient/Profile/Relief Scale Projection Buffer	<b>Location</b> Conditions Connections  <b>Modes of Spatial Thinking</b> Comparison Aura Region Hierarchy Transition Analogy Pattern Spatial Association  <b>Spatio-Temporal Thinking</b> Change Movement Diffusion (expansion or contraction) Spatial Models	Location  Distance  Neighborhood and Region  Networks  Overlays  Scale  Spatial Heterogeneity  Spatial Dependence	<b>Visualization</b> Ability to mentally manipulate, rotate, twist or invert two- or three-dimensional visual stimuli.  <b>Orientation</b> Ability to imagine how a configuration would appear if viewed from a different orientation or perspective.  <b>Spatial Relations</b> 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.

## 5 SPATIAL THINKING TO GEOSPATIAL CRITICAL THINKING

### 5.1 Spatial thinking – critical thinking

Spatial thinking traditionally was linked to spatial visualization and orientation (McGEE, 1979; PELLEGRINO and KAIL, 1982), to spatial perception and mental rotation as integration in spatial visualization (LINN AND PETERSEN, 1987); to spatial relations, associations and spatial patterns (GILMARTIN and PATTON, 1984; SELF et al, 1992; ALBERT and GOLLEDGE, 1999). LEE and BEDNARZ (2009 and 2012) restate that spatial thinking is linked to spatial visualization in order to get a better interpretation of patterns of entities of the territory framework (associations, relations, connections or hierarchies).

SCHULZE et al. (2013) analysed the major dimensions connected with spatial thinking during the Spatial Citizenship project. They extracted and described seven interconnected competencies, critical thinking, geography, GIS knowledge and skills, problem solving, spatial thinking, teamwork and collaboration and visualisation and communication (Table 4).

Table 4: Domains connected with spatial thinking (after Schultz et al, 2013)

Competence areas	Description
Critical Thinking	Apply GIS critically and independently; use GI technologies as appropriate within applied context; identify effective application of GIS.
Geography	Geographic knowledge and understanding of the nature of geographic relationships, including changes, patterns, and processes.
GIS Knowledge and Skills	Acquire, manage, handle, manipulate, analyse and model; visualize and communicate spatial data and geographic information; knowledge of the concepts of GIScience.
Problem-Solving	Deal with real world problems applying geographic knowledge and understanding; develop problem-oriented knowledge and skills in GIScience.
Spatial Thinking	Fundamentals of spatial understanding, spatial analysis and application; performance of complex spatial analysis and modelling; present complex spatial information.
Teamwork and Collaboration	Participate in and use GIS within multidisciplinary teams and environments; cooperate with other specialists; manage and coordinate GIS projects.
Visualization and Communication	Represent and visualize of (geo)spatial data; effectively communicate geographic information to different target groups such as researchers, decision-makers, and the general public.

JOHNSON and SULLIVAN (2010) stated that spatial thinking will play a significant role in the information-based economy of the 21st century and BEVINGTON-ATTARDI and RICE (2015) added that technological transformations and changes due to new mapping tools and new sources of data, are altering educational aims and innovation contexts improving data analysis, data exploration, and user experience. KERSKI (2008a) comments that spatial thinking helps us make sense of spatial patterns, linkages, and relationships.

KERSKI (2008b) summarizes spatial thinking as the ability to study the characteristics and the interconnected processes of nature and human impact in time and at appropriate scales. In fact, this is real geography: be able to think critically about the earth, the activities of people and the

interaction between the two. Thinking spatially is more than knowing where things are located, it's about asking geographic questions: why there, how originated and what if...

BEDNARZ and LEE (2011) concluded in presenting their spatial thinking ability test (STAT) that spatial thinking is not a single ability but comprised of a collection of different skills, whereby following spatial thinking components emerge: map visualization and overlay, identification and classification of map symbols (point, line, area), use of Boolean operations, map navigation and recognition of spatial correlation.

Geodata quality and adequate representation allows critical thinking to be built in. Key questions and assessment features with clear guidelines facilitate this (RUSSEL, 2013) and critical spatial thinking. The assessment of the sources used can help to establish a critical approach to territory. In our daily lives direct observation on territory is a way to learn and build spatial thinking, but we can improve it with other ICT or GI (Geographic Information) technology tools in order to complete a spatial perspective. Critical thinking generally emphasizes the reflective evaluation processes regarding information, argument, and knowledge (KIM and BEDNARZ, 2013). Spatial questioning strategies are very important in its development (JO, BEDNARZ, and METOYER 2010).

Critical perspectives of spatial thinking are addressed by GOODCHILD & JANELLE (2010). They make the case that place has emerged as an important contextual framework for certain critical societal issues. So, they argue concepts of space and place, and space and time should be central themes in education, as part of a fundamental shift from disciplinary to multidisciplinary systems. The term 'critical' is described as a reflective and analytical approach, which can be related to the ways spatial tools and data are used to generate questions and provoke critical thinking. They suggest critical spatial thinkers will be able to recognise and understand the assumptions and limitations underlying spatial data, its representation and reasoning associated with it. Spatial technologies are perceived as an essential, integrating element that cut across disciplines through common language and concepts.

Criticality is central to engagement, participation and action. It is relatedly directly to concepts of spatial citizenship (GRYL et al., 2010). The concept of spatial citizenship was developed as 'smart' spatial thinking because it includes: i) deconstruction of spatial information from various sources; ii) establishment of personal visions of social space and iii) translating and communicating these visions with the help of geoinformation. Geo-media is used in a spatial citizenship context to help acquire instrumental knowledge and help find solutions to problems and understand more complex issues. Web 2.0 developments actively promote the importance of geo-participation and geo-communication.

## **5.2 Geospatial critical thinking**

KOUTSOPOULOS (2011) proposed an epistemological change had taken place in geographic disciplines, which is developing into a new scientific praxis, labelled by MORENO (2013) as a geotechnological-defined paradigm, as a new way of doing science. This is not only derived from technological advances, but also because of the huge increase in spatial data (big data, mining data and crowdsourcing data, among others) available to citizens whose knowledge on quality of data now appears to be essential (KERSKI, 2015). This scientific paradigm inspires the proper use of technologies, which in Geography can be translated into GIS technologies as a science, not only as an applied tool (teaching GIS) but for learning, teaching and researching: teaching with GIS (KOUTSOPOULOS, 2010). COOK et al. (2014) describe this as strategic spatial thinking, which is useful for drawing up plans or programs designed for achieving future goals and using available



resources. Developing a strategy enables the design of approaches that will help meet future challenges. This stipulates preparation and anticipation to reach an ideal but possible state. Therefore, how changes take place is decisive. Participatory processes are being increasingly encouraged, often based on visual access to knowledge that stimulates and develops attitudes and shapes participative behaviours leading to collective commitment (WANNAPA and SUPOL, 2012).

A geospatial focus, according to ROCHE (2014) includes not only geographical scales (local, municipal, regional, national and international) and spatial analysis and research, but also explicit GIScience and tools. This is not very different from the definition of spatial thinking proposed by the NRC (2006). Geographic skills provide necessary tools and techniques to think spatially. They enable us to observe patterns, associations, and spatial order. As described, “Geographic representations ... are essential because they assist in visualizing spatial arrangements and patterns” (NATIONAL GEOGRAPHY STANDARD, 2012).

KING (2006) draws attention to the fact that developing geospatial literacy is important and it should be based on certain spatial skills, which are not practical skills that can be easily taught, but that these skills exist as part of the student engagement in a learning process. This sequence of spatial competences includes:

- spatial orientation (the ‘where?’ component)
- thinking and acting (where is it in relation to?)
- the spatial process (or what changes are taking place?)
- the spatial systems (or how are they being affected?)
- the wider issues (or how does it connect beyond?)
- making decisions (or which solutions are there?) and
- how can I make a difference?

DONERT (2008) suggests these spatial skills should drive an active learning pedagogy where the exploration (of places) happens, measurements (associated with location) are collected, observations (of places) are made, information (about places) are attached to place marks, journeys and tours based on maps. These could be described as baseline components of strategic spatial thinking as COOK et al (2014) assume.

Spatial analysis and research with GIScience connects spatial problems and spatial relations to the Earth’s surface and its representation on conventional or digital and interactive maps in order to solve them (HUYNN and SHARPE, 2013). This requires the development and use of geospatial skills. LOBBEN and LAWRENCE (2014) organize this in a very similar way to Gersmehl and Gersmehl (table 1) with prime geospatial skills categories as: Location, Identity and Magnitude (including all spatial aspects) and Time.

Therefore, explicit GIScience methods and tools, linking reality with maps and technologies (Figure 3), geographic information, Global Navigation Satellite Systems (GNSS, such as the American GPS or in the future the European Galileo) and GIS are essential critical components, with important elements such as quality of geodata (geospatial data: aerial, satellite or crowdsourced) and interoperability as fundamental geospatial features.

All of them needs a smart focus, such as learning and acting smart, it means intelligent, personalized and significant. It is support by smart devices (phones or tablets among others) but also for humans who take the best services from devices.



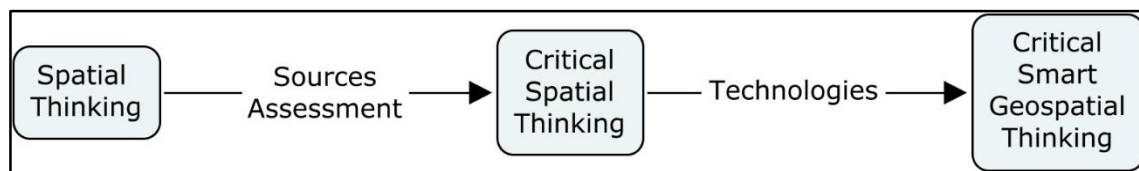


Figure 3: GIScience methods line. Its aim is to link Earth reality and virtual reality for spatial analysis in order to achieve the ability to solve spatial problems based on correct and wise decisions (Lázaro, 2015).

The topics and competencies necessary to help acquire critical and smart geospatial thinking needs also to be reviewed. Although GIScience methods are essential for learning, some years ago teachers' experiences didn't always concur with this point of view. We have summarized results of several teachers using GIScience at school in Table 5.

Table 5: GIScience for learning ( Lázaro, 2016)

Author	Year	GIScience experience results
Abbott Albert and Golledge	2001 1999	There are not many differences between students using GIS and those who do not.
Kerski	2000	Better results and skills to encapsulate, identify and discover territorial elements.
Hagevik	2003	It develops visualization skills and spatial territorial thinking.
Patterson, Reeve and Page	2003	Can develop students' critical spatial thinking (many other authors agree: Wigglesworth, 2003; Liu and Zhu, 2008; Milson and Curtis, 2009).
Lázaro and González	2005	The potential of GIS tools for learning is coming
National Research Council/ Committee on Support for Thinking Spatially	2006	GIS had a clearly demonstrated potential as a support system for spatial thinking.
Kidman and Palmer	2006	The technology is there but the teaching is yet to catch up.
Demirci	2009	Teachers in Turkey have developed a favourable attitude towards GIS, although they are still seeking opportunities to use it in their geography lessons. However, the study indicates that still need to overcome a number of obstacles ranging from lack of hardware and software to their lack of knowledge and skills about GIS.
Li et al.	2010	GIS and PBL develop analytical and evaluation skills of students.
Favier and Van der Schee	2012	Improve learning based on research projects, although teacher and student training is necessary to achieve learning tasks.
Kim and Bednarz	2013	Improve critical spatial thinking that curricula promote.
Buzo	2014	Students get actively involved in the learning process using

		technology, opening a different window to the world of knowledge and digital skills.
De Miguel	2014	Improve critical thinking, motivation and functionality of learning tools.
Esteves H.M. & Rocha J.	2015	It foster significant learning with tools that are also available in the world outside classrooms and that are being used by students in their daily life.

### 5.3 Participation and spatial citizenship

In schools GIS is often linked to computers and technical interests (HARVEY, 2014). Learning processes and knowledge strongly oriented towards technical interests largely produces instrumental knowledge. GRYL et al. (2010) comment on how the use of GIS at secondary school level is predominantly used as a support tool to encourage spatial thinking, but it should also be implemented to assist the development of citizenship. They suggest that this perspective is important as students can acquire a much broader set of competences with GI-based learning.

GRYL et al. (2010) recommend three main fields of competence (Figure 4) and further developed in Table 6.

- technical and methodological competences to deal with spatial information
- competences to reflect/ appraise/ evaluate spatial representations and
- competences to actively engage with the spatial dimensions of society and communicate meaning using spatial information in an informed way.

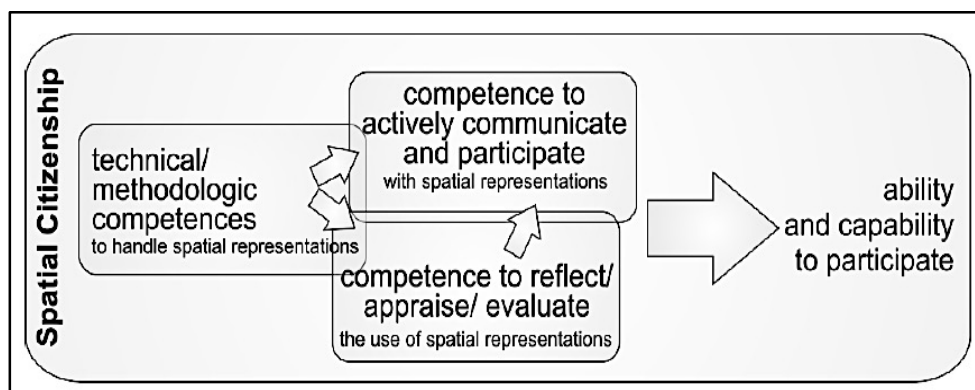


Figure 4: Competences for Spatial Citizenship (Gryl et al., 2010)

Table 6: Developing Competences for Spatial Citizenship (after Gryl et al., 2010)

Technical / methodological competences include i) map reading, orientation and navigation, finding one's place and identifying a destination, ii) the ability to label a feature, mark and rate a place or feature of interest, comment on alternative spatial scenarios; iii) contribute one's own data and iv) analyse and answer simple questions and fulfil single-step analytical tasks.

The competence to reflect, appraise and evaluate spatial representations concerns knowledge about geomedial construction; recognition of specific representations; comparison of geomedial

information order to detect limitations; deconstruction to identify intentions in the use of geomedia from multiple perspectives.

The competence to actively communicate and participate concerns construction of a process of meaning which involves democratic negotiation; expression by finding a way to convincingly communicate meanings; communication to share ideas and meanings for adoption; and dialogue to engage in, discuss, stand-up for and re-negotiate. This is an iterative non-linear process, which actively uses geomedia to further interests in democratic decision making.

The concept of spatial citizenship (ibid) was developed as 'smart spatial thinking' to address this because it includes: i) the deconstruction of spatial information from various sources; ii) an establishment of personal visions of social space and iii) being able to translate and communicate these visions with the help of geoinformation as Web 2.0 developments actively promote the importance of these geo-participation and geo-communication skills (Figure 5). Spatial citizenship education is thus about learning how to navigate our world in respect to a) the physical world, b) the meanings attached to physical objects and the environment and c) the power relations involved in the production of meaning.

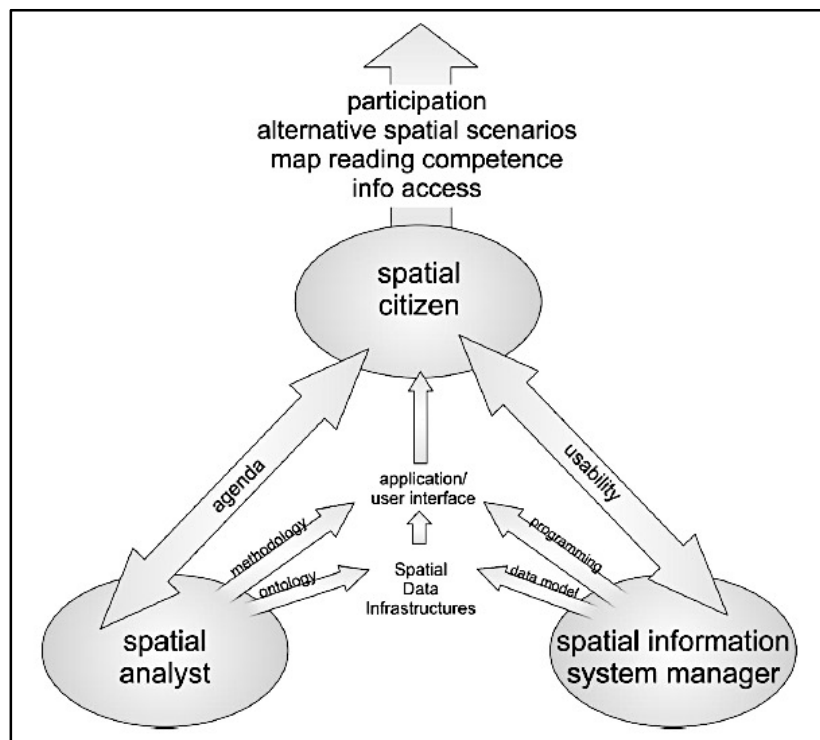


Figure 5: Spheres of activities/roles regarding geoinformation (Gryl et al., 2010)

GIS, used in a spatial citizenship context, encourages instrumental knowledge to be acquired, but also helps find solutions to problems and understand more complex issues. GRYL et al. (ibid) advocate for a more participative approach to using GIS in school education, one that explores the competences needed for active and critical participation in society using spatial media.

## 6 INTEGRATING GIS AS TOOL FOR GEOSPATIAL CRITICAL THINKING

### 6.1 GIS in education

Mapping can be an effective method for communicating large volumes of data to others. However, the effectiveness of communication with maps is dependent on the spatial literacy of the observer (CLAGETT, 2009). GIS plays an important role in acquiring Geographic Information Literacy. Sharing geographic literacy (knowledge about geography) with information literacy (information search strategies, critical evaluation of sources) leads to Geographic Information Literacy (Figure 6): the possession of concepts, abilities, and habits of mind (emotional dispositions) that allow an individual to understand and use geographic information properly and to participate more fully in the public debate about geography-related issues (MILLER and KELLER, 2005).

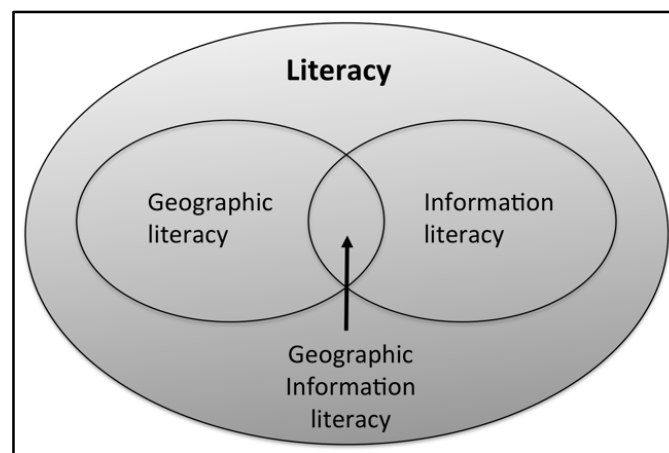


Figure 6: Contextual diagram for geographic information literacy (Miller and Keller, 2005)

When referring to GIS the term '*Geographic Information System*' is mostly used, defined as a set of computer technologies that allow visualizing and manipulating of geodata in an easy graphical method. But GIS has also been called '*Geographic Information Science*' (GOODCHILD, 1992), thus also involving scientific methods and approaches of looking at and understanding the world (MILSON, 2012), whereby GIS is used to help obtain spatial thinking skills.

FREEMAN (1997) stated 'changes in technology pervade the pedagogy and methodology of geography' so with the possibilities offered to use GIS nowadays (free software, available datasets, computers with internet common) we can now longer ignore the use of it in education'. KOUTSOPOULOS (2010) mentions two approaches for using GIS in education:

- We can use the powers of GIS to teach geography for it can help us understand our world through both the natural and the man-made manifestations which are the essence of geography.
- In teaching with GIS a positive effect can be created on the development of spatial thinking and reasoning.

THOMPSON (1991) suggests that GIS is an 'educational delivery system for improving the student's knowledge of the world in which she or he lives.' GIS is able to answer all the questions

that knowledge, understanding and application in geography education requires (KOUTSOPOULOS, 2010). Thus 'GIS can be defined as the study of the fundamental issues of geographic information, and is often motivated by the need to improve geographic information technologies' (GOODCHILD, 2011).

Because of its capabilities, GIS is inherently an excellent vehicle in expressing the five themes of geography, as defined by THE JOINT COMMITTEE ON GEOGRAPHIC EDUCATION (1984): location, place, relationships with places, movement and region. NIELSEN et al. (2011) advocate for a stand-alone K–12 curriculum for geospatial technology and spatial thinking and discusses its development in an experimental teacher education institution. The focus of the course was in building students' knowledge and skills in geospatial technologies, making student teachers aware of their spatial thinking skills, offering opportunities to use tools to solve community issues. They start by not using technologies, including readings and sequencing and strategy games. Through this they develop an initial understanding of spatial thinking by reflecting, observing, comparing, and practicing spatial thinking skills. They then learned to use geospatial technologies, sources of data and transforming primary data into maps and other graphical representations, GIS and GPS followed and then using the guidelines of ESRI's "Community Atlas", students created a general atlas of the community. After evaluation, they recommended a course with prescribed activities, foundational concepts and simple skills, which then requires students to design a real-world project that investigates their community. The latter gives students control of their education and fosters an environment of learning that will serve them well.

A habit of mind can be described as the broadest learning outcome which is sometimes based on ways of thinking. KIM and BEDNARZ (2013) used this to identify and defined five subdimensions of spatial habits of mind. These were pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use (Table 7).

*Table 7: Five spatial habits of mind (after Kim and Bednarz, 2013)*

<b>Pattern Recognition</b>	students should be taught and encouraged to foster their spatial habits to recognize patterns in their everyday life	extension: "recognize, describe, and predict spatial patterns"
<b>Spatial Description</b>	Students can use spatial vocabulary proficiently	extension: a more advanced spatial lexicon and more frequent use of spatial vocabulary
<b>Visualization</b>	Students increase understanding through the aid of graphical representations	extension: enhance comprehension by converting the information into visual representations, understand the benefit and power of graphic representations
<b>Spatial Concept Use</b>	Students use or apply spatial concepts to understand and perform various tasks	extension: employ spatial concepts to understand surroundings
<b>Spatial Tool Use</b>	Students use spatial representations and tools to support spatial thinking exposure to tools helps understand space and	extension: spatial thinkers using spatial tools to solve problems



	develop spatial cognition	
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KIM and BEDNARZ (ibid) then created an inventory to measure these sub-dimensions (Table 8) and tested it to assess whether the development of Spatial Habits of Mind can be enabled through GIS learning.

Table 8: A spatial habits of mind inventory (Kim and Bednarz, 2013)

Item #	Test items by dimension	Factor loading (SE)
<b>Pattern recognition</b>		
1	I tend to see patterns among things, for example, an arrangement of tables in a restaurant or cars in a parking lot.	.28 (.07)
2	I tend to see and/or search for regularity in everyday life when viewing objects or phenomena.	.31 (.07)
3	I do not pay attention to reading and interpreting spatial patterns such as locations of cars in a parking lot.	.59 (.07)
4	When I use maps to find a route, I tend to notice overall patterns in the road network.	.66 (.08)
5	I am curious about patterns in information or data, that is, where things are and why they are where they are.	.63 (.07)
6	When I use maps showing things such as population density, election results, or highways, I try to recognize patterns.	.67 (.07)
<b>Spatial description</b>		
7	I rarely use spatial vocabulary such as location, direction, diffusion, and network.	.82 (.08)
8	I use spatial terms such as scale, distribution, pattern, and arrangement.	.80 (.08)
9	Using spatial terms enables me to describe certain things more efficiently and effectively.	.67 (.06)
10	I have difficulty in describing patterns using spatial terms, such as patterns in bus routes or in the weather.	.44 (.06)
11	I tend to use spatial terms such as location, pattern, or diffusion to describe phenomena.	.76 (.07)
<b>Visualization</b>		
12	When I am thinking about a complex idea, I use diagrams, maps, and/or graphics to help me understand.	.63 (.07)
13	It is difficult for me to construct diagrams or maps to communicate or analyze a problem.	.62 (.07)
14	When a problem is given in written or verbal form, I try to transform it into visual or graphic representation.	.46 (.07)
15	When I assemble something such as furniture, a bicycle, or a computer, written instructions are more helpful to me than pictorial instructions.	.20 (.08)
16	I find that graphs, charts, or maps help me learn new concepts.	.47 (.05)
17	It is helpful for me to visualize physical phenomena such as hurricanes or weather fronts to understand them.	.56 (.06)
18	I like to support my arguments/presentations using maps and diagrams.	.60 (.06)
19	I like to study data or information with the help of graphics such as charts or diagrams.	.65 (.06)
<b>Spatial concept use</b>		
20	When trying to solve some types of problems, I tend to consider location and other spatial factors.	.54 (.07)
21	I have difficulty in explaining spatial concepts such as scale and map projection to my friends.	.61 (.08)
22	When reading a newspaper or watching news on television, I often consider spatial concepts such as location of the places featured in the news story.	.49 (.07)
23	Spatial concepts, such as location and scale, do not help me solve problems.	.60 (.06)
<b>Spatial tool use</b>		
24	I use maps and atlases (including digital versions) frequently.	.77 (.09)
25	I do not like using maps and atlases (including digital versions).	.81 (.08)
26	I enjoy looking at maps and exploring with mapping software such as Google Earth and GIS.	.66 (.08)
27	Activities that use maps are difficult and discourage me.	.56 (.06)
28	I like to use spatial tools such as maps, Google Earth, or GPS.	.47 (.08)

Source: Kim (2011, 107-108)

NEWCOMBE and SHIPLEY (2015) identified five classes of spatial skills on which training research has been done to classify spatial abilities (Table 9). They identified an intrinsic-static skill (disembedding), two intrinsic-dynamic skills (spatial visualization and mental rotation), one extrinsic-static skill (spatial perception) and one extrinsic-dynamic skill (perspective taking). They envisage this process

Table 9: Organising spatial skills (Newcombe and Shipley, 2015)

Outcome category	Description
<b>Disembedding</b>	Perceiving objects, paths, or spatial configurations amidst distracting background information.
<b>Spatial Visualization</b>	Piecing together objects into more complex configurations or visualizing and mentally transforming objects, often from 2D to 3D or vice versa.
<b>Mental rotation</b>	Rotating 2D or 3D objects
<b>Spatial Perception</b>	Understanding abstract spatial principles, such as horizontal invariance or verticality
<b>Perspective Taking</b>	Visualizing an environment in its entirety from a different position

TSOU and YANOW (2010) consider General Education undergraduate courses, where the main goal is to equip students with a spatial literacy foundation (including spatial awareness and spatial and quantitative reasoning methodologies) so students can discover the value of geographic knowledge and develop their ability to explore and visualize real-world, critical problems such as global climate change, natural disaster recovery and responses, and watershed conservation.

They argue that with a solid foundation in spatial literacy, students will be better prepared to consider the crucial scientific and social questions of the 21st century and suggested an education model with five major teaching components to support the learning objectives effectively and provide pedagogical guidelines for teaching (Figure 7).

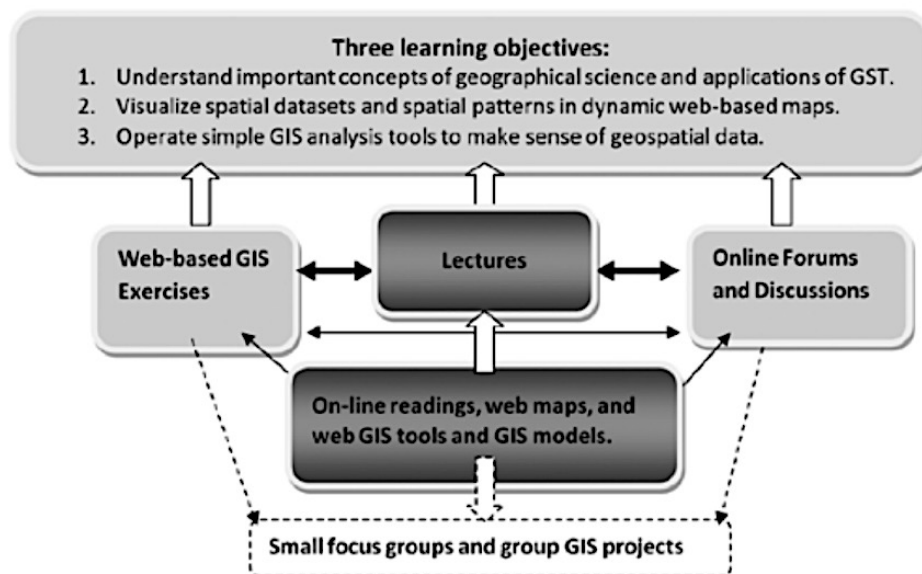


Figure 7: A conceptual education model of GIS and Technology for general education (Tsou and Yanow, 2010)

KOUTSOPOULOS (2010) developed a conceptual framework for using GIS. For his idea he uses the GEOGRAPHIC EDUCATION STANDARDS PROJECT (GESP, 1994), stating that geography is composed of three components: skills, subject matter and perspectives whereby all three are necessary to be 'geographically informed' and thus should be examined (Figure 8). In this respect:

- Geographic skills are a series of tools and techniques, including asking geographic questions, acquire and organize spatial information. The purpose is mainly focused on the level of knowing ("where is it?"), although some questions will lead to the process of understanding ("why is it there?") or even applying ("what if ...?").
- The subject matter is divided - according to GESP - into six "essential elements". Most of these refer to the process of understanding.
- A geographic perspective is a lens through which geographers look at the world. It involves the ways that knowledge and understanding can be used to solve geographic problems (process of applying). The specific aspect of geography – linking human and physical systems in a spatial lens – provides everything to solve spatial problems by active participation.

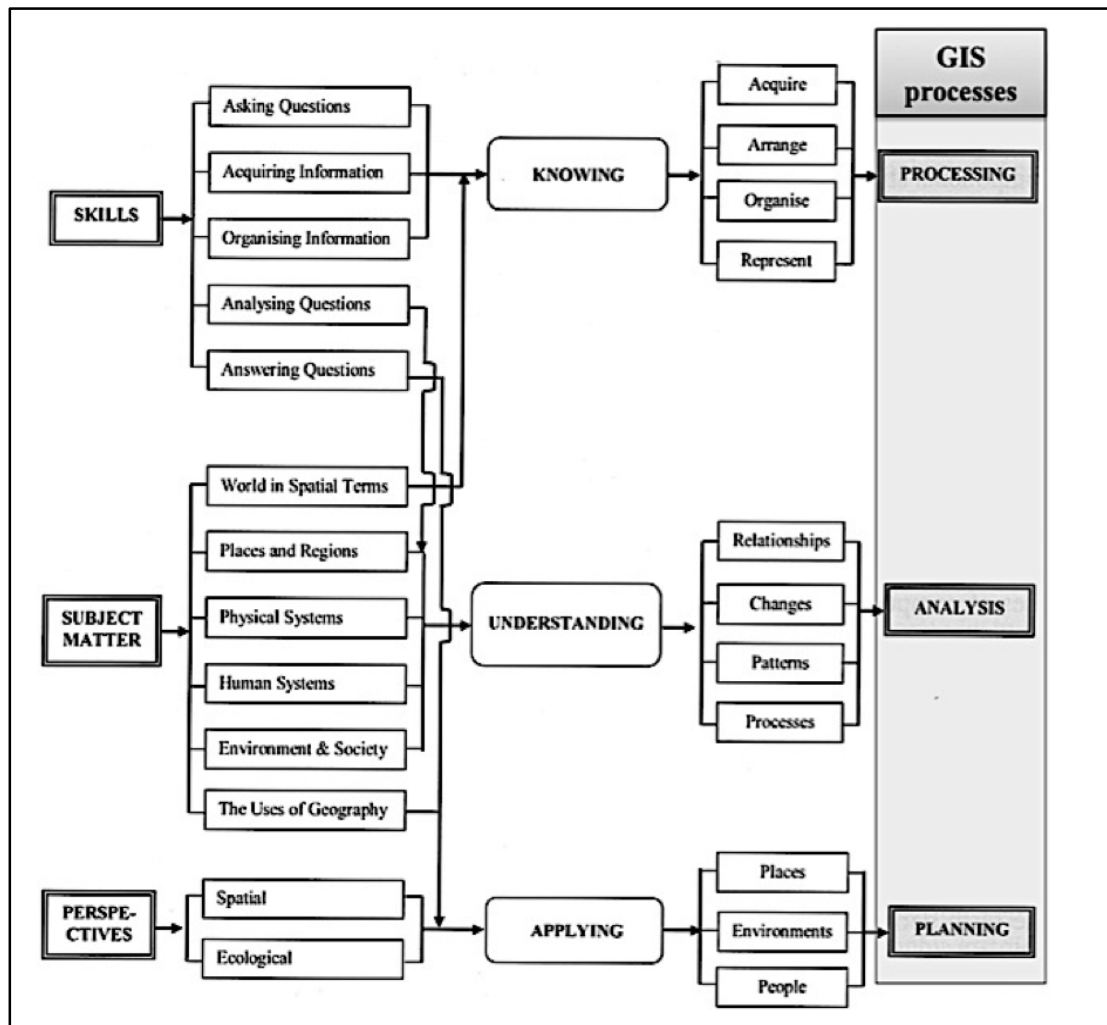


Figure 8: Linking the science of geography to GIS – instructing with GIS (adapted from Koutsopoulos, 2010)



Geographic skills, subject matter and perspective correspond to the processes of knowing, understanding and applying: by “learning the concepts and vocabulary of geography (knowing) students may begin to think about what they mean (understanding) and apply to real problems (applying)” (NAEP GEOGRAPHY CONSENSUS PROJECT, 2010). Knowing is in spatial terms expressed by the questions ‘What is it?’ and ‘Where is it?’, in GIS this means processing spatial data. Understanding is expressed by questions such as: ‘Why is it there?’, ‘What has changed?’, ‘What is the pattern?’, ‘What is the interaction?’, in GIS this is spatial analysis. Applying is expressed by the question ‘What if ...?’ to solve spatial problems, in GIS this means planning.

KOUTSOPOULOS (2010) then linked the three GIS processes with the questions and the five themes of geography – created by the JOINT COMMITTEE ON GEOGRAPHIC EDUCATION (1984): location, place, relationship with places, movement, and region (Figure 9).

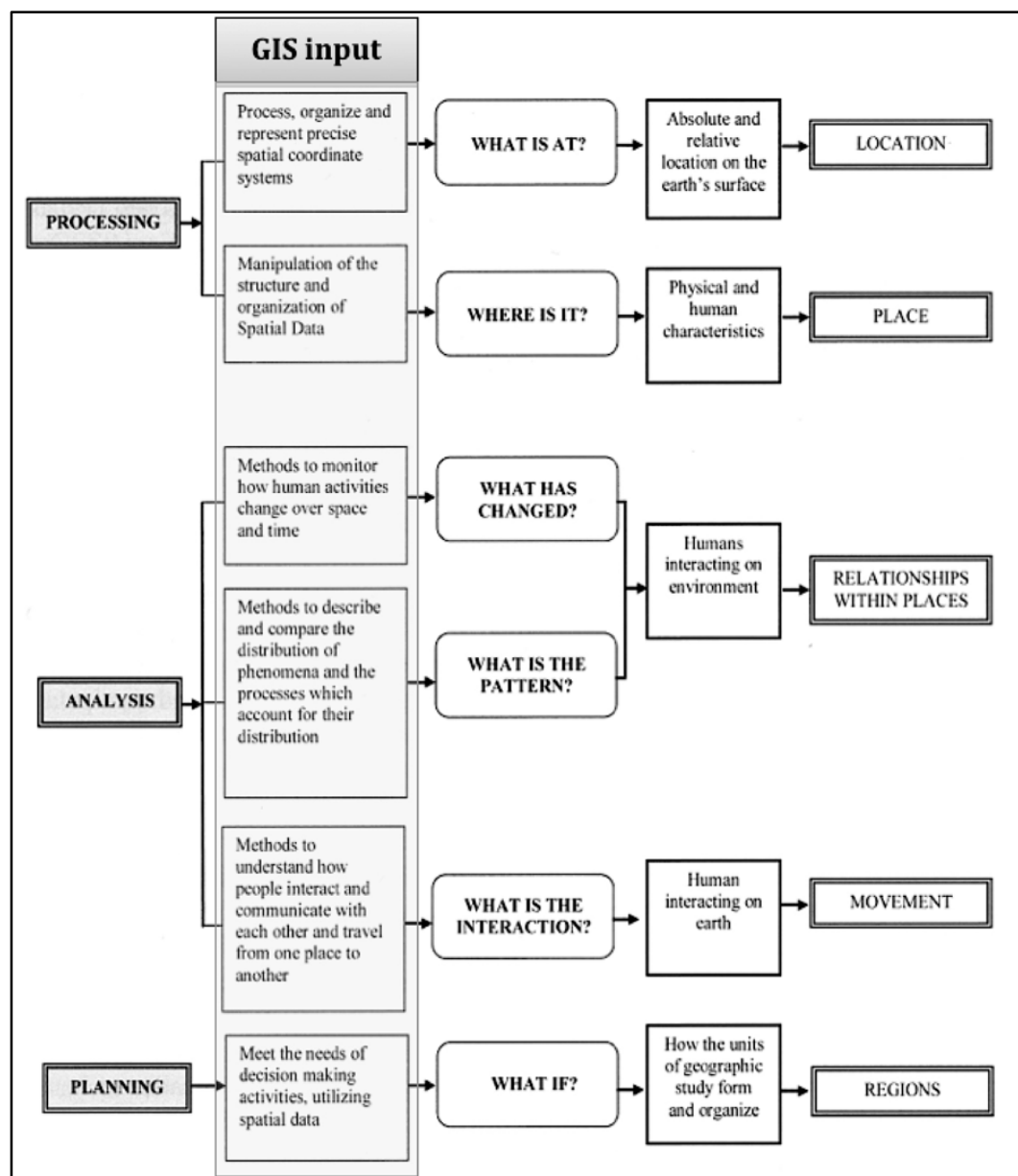


Figure 9: A conceptual framework in Instructing about GIS (adapted from Koutsopoulos, 2010)

His framework shows very clearly the impact and importance of GIS in answering the questions on the level of the three processes. He results that “GIS can serve as a unique educational tool in

which the manipulation, analysis and presentation of spatial data can support the teaching of geography” (KOUTSOPOULOS, 2010).

More specifically, typical spatial thinking skills are enhanced using GIS. By involving student activities using GIS “students not only learn by hearing and seeing, they also have the ability and opportunity to personally apply the knowledge using higher-order skills such as problem solving and synthesis” (SANDERS, 2002) In order to foster such skills teachers and students may need to work in new ways such as through enquiry based methods and problem-based learning.

The approach developed by Koutsopoulos follows one of the four GIS schools described by KEMP (1992, quoted in SUI, 1995, Figure 10): GIS as an enabling Technology for Science, arguing that GIS is not a goal in itself but a means to use spatial thinking skills.

<b>Implications for GIS Instructional Approaches</b>			
<i>Relationship between Geography and GIS</i>	<i>Instructional Focus</i>	<i>Course content</i>	<i>Format of delivery</i>
<b>Geography as home discipline of GIS</b>	education	application	combination of lab and lecture
<b>GIS as a collection of marketable skills</b>	training	technical	lab
<b>GIS as a new tool for spatial science</b>	training	application	lab
<b>GIS as a new discipline</b>	education	technical	lecture

*Figure 10: Four schools of thought about the relationship between geography & GIS (Kemp. et al, mentioned by Sui, 1995)*

Two of the four schools describe the ideal vision for secondary education:

- The first schools stating that Geography is uniquely suited as the home discipline of GIS. It simply automates the tasks geographers have been doing for several thousands of years, and aims at a full integration of GIS into all aspects of geography curriculum.
- The third school seeing GIS as the tool to support scientific inquiry as ultimate goal in a variety of disciplines, thus GIS is as enabling tool for science.

Both put the emphasis of the course content on application – GIS as a tool, whereas the two other schools are focusing on the technical aspects of GIS.

Generally speaking, geospatial technologies can be used to ask or answer different sorts of spatial question, which can be related to many different study areas. It helps foster geographic skills, knowledge, and understanding by developing the spatial thinking capabilities of students. The prevalence of GIS technology is thus a solution to the need to develop spatial skills and being able to reason spatially.

It is this multiple functionality that makes GIS an excellent component to learn according the TPCK framework as described by MISHRA and KOEHLER (cited by FAVIER et al, 2012): ‘the knowledge a teacher should have about how to use technology in instruction in such a way that students develop knowledge and skills in a certain domain’. The TPCK framework is added with the GIS component in his GIS-TPCK framework approach (Figure 11).

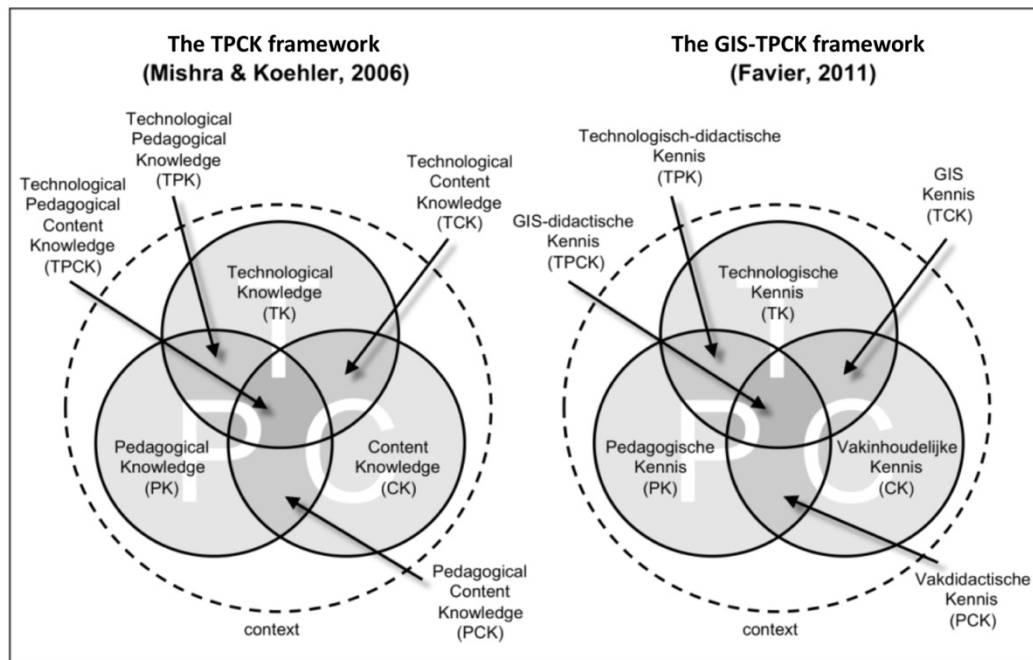


Figure 11: The general TPACK model (left) and the GIS-TPACK framework (Favier et al., 2012)

## 6.2 Integrating geospatial thinking in GIScience for secondary school students using GIS

The introduction of GIS in education has been argued by three complementary rationales that correspond to GIS's strengths:

- The educative rationale: GIScience and GIS support the teaching and learning of geography.
- The place-based rationale: GIS is the ideal tool to use to study geographical problems at a range of scales.
- The workplace rationale: GIS is an essential tool for knowledge workers in the twenty-first century.

VAN LEEUWEN and SCHOLTEN (2009) see an added value of using GIS based on five senses:

- Sense of reality: using realistic data – e.g. of the own environment - makes abstract spatial theories become real
- Sense of urgency: by using realistic data and thematic items students get interested.
- Sense of experience of having influence: using GIS students get the opportunity to visualize a today's and tomorrow's landscape, influenced by (their) own decisions
- Sense of fun: people learn more easily when they are enjoying what they are doing and using GIS is fun when the tools are easy, interesting data is available and the case study is exiting.
- Sense of location: by using GIS in combination with GPS routes, tracking and tracing games or doing field work gives an extra dimension, location (x,y,z coordinates) becomes an exciting thing to explore.

These arguments have not appealed to large numbers of teachers however. According to the research of BEDNARZ and VAN DER SCHEE (2006) the main reasons are:

- In teacher training (pre-service and in-service) GIS is not a core item.

- Non-geographers, leading to teachers with limited pedagogical content knowledge, resulting in fewer teachers recognizing the potential opportunities GIS offers to teach geography content and skills, teach more and more geography.
- The curriculum doesn't include or impede adoption to include GIS.
- The availability of free data and easy-to-use software.
- The attitude of teachers. It seems difficult to persuade teachers to use new technologies, certainly if they are highly technical demanding and if teachers are not fully convinced of the effectiveness and added value.

They made three recommendations,

1. Address the key internal issues related to GIS implementation: teacher training, availability of user friendly software, ICT equipment in schools

This was a matter of developing easier to use software with data access. As GOODCHILD (2011) concludes in his analysis of GIS software programs: "the GIS user interface remains complex, hard to learn and use, and lacking in any consistent conceptual or theoretical framework."

A lot of progress has been made. There are free GIS viewers (no need to install software) or open source full GIS software programs available. Schools are nowadays well equipped with computers and a high speed (mobile) Internet. As a result of the INSPIRE directive more and more governments are offering datasets (for free) or provide open access to database servers. In different countries specific educational GIS-frameworks have been developed, like EduGIS in the Netherlands (VAN DER SCHEE et al., 2006), the Pairform@nce Project in France (GENEVOIS, 2011) or PaikkaOppi in Finland (Houtsonen et al.: 2014). These learning environments offer a simplified viewer – mostly inside a browser – with content that fits into the existing national curriculum.

2. Use a community of learners approach.

A community of learners means bringing together within a school or school region all involved and crucial stakeholders in the educational process. Together they reflect and act upon best practices. Although this is a much praised and effective method, reality shows that certainly in secondary education this is not always working.

The Digital-Earth.eu network has launched in many countries 'Centre of Excellence'. These centres will help building up the community of geomedial learners, e.g. by collecting and disseminating good practice examples, organizing informal sessions with teachers.

3. Institutionalizing GIS into curricula, making sure that it is aligned with significant general learning goals like graphicacy, critical thinking and citizenship skills.

This is also mentioned by The National Academy of Science (DOWNS et al. 2006) who stated as one of the primordial recommendations the development of spatial thinking standards and curriculum material.

FAVIER (2013) describes five ways on how GIS can be integrated in secondary education (Figure 12). Teaching and learning about GIS focuses more on the theoretical aspects of GIS (knowledge of GIS, structure of the technology), where the three other ways use the technology to develop and use spatial thinking skills.

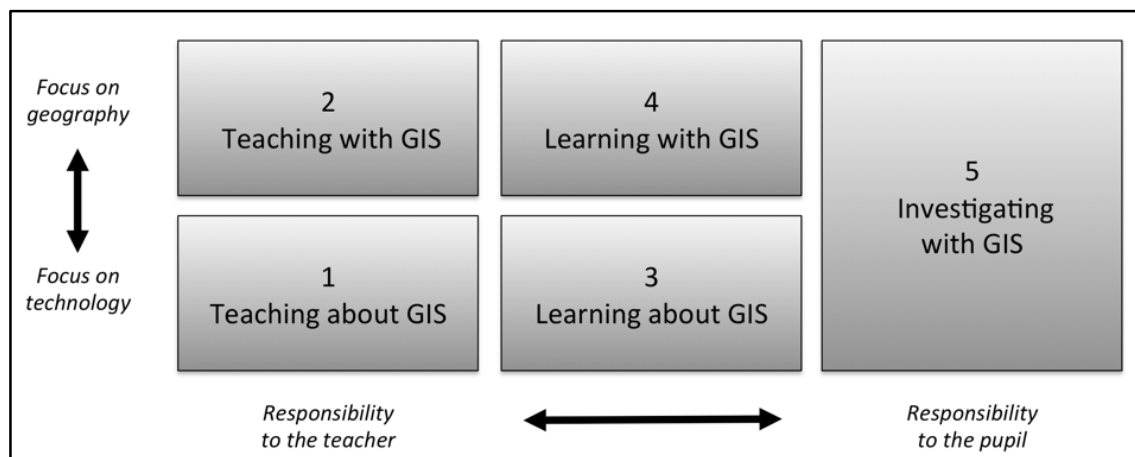


Figure 12: Five ways of integrating GIS in geography education (Favier, 2013)

Research shows that most ‘successful’ and easiest integration of GIS is done in ‘Investigating with GIS’, where students are asked to do a real geographic enquiry. LIU and ZHU (2008) explain this by linking GIS to constructivism. Geography enquiry draws on constructivism, emphasizing problem-solving and inquiry-based learning instead of instructional sequences for learning content skills. And GIS provides useful tools for constructing a computer-based constructivist-learning environment for geography education.

Without questioning the importance of this we must nevertheless try to generate a more continuous integration of GIS in education, using all five ways. The Irish pilot project ‘GIS into schools’ is a good attempt to create and test curriculum materials for teaching GIS principles and practice (TSCHIRNER and O’BRIEN, 2006). They indicate – just like KOUTSOPOULOS (2010) and FAVIER (2013) - to achieve an overall integration of GIS that students first need to learn about GIS (theory and practice) and then apply this knowledge to learn with GIS. The Irish example used several geography curricula based topics and is thus not really integrated over the different years of the curriculum.

### 6.3 Creating GIS learning outcomes through education

The Special Interest Group 3 of the Digital-Eath.eu network (WOLOSZYNSKA et al. 2013) see the importance of introducing GIS (use of geo-media) for three competences (Figure 13):

- Personal competencies:  
Developing spatial literacy assumes interaction with geoinformation. A geographic approach is necessary to answer questions critically and constructively. Therefore, teachers must understand basic geographic concepts and be able to support students’ learning needs. Employability is enhanced by geo-media skills.
- Social competencies:  
Education for active citizenship equips people with the content knowledge, skills and understanding to play an effective role in society. They become interested in controversial issues and engaged in discussion, debate and decision-making. Therefore, education for spatial citizenship plays an important role for the learning process. To enable teachers to bridge the technological gap between students and themselves, they need to use geo-media in the classroom to allow learners to explore real world issues and encourage lifelong learning strategies.
- Professional competencies:

Geo-media brings the real world into the classroom. Constructive and active learning practices like problem solving, project-based learning, fieldwork strategies and enquiry approaches are favoured and will help them to face future challenges.

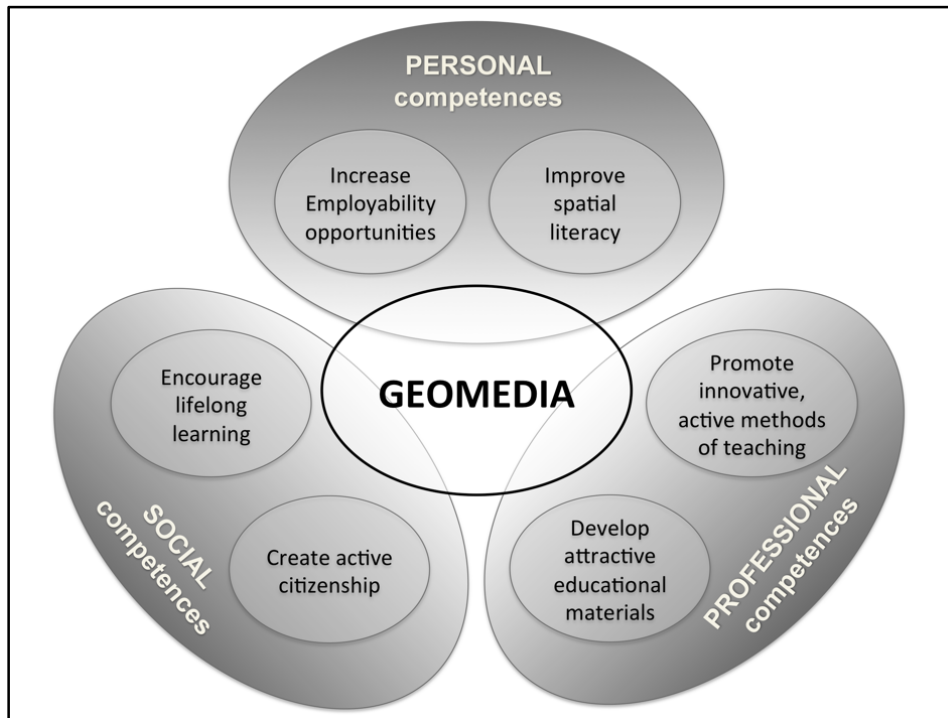


Figure 13: Why geo-media in teacher training (Woloszynska et al. 2013)

Therefore, teachers must understand basic geographic concepts and be able to support students' learning needs. Taking in account the different levels of age and education, teachers must be enabled to apply different methods and tools in the respective learning environments.

To help a benchmark has been developed<sup>1</sup>, indicating the competencies needed for spatial literacy.

#### Competencies:

- Spatial thinking
  - To know concepts of spatial thinking
  - Be able to use tools of spatial representation,
  - To apply processes of reasoning (Where is it? Why is it there? What if it was somewhere else? Making informed decisions and defend personal points of view)
- Pedagogic and didactical skills for the use of digital earth tools in school
- Ability to use spatial skills in real world problem-solving context
- Understanding complex and changing interrelationships
- Awareness and understanding for the digital earth concept
- Ability to use digital earth tools (also technological skills)
- Lifelong learning competencies: ability to find training opportunities, time management, planning competency, communication competencies

<sup>1</sup> This benchmark statement has been produced as a result of the digital-earth.eu COMENIUS network SIG 3 (Teacher education and teacher training) meeting in Brugge, Belgium in October 2011  
[www.digital-earth.eu](http://www.digital-earth.eu)

- Being able to identify and evaluate resources
- Social learning:
  - Being able to work with others – teamwork
  - Use professional social networks (virtual and face-to-face)

In order to prepare teachers to effectively implement digital earth in their practice, teacher training and teacher education needs to appropriately prepare teachers for different levels of education.

*Primary school teachers need to be able to enable students (year 1-6) to*

- Open digital maps and virtual globes on a computer
- Indicate the different parts of digital maps/virtual globes (navigation bar, menu, scale, map window)
- Interpret symbols on digital maps
- Work with digital maps and 3D representations of the world
  - Find significant locations (their home, school or town) on a virtual globe
  - Pan, zoom, orientate
  - Make measurements
  - Use the layers to focus on specific features
  - Update maps
- Be aware of generalization levels applied in different zoom levels (e.g. road density)
- Access information efficiently and effectively, evaluate information critically and competently (see maps as manipulated representations created by people/organizations with a certain purpose, e.g. classification methods, colour schemes, map contents)
- Use digital maps and virtual globes for a variety of different purposes

*Secondary school (year 7-12)*

In addition to the learning outcomes of primary school, secondary school teachers need to enable their students to

- Know the digital earth concept and its tools
- Understand the basic purpose and application of digital earth to real world problems
- Be able to gather and evaluate information
- Use advanced digital earth tools for learning (starting with Web-GIS, GIS viewers to GIS software)
- Manipulate maps
  - Display information on maps
  - Create own maps
  - Communicate cartographic information
- Understand the construction of digital maps as a representation of the real world
  - The power of maps (reliability of data, classification and colour schemes)
  - Topology: points, lines, polygons
  - Layers
  - Database
- Know about the professional use of GIS and other digital earth tools
- Gather information from data resources or through fieldwork activities (use GPS devices, mobile applications)
- Use digital earth tools for investigation/research

- Interpret content
- Identify and ask significant questions that clarify various points of view and lead to sustainable solutions
- Frame, analyse and synthesize information in order to solve problems and answer questions.

## 6.4 Some initiatives on geospatial critical smart thinking for students at school

Empirical research that explicitly examines the role of GIS in promoting critical spatial thinking is lacking (HALL-WALLACE & McAULIFFE, 2002). Nowadays an increased number of studies and initiatives around the world on geospatial critical and smart thinking have been created for secondary and high schools. MILSON, DEMIRCI and KERSKI (2012) give a vision of 27 countries and after a comparative study among 33 countries (KERSKI et al, 2013).

We can here stress some of the most recent and successful initiatives such as “Geospatial Semester” promoted by James Madison University, USA (KOLVOORD, 2012) (<http://www.isat.jmu.edu/geospatialsemester>), or the Finnish experience of teaching and learning using the PaikkaOppi learning environment (<http://www.paikkaoppi.fi/>). The Finnish initiative shows the suitability of the Spatial Data Infrastructures (SDI) for school uses (Houtsonen et al.: 2014). The main problem is to adapt the geodata information to visualisation adapted to pedagogic content. GONZÁLEZ (2012) advises the use of SDI and PBL in secondary schools after GRANEL, MANSO and others work (2009). LÁZARO et al (2015) improve the idea using SignA, the natural node of SDI in Spain, a GIS of the Spanish National Geographical Institute (Potti et al., 2011).

Active inquiry methods for outdoor activities can be used when learning geography with web maps, through navigation and using interactive maps as storytellers. These are school practices identified by LÁZARO et al (2008, 2013, 2016), by BUZO (2014, 2015) (Figure 43 and Table 10) and by DE MIGUEL et al. (2015) with the Digital School Atlas initiative and the ArcLessons available on: <http://atlas.digitalescolar.es>.

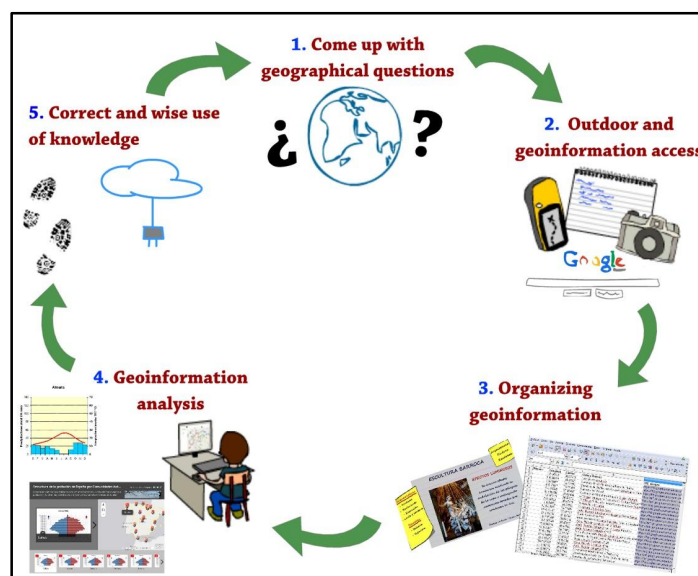


Figure 14: GI science for learning (Buzo, 2015)



Table 10: Spatial projects in IES San Roque School (Buzo, 2015)

Programme	2013/14 Year	2014/15 Year
Innovation Educative Projects	GISWeb in Geography (3rd year of secondary school)	Project Based Learning (PBL) for spatial thinking in Geography (2nd year bachelor).
R&D and innovation School Programs	Environmental reality analysis and improvement proposals in the town of Badajoz.	Physical exercises in Badajoz public spaces.
Social support network and educative innovation: Extremadura network of innovative education.		Spatial thinking as the foundation for scientific knowledge.

As a result of these and other innovative developments, WOLODTSCHENKO (2012) suggests that the traditional maps have lost their monopoly position in communicating geospatial information, now sharing it with digital interactive cartography. In order to take advantage of critical cartography, teacher education is essential to support critical and smart geospatial thinking and geospatial literacy based on a pedagogical content knowledge.

GIS technologies are important in teacher education, but for building GIScience for schools, a new approach to spatial problems in the 21st century. The results of SHIN, MILSON and SMITH (2015) indicate that additional attention is needed to spatial thinking in teacher preparation programs. The efforts undertaken to improve the preparation of future geography teachers should include explicit attention to spatial concepts, spatial reasoning processes, and spatial representations (JO and BEDNARZ 2014). Further empirical research is needed to improve teacher's education for the wider use of GIScience at schools. This does not mean teaching GIS, it means learning and teaching with GIS (FAVIER, 2013). KOUTSOPOULOS (2011) has stressed how useful GIS is in answering questions on knowing, understanding and solving territorial problems.

The benchmark created by the Digital Earth project was a first step towards integrating GIS in school and college education. When combining this with the concept of learning lines we can construct the content depending of the pupil age. With input from others this might lead to a real curriculum reform (ZWARTJES, 2014).

## 7 TAXONOMY INITIATIVES TO EVALUATE SPATIAL THINKING COMPONENTS

JARVIS (2011) considers the term spatial thinking to be a very broad subject but integral to the process of spatial literacy acquisition. In order to bring order to the task, her initial focus was on highly visual and non-mobile contexts for spatial thinking. To do this she examines the process of spatial literacy via spatial thinking dependant on three components, abilities, strategies and knowledge (Figure 15). Fostering an ability to make the links between space, representation and reasoning (or to think spatially) is central to spatial literacy. She says that In educational terms, the fact that spatial literacy is so integral to Geography in particular may result in it being being neglected.

She offers a meta framework for spatial literacy, adapted from other authors, for GI Science. In terms of the types of representations, transformations and complex thinking, it includes i) Representations: The Properties of Entities; ii) Comparisons: The Relations Between Static Entities; iii) Comparisons: The Relations Between Dynamic Entities; iv) Transformations of Representations of Entities and v) Complex spatial reasoning: Combining components to solve questions.

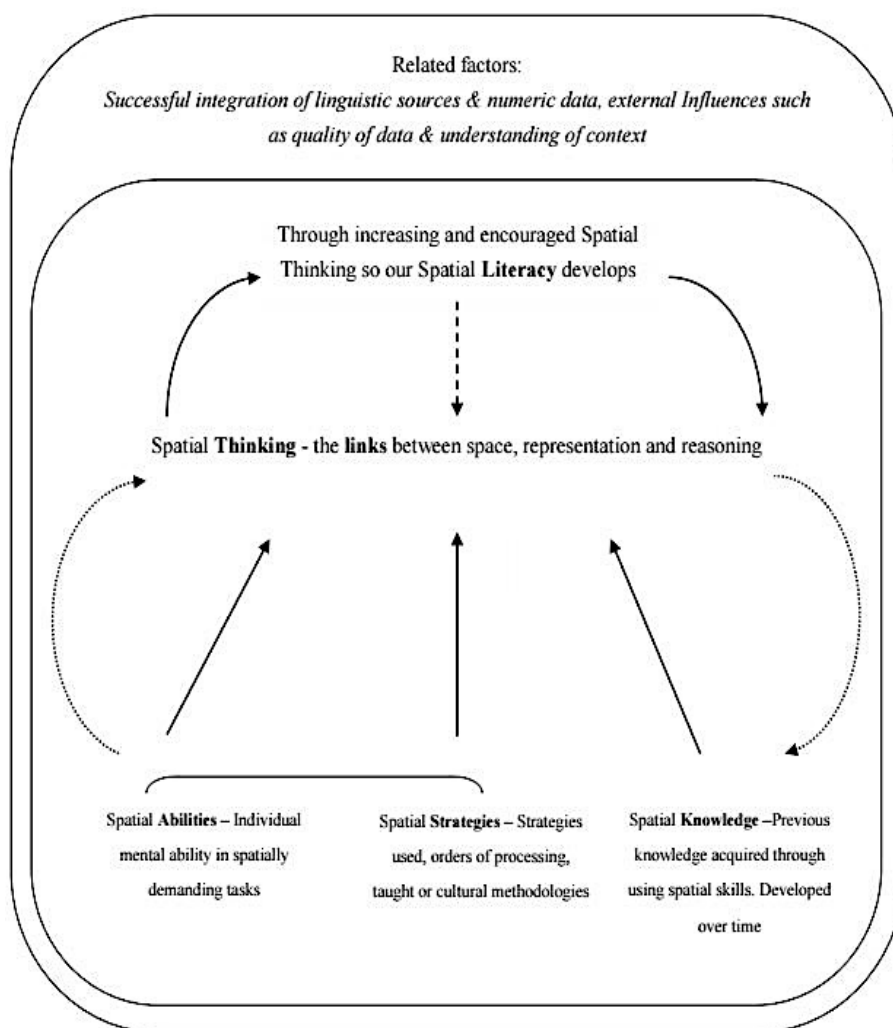


Figure 15: The process of, and constituent parts of, spatial literacy (Jarvis, 2011)

JO and BEDNARZ (2009) developed a taxonomy to evaluate different components of spatial thinking in the curriculum, textbooks, lesson plans, and other instructional materials. Jo et al. (2010) use this to examine questioning in spatial thinking as part of everyday teaching practice applied to the pedagogical strategy of questioning, in both texts and as part of classroom activities. They develop this as Bloom's Taxonomy does not address major components of spatial thinking, namely concepts of space and using tools of representation, in its knowledge and cognitive dimensions.

The taxonomy (Figure 16) uses three components of spatial thinking: (1) concepts of space, (2) using tools of representation, and (3) processes of reasoning as primary categories. The subcategories differentiate varying levels of abstraction or difficulty (Table 3). JO et al. (ibid) go on to make the case that the taxonomy of spatial thinking is a useful tool for designing and selecting questions that integrate the three components of spatial thinking and for determining the degree of complexity of a question in regards to its use of spatial concepts and the cognitive processes required.

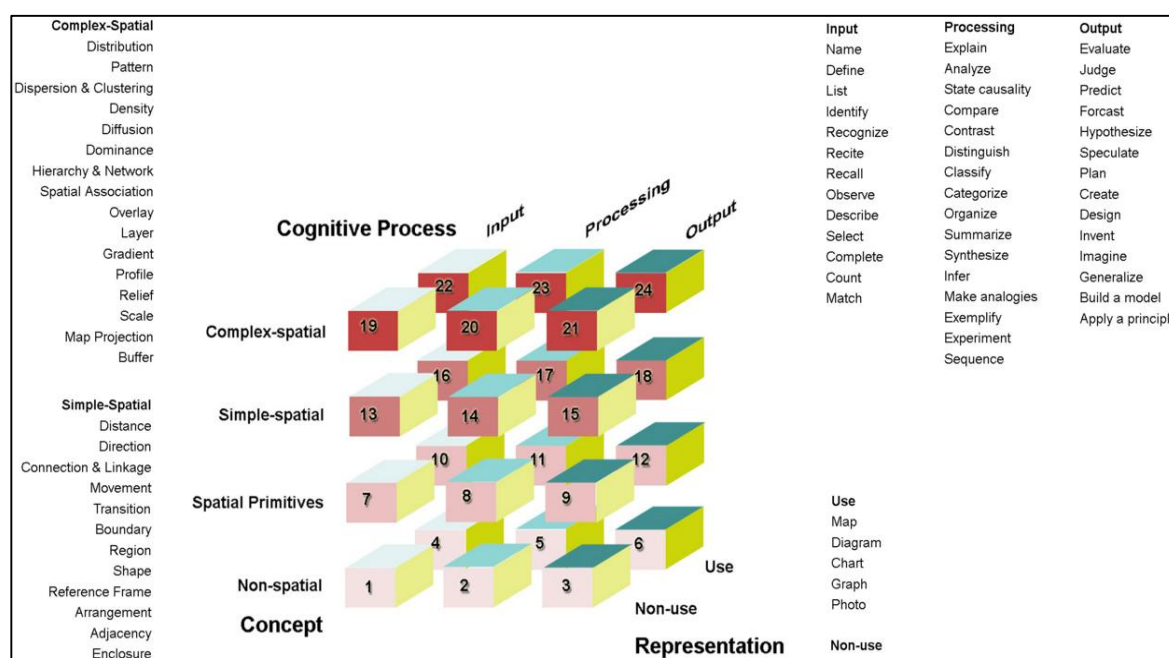


Figure 16: Taxonomy of spatial thinking (Jo and Bednarz, 2009)

SCHOLZ et al. (2014) use this system to identify the level and type of spatial thinking found in textbook questions as described in Table 11 and suggest a simplified taxonomy for evaluating materials integrating all three components (Figure 17).

Table 11: Three components of spatial thinking in questions (after Scholz et al., 2014)

### Component 1: Concepts of Space

Nonspatial: No spatial component in the question.

Spatial Primitives: the lowest level concept of space, involves the concepts of location, place-specific identity, and/or magnitude.

Simple-Spatial: A higher level concept of space, based on concepts and distributions derived from spatial primitives (Golledge 1995) including distance, direction, connection and linkage, movement, transition, boundary, region, shape, reference frame, arrangement, adjacency, and enclosure.

**Complex-Spatial:** The highest level concept of space, based on spatial distributions derived from spatial primitives and high-order derived concepts (Golledge 1995) including distribution, pattern, dispersion and clustering, density, diffusion, dominance, hierarchy and network, spatial association, overlay, layer, gradient, profile, relief, scale, map projection, and buffer.

### Component 2: Tools of Representation

These relate to the use of maps, graphics and other representations to answer a question.

**Use:** The question involves a tool of representation to answer the question

**Non-use:** The question is not considered a spatial-thinking question.

### Component 3: Processes of Reasoning

The processes of reasoning component evaluates the cognitive level of the question.

**Input:** The lowest level - receiving of information and includes name, define, list, identify, recognize, recite, recall, observe, describe, select, complete, count, and match.

**Processing:** A higher level of reasoning, analysing information, includes: explaining, analysing, stating causality, comparing, contrasting, distinguishing, classifying, categorizing, organizing, summarizing, synthesizing, inferring, analogies, exemplifying, experimenting, and sequence.

**Output:** The highest level of processes of reasoning, uses the analysis of information received to evaluate, judge, predict, forecast, hypothesize, speculate, plan, create, design, invent, imagine, generalize, build a model, or apply a principle.

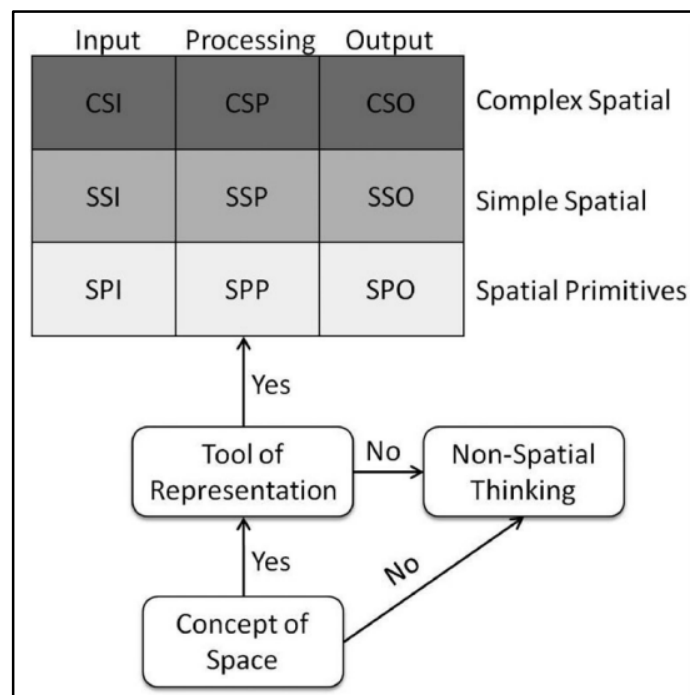


Figure 17: A simplified taxonomy for evaluating textbook materials, integrating all three components (Scholtz et al., 2014)

## 8 A LEARNING PROGRESSION LINE ON SPATIAL THINKING

### 8.1 Learning progression

A learning progression is defined as “descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time (e.g., 6 to 8 years). They are crucially dependent on instructional practices if they are to occur” (NRC 2007, 219, cited by SOLEM et al., 2014).

A learning progression should consist of following essential features (SOLEM et al., 2014):

1. the learning goals or learning targets, based on knowledge, skills and abilities needed for making the next step in understanding
2. the developmental progressions of thinking and learning in which students might engage, this is what we call the **learning line**
3. assessments: tasks that allow students to reveal their reasoning about the levels in the learning progress
4. (sometimes) learning activities or sequences of instructional tasks.

### 8.2 Learning line

LINDNER-FALLY & ZWARTJES (2012) defined a learning line as an educational term for the construction of knowledge and skills throughout the whole curriculum. It should reflect a growing level of complexity, ranging from easy (more basic skills and knowledge) to difficult as illustrated in the Flemish curriculum for secondary geography (Table 12).

Table 12: Learning line (*Leerplancommissie aardrijkskunde, 2010*)

<b>Level 1</b>	Perception – knowledge of facts
<b>Level 2</b>	Analysis – selection of relevant geographic information
<b>Level 3</b>	Structure – look for complex connections and relationships
<b>Level 4</b>	Apply – thinking problem solving

BLOEMEN & NAAIJKENS (2014) describe a ‘learning line’ as an overall framework for education and training, with a distinct sequence of steps from beginners to experts. Their learning line was i) analytical; i.e. it distinguishes in detail the skills, knowledge and attitudes on several levels that may be expected and ii) competence-based; the learning line distinguishes a set of competences that together build the overall competence in the field. They distinguished eight competences for translators, of which six were core and two peripheral; and five indicative levels; breakthrough, beginner, advanced, professional and expert.

VAN MOOLENBROEK & BOERSMA (2013) describe the elaboration of a learning line for biology education, using a concept-context approach for selecting learning goals and organizing knowledge. The approach related scientific concepts to contexts thereby improving engagement with the science curriculum by selecting contexts that have relevance for the students. They decided to establish a problem posing approach that takes explicitly a learners’ point of view.

PERDUE et al. (2013) proposed a spatial thinking framework and hypothesized that certain spatial thinking skills are higher order than others and build upon previous, less complex skills (Figure 18). So, in the example shown, regional identification is conceptualized as a high level skill achieved through the accumulation of proximity, boundary, clustering, and classification skills.

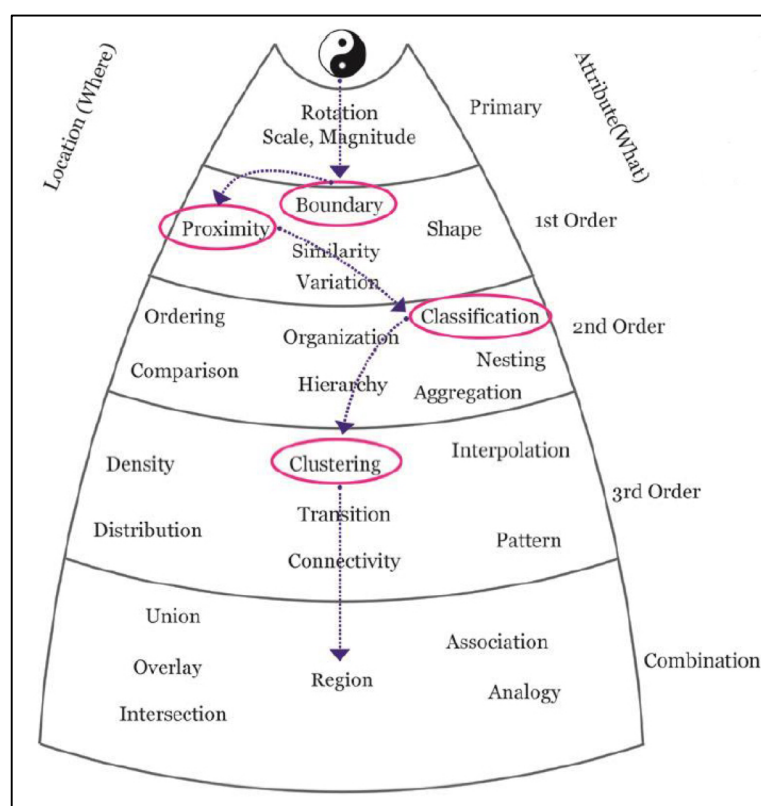


Figure 18: Spatial thinking framework (Perdue, 2013)

Learning lines imply a conceptual process of learner progression. However, YOUNG (2010) suggests these cannot be developed through generic curriculum approaches and they must involve a curriculum that is driven by content as the carrier of concepts, rather than purely one based on skills and competences. GI-Learner focuses on geographical education, but takes account of national differences in curricula.

Several authors try to use a learning line to integrate geographical inquiry processes (after DE MIGUEL, 2016) – see table 13.

Table 13: Learning lines and geographical inquiry process (De Miguel, 2016)

	<i>Zwartjes</i>	<i>Roberts</i>	<i>Kerski</i>	<i>Araya, Souto and Herrera</i>
Level 1	Perceiving	Creating a need to know	Asking geographical questions	Perceiving geographical environment
Level 2	Analyzing	Using geographical sources as evidence	Acquiring geographical resources	Analyzing geographical environment
Level 3	Structuring	Making sense of geographical information	Exploring geographical data	Interpreting geographical environment
Level 4	Applying	Reflecting on learning	Analyzing geographical information	Acting on geographical environment
Level 5			Acting on geographical knowledge	

### 8.3 A draft learning line on geospatial thinking

When applying the learning line concept of the LEERPLANCOMMISSIE AARDRIJKSKUNDE (2010) – see table 12 - to the learning outcomes (described in the previous section) we get this result:

*Level 1: **Perception** – being able to work with digital maps and virtual globes:*

- Open digital maps and virtual globes on a computer
- Indicate the different parts of digital maps/virtual globes (navigation bar, menu, scale, map window)
- Interpret symbols on digital maps
- Understand the construction of digital maps as a representation of the real world (topology, layers, database)

*Level 2: **Analysis** – selection of the relevant geographic information*

- Work with digital maps and virtual globes: find locations, pan, zoom, orientate, make measurements
- Access information efficiently and effectively, evaluate information critically and competently
- Be able to gather and evaluate information from data resources or through fieldwork activities
- Interpret content

*Level 3: **Structure** – look for complex connections and relationships*

- Use digital maps and virtual globes for a variety of different purposes
- Identify and ask significant questions that clarify various points of view and lead to sustainable solutions
- Manipulate maps by creating own maps
- Communicate cartographic information

*Level 4: **Apply** – thinking problem solving*

- Be aware of generalization levels applied in different zoom levels (e.g. road density)
- Understand the basic purpose and application of digital earth to real world problems
- Use advanced digital earth tools for learning (starting with Web-GIS, GIS viewers to GIS software)
- Frame, analyse and synthesize information in order to solve problems and answer questions

For introduction in the different grades of schools the level would depend of the age. Level 1 should be reached in primary education; level 2 can already be reached in primary – depending of the class group - but must be reached in lower secondary education. Level 3 can be reached in lower secondary – again depending of the class group, but must be reached together with level 4 in upper secondary education.

	Level 1 Perception	Level 2 Analysis	Level 3 Structure	Level 4 Apply
Primary (6-10 y)				
Lower Secondary (11-14 y)				
Upper Secondary (15-18 y)				

Figure 19: Learning line on Secondary school

Another method which could be used is the cataloguing of the required competencies into competency areas as the basis for a learning line (WOLOSZYNSKA et al. 2013) – table 14, whereby teachers would be able to choose suitable tools to use, based on the abilities of their students, their own capabilities and their curriculum.

Table 14: Learning Line (Woloszynska et al. 2013)

Competence Areas	Primary 6 – 10 y	Lower Secondary 11 – 14 y (In addition to 6-10 y)	Upper Secondary 15 – 18 y (In addition to 11-14 y)
understanding / analysing digital geomedia	reading, orientating, combining, interpreting, measuring, comparing, querying		geo processing network analysis spatial analysis
producing and communicating digital geomedia	collaborative activities, mapping, visualising, sharing, discussing update geo-media, maps, infographics, charts, presentations collect and represent information add information to maps and other geo-media thematic mapping ... at different levels of scale and complexity over the years		
critical use / awareness of digital geomedia in everyday life	awareness of generalization, different zoom levels, perspectives, intentions, manipulated representations, volunteered geographical information (vgi) reflect on content and representation, information rights and ethics identification of digital media in everyday life geomedia as part of decision making		
geographical technology: hardware & tools	GPS, digital maps, virtual globes web mapping	3D representations of the world (DEM) satellite images open geodata online, desktop and mobile GIS	

In their research SOLEM et al. (2014) state that “Every learning line has both a lower anchor and an upper anchor; the lower anchor represents the emerging knowledge students have as novice learners of a construct or practice, and the upper anchor is a depiction of what learners should know and be able to do after learning has occurred”. To illustrate this, they give the example of hypothetical learning line on spatial aspects of a conflict (table 15), where they determine the upper and lower anchor.



Table 15: upper and lower anchor of a hypothetical learning line (own work, based on Solem et al., 2014)

theme	Upper anchor	Lower anchor
Spatial Aspects of Conflict	<ul style="list-style-type: none"> <li>all students graduating from high school need to be able to understand the role that resources, such as water, oil, and natural gas, play in conflicts around the world</li> <li>-Students must be able to understand news reports and newspaper articles on the topic of worldwide resource conflict so that they can be knowledgeable citizens—not experts—on the topic</li> </ul>	<ul style="list-style-type: none"> <li>The concepts and skills the learning progression will encompass (table 16)</li> <li>determine the age that would make the most sense for the lower anchor of the progression (table 17)</li> </ul>

Table 16: Determining the concept and skills of the learning progression (Solem et al., 2014)

Spatial Concepts	Student Understandings and Possible Misconceptions and Challenges		
	Ages 3-6 (Pre-K through Grade 1)	Ages 7-9 (Grades 2-4)	Ages 10-12 (Grades 5 and 6)
Identity and Location	Students in this age group can typically identify places on maps, landscape features on maps and aerial photographs, and can locate familiar places on maps. While children at this age can identify places, they may be limited by vocabulary development. Students might also use landmarks as a way to identify where places or items are located on a map, but they can easily confuse locations on maps if the map is not well aligned to their real world. <b>Studies of Interest:</b> Blades and Spencer 1990; Blaut and Stea 1974, 1971; Blaut, Stea, Spencer, and Blades 2003; Bluestein and Acredolo 1979; Downs, Liben, and Daggs 1988; Huttenlocher, Newcombe, and Vasilyeva 1999; Liben 2008; Liben and Downs 1993; Presson 1982; Sowden, Stea, Blades, Spencer, and Blaut 1996	Students can accurately locate places and landscape features on a map, but perform better with familiar locales as opposed to foreign locales. Map alignment issues also improve at this age. However, students inconsistently use landmarks to verify locations. <b>Studies of Interest:</b> Blaut and Stea 1971; Golledge, Battersby, and Marsh 2008a; Kastens and Liben 2010, 2007	Students need to be primed to use all the resources available to determine locations, and encouraged self-explanation of decisions, to cue thinking more about landmarks, distances, and directions. Students do not readily use map scales, metric distances, or cardinal directions to help determine locations, but can do so if prompted during instruction. Accuracy on these tasks is better for familiar places and becomes less accurate for more foreign or large-scale tasks. <b>Studies of Interest:</b> Blaut and Stea 1971; Golledge and Stimson 1997; Liben 2008; Liben and Downs 1993; Tretter et al. 2006
Magnitude	Students seem to innately understand magnitude of objects (bigger, smaller), but they might confuse the size of an object with the number of objects (numerosity). <b>Studies of Interest:</b> Golledge, Battersby, and Marsh 2008a; Mix 1999; Rousselle, Palmers, and Noel 2004		
Distance and Direction	Understand relative distance, such as near, far, next to, and can begin using relative direction on maps, such as navigating mazes. Struggle with knowing which way to "hold a map" and easily get confused if it is not aligned to the real world; Students also do not intuitively think about distances without being prompted to do so. <b>Studies of Interest:</b> Blades, Sowden, and Spencer 1995; Blades and Spencer 1987; Liben 2008; Liben and Downs 1993; Rutland, Custance, and Campbell 1993	This is a transition period between topological (e.g., near, far) concepts of distance to metric measurements; by 4th grade, students should readily use metric distances. They will still need guidance to transition to metric measurements though. Students also frequently use landmarks and relative direction, but some ready to learn cardinal directions. <b>Studies of Interest:</b> Kastens and Liben 2010	
Frames of Reference and Perspective Taking	Children at this age view the world from an egocentric frame of reference (i.e., how they see the world rather than how another perspective might see it, such as a bird flying over a house). <b>Studies of Interest:</b> Newcombe and Frick 2010; Newcombe and Huttenlocher 2000;	Students can begin to understand grid systems (coordinate system) and begin learning absolute location. Students might get distracted by features that are not useful and neglect useful features on maps. <b>Studies of Interest:</b> Bell 2000; Liben 2008; Kastens and Liben 2010; Newcombe and Frick 2010	
Scale	Students at this age can handle scale better using smaller, familiar spaces, such as a classroom. Students do not have a systematic way to handle scale- they cannot move between scales easily, such as the size of the school in real life v. the size of a school depicted on a map. <b>Studies of Interest:</b> Liben 2008; Uttal 2000		
Symbols	Abstract, unrelated symbols are not understood well at this age level. Students might also confuse the colors used on representations and expect those colors to be the same in the real-world (e.g., a red road on a map should be red in real life). <b>Studies of Interest:</b> Liben 2009, 2008; Myers and Liben 2008	During this age, students transition between iconic real-world symbols to abstract symbols, but they still make significant errors; explicit guidance needed on what symbols mean. <b>Studies of Interest:</b> Golledge, Battersby, and Marsh 2008a; Liben 2009, 2008; Myers and Liben 2008	Students can use abstract symbols and understand symbols do not always "look like" the referent. <b>Studies of Interest:</b> Golledge, Battersby, and Marsh 2008a; Liben 2009, 2008; Myers and Liben 2008
Hierarchies		Concept of hierarchy (or nesting) is not well established innately with this age group, but can possibly be introduced with close guidance. <b>Studies of Interest:</b> Lowes 2008	
Overlay and Other Complex Spatial Tasks			About half of all 6th grade students incidentally understand the concept of overlay without formal instruction. Guidance using map overlays can likely improve student success. Students can also move onto complex spatial concepts such as distribution, patterns, overlays, and projection with support if mastery of the basic spatial concepts of location, distance, direction, boundaries, regions achieved. <b>Studies of Interest:</b> Battersby, Golledge, and Marsh 2006

Table 17: Determining the spatial concepts of the lower anchor in table 15 by grade (Solem et al., 2014)

	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

## 9 CONCLUSIONS

The frameworks, benchmarks and taxonomy reviewed here have been an important first step in defining and describing the complex context of geospatial thinking and geospatial learning. Through GI-Learner and its learning lines approach, it is hoped to construct suitable content to meet the needs of the pupil. This implies an individualized, learner-focused, open education environment like that envisaged by the use of Cloud-based technologies (KOUTSOPOULOS & KOTSANIS, 2014). As SHIN et al. (2015) suggest, it will also necessitate that additional attention is paid to spatial thinking in teacher preparation programs.

This publication is not an attempt to comprehensively review spatial thinking research, but to examine how its evolution has been rooted in many different domains, as widespread as neuroscience, psychology and geography. From this it is clear that spatial thinking involves highly complex cognitive activities. It embraces language and action and concerns comprehension, reasoning, and problem solving. It includes direct experiences that may be real and virtual, individual and collective, intuitive and taught.

Based on this review, in no particular order, ten geospatial thinking competences are proposed by the GI-Learner project team:

- Critically read, interpret cartographic and other visualisations in different media
- Be aware of geographic information and its representation through GI and GIS.
- Visually communicate geographic information
- Describe and use examples of GI applications in daily life and in society
- Use (freely available) GI interfaces
- Carry out own (primary) data capture
- Be able to identify and evaluate (secondary) data
- Examine interrelationships
- Synthesise meaning from analysis
- Reflect and act with knowledge

These will be the lower anchors in a learning progression line concept that will be created in the next phases of the GI Learner project, taking existing themes common in all curricula of the countries involved as upper anchor.

## 10 REFERENCES

- Abbott, T. D. (2001). An Evaluation of Geographic Information System Software and its Utility in Promoting the Use of Integrated Process Skills in Secondary Students. Ph.D. diss., University of Connecticut, Storrs.
- Albert, W.S., Golledge, R.G. (1999). The use of spatial cognitive abilities in geographical information systems: The map overlay operation. *Transactions in GIS* 3: 7-21.
- Alibrandi, M., Palmer-Moloney, J. (2001). Making a Place for Technology in Teacher Education with Geographic Information Systems (GIS). *contemporary Issues in Technology and Teacher Education* [Online serial], 1 (4) 483-500.
- Alibrandi, M. (2003). *GIS in the Classroom*. Portsmouth, New Hampshire: Heinemann.
- Baker, T.R., Battersby, S., Bednarz, S.W., Bodzin A.M., Kolvoord B., Moore, S., Sinton, D., Uttal, D. (2015). A Research Agenda for Geospatial Technologies and Learning. *Journal of Geography* 114 (3):11–130.
- Bednarz, S.W., Bockenbauer, M.H., Walk, F.H. (2005). Mentoring: A New Approach to Geography Teacher Preparation. *Journal of Geography* 104(3): 105-112.
- Bednarz, S., Van der Schee, J. (2006). Europe and the United States: the implementation of geographic information systems in secondary education in two contexts, *Journal of Technology, Pedagogy and Education*, Vol. 15, No. 2, 191-205
- Bednarz, S., Bednarz, R. (2008). The key to success in using geospatial technologies in the social studies classroom. In *Digital Geography*, eds. A. J. Milson and M. Alibrandi, 249-270. Charlotte, NC: Information Age Publishing.
- Bednarz, R., Lee, J. (2011). The components of spatial thinking: empirical evidence. *Procedia Social and Behavioral Sciences* 21 (2011) 103–107.
- Bednarz S., Heffron, S., Huynt, N.T. (eds.) (2013). *A road map for 21st century geography education: Geography education research (A report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education Project)*. Washington, DC: Association of American Geographers.
- Bevington-Attardi, D., Rice, M. (2015). On the map: American cartography in 2015, *Cartography and Geographic Information Science*, 42:sup1, 1-5, DOI: 10.1080/15230406.2015.1060112
- Bodzin, A.M.; Fu, Q. and Kulo, V. (2014). Examining the Effect of Enactment of a Geospatial Curriculum on Students' Geospatial Thinking and Reasoning. *J Sci Educ Technol* 23:562–574. DOI 10.1007/s10956-014-9488-6
- Bullens, J., Nardini, M., Doeller, C.F., Braddick, O., Postma, A., Burgess N. (2010). The role of landmarks and boundaries in the development of spatial memory, *Development Science*, DOI: 10.1111/j.1467-7687.2009.00870.x.
- Buzo, I., De Miguel, R., Lázaro, M.L. (2015). School on the Cloud: a Spanish perspective. In *Proceedings of INTED2015. 9th International Technology, Education and Development Conference*, pp.793–801. Madrid: IATED Academy.

- Charcharos, C., Tomai, E., Kokla, M. (2015). Assessing Spatial Thinking Ability, GEOTHNK International Closing Conference, Athens, Greece, 7 November 2015, [https://www.academia.edu/20584709/Assessing\\_Spatial\\_Thinking\\_Ability](https://www.academia.edu/20584709/Assessing_Spatial_Thinking_Ability)
- Clagett, K.E. (2009). Virtual globes as a platform for developing spatial literacy (Doctoral dissertation), <https://run.unl.pt/handle/10362/2317>
- Committee on Support for Thinking Spatially (2006). Learning to Think Spatially (Washington, DC: National Academies Press).
- Cook, C.N., Inayatullah, S., Burgman, M.A., Sutherland, W.J., Wintle, B.A. (2014). Strategic foresight: how planning for the unpredictable can improve environmental decision-making. *Trends in ecology & evolution*, 29(9), pp.531-541.
- De Miguel, R. (2013). Aprendizaje por Descubrimiento, Enseñanza Activa y Geoinformación: Hacia una Didáctica de la Geografía Innovadora. *Didáctica Geográfica* nº 14, 17-36, <http://www.didacticageografica.es/index.php/didacticageografica>
- De Miguel, R. (2014). Concepciones y usos de las tecnologías de información geográfica en las aulas de ciencias sociales. *Iber. Didáctica de las Ciencias Sociales, Geografía e Historia* nº 76, 60-71.
- De Miguel, R. (2014). Innovative Learning Approaches to Secondary School Geography in Europe: New Challenges in the Curriculum, in De Miguel, R. y Donert, K. (Eds) *Innovative Learning Geography in Europe: New Challenges for the 21st Century*. Cambridge Scholars Publishing, pp. 21-38.
- De Miguel, R., Lázaro, M.L., Velilla, J., Buzo, I. y Guallart, C. (2015). Atlas Digital Escolar: Aprender Geografía con ArcGIS Online in *Investigar para innovar en la enseñanza de la Geografía*, Universidad de Alicante-Grupo de Didáctica de la AGE .951-963.
- De Miguel, R., Lázaro, M.L., y Buzo, I. La educación geográfica en la nube: adquisición de la competencia digital y desarrollo del pensamiento espacial (In press).
- De Miguel; R., Lázaro, M.L. de (2016). Educating geographers in Spain. *Geography teaching renewal by implementing the European Higher Education Area. Journal of Geography in Higher Education*,
- De Miguel, R., Buzo, I. y Lázaro, M.L. de. (2016) Nuevos retos para la educación geográfica y la investigación docente: el Atlas Digital Escolar (New challenges for geographical education and researching: The Digital School Atlas), Aportación española al XXXIII Congreso de la UGI (Beijing, 2016).
- Demirci, A. (2009). How do Teachers Approach New Technologies: Geography Teachers' Attitudes towards Geographic Information Systems. *European Journal of Educational Studies* 1(1).
- Donert, K. (2008), Spatial learning for the young European citizen: a Geography toolkit, 105-113 In S Philippou, *Exploring Europe and Ourselves: Geographies and Identities at Work*, Cyprus, United Nations Development Programme.
- Donert, K. (2015) Digital Earth–Digital World: Strategies for Geospatial Technologies in Twenty-First Century Education. In: Solari, O.M., Demirci, A. and van der Schee, J., *Geospatial Technologies and Geography Education in a Changing World*, 195-204. Springer Japan.

- Downs, R.M. (chair) (2006). Learning to think spatially: GIS as a Support System in the K-12 Curriculum, National Research Council, National Academy Press, 313 p.
- ESRI (2003). Geographic Inquiry: Thinking Geographically, ESRI Schools and Libraries Program, [www.esri.com/Industries/k-12/education/~media/Files/Pdfs/industries/k-12/pdfs/geoginquiry.pdf](http://www.esri.com/Industries/k-12/education/~media/Files/Pdfs/industries/k-12/pdfs/geoginquiry.pdf)
- Esteves H.M. & Rocha J. (2015). Geographical information systems in Portuguese geography education European Journal of Geography Volume 6(3), 6 -15.
- Favier, T., Van der Schee, J. (2012). Exploring the characteristics of an optimal design for inquiry-based geography education with Geographic Information Systems. Computers & Education, vol. 58(1) p. 666-677.
- Favier, T., Van der Schee, J. (2012). Op zoek naar een kennisbasis voor lesgeven met GIS. Aardrijkskundeonderwijs onderzocht, Landelijk Expertisecentrum Mens- en Maatschappijvakken – Centrum voor Educatieve Geografie, p. 135-146.
- Favier, T. (2013). Geo-informatietechnologie in het voortgezet aardrijkskundeonderwijs: Een brochure voor docenten, Vrije Universiteit Amsterdam, 80 p.
- Freeman, D. (1997). Using Information Technology and New Technologies in Geography, Teaching and Learning Geography, London: Rutledge, 202-217
- Gardner, H. (1993). Multiple intelligences: The theory in practice. New York, NY: Basic Books. Selected by three book clubs. Excerpted in the magazine Behinderte in Familie, Schule und Gesellschaft, vol. 2, 1997. Abridged, Danish translation, 1997, Copenhagen: Glydendal Undervisning. Translated into Spanish, Portuguese, Italian, French, Chinese (Taiwan), Hebrew, Korean, Polish, Chinese (R.C.), Danish, Ukrainian, Japanese, Norwegian, Indonesian, Arabic, and Turkish.
- Gardner, H. (2006). Multiple intelligences: New horizons. New York, NY: Basic Books. Translated into: Romanian, Chinese (SC), Vietnamese, Indonesian, and Korean.
- Genevois, S. (2011). Teacher Training for Using Geo Information in Secondary Education, in Jekel, T, Koller, A., Donert, K. & Vogler, R. (Eds.) (2011): Learning with GI 2011.
- Geography Education Standards Project (1994). Geography for Life – National Geography Standards National Geographic Society, Washington D.C., 272 p.
- Geography Education Standards Project (2012). Geography for Life – National Geography Standards, Second edition National Geographic Society, Washington D.C., 272 p.
- Gersmehl, P.J., Gersmehl, C.A. (2006). Wanted: A Concise List of Neurologically Defensible and Assessable Spatial-Thinking Skills. Research in Geography Education 8: 5-38.
- Gersmehl, P.J., Gersmehl, C.A. (2007). Spatial thinking by young children: Neurologic evidence for early development and “educability”. Journal of Geography, 106(5), pp.181-191.
- Gersmehl, P.J., Gersmehl, C.A. (2011). Spatial Thinking: Where Pedagogy Meets Neuroscience. Problems of Education in the 21st Century, 27: 48-66.
- Gilmartin, P.P., Patton, J.C. (1984). Comparing the Sexes on Spatial Abilities: Map-Use Skills. Annals of the Association of American Geographers, 74: 605–619. doi: 10.1111/j.1467-8306.1984.tb01477.x

- Goldstein, D., Alibrandi, M. (2013). Integrating GIS in the Middle School Curriculum: Impacts on Diverse Students' Standardized Test Scores, *Journal of Geography*, 112:2, 68-74, DOI: 10.1080/00221341.2012.692703
- Golledge (1995). Primitives of spatial knowledge. In *Cognitive Aspects of Human Computer Interaction for Geographic Information Systems*, eds. T. L. Nyerges, D. M. Mark, R. Laurini and M. J. Egenhofer, 29-44. Dordrecht: Kluwer Academic Publishers.
- Golledge, R., Marsh, M., Battersby, S. (2008). A conceptual framework for facilitating geospatial thinking. *Annals of the Association of American Geographers*, 98 (2), 285-308.
- González, M.E. (2012). Tesis Doctoral: Las Infraestructuras de Datos Espaciales (IDE) como un recurso educativo TIC. Estrategias de formación y difusión para el profesorado de la Educación Secundaria Obligatoria. Mayo (2012), [http://oa.upm.es/11015/1/MARIA\\_ESTER\\_GONZALEZ.pdf](http://oa.upm.es/11015/1/MARIA_ESTER_GONZALEZ.pdf)
- Goodchild, M. F. (1992). Geographical information science. *International Journal of Geographical Information Systems* 6: 31-45.
- Goodchild, M. (2006). The Fourth R? Rethinking GIS Education, *ArcNews* Fall 2006.
- Goodchild, M. F., Janelle, D.G. (2010). Toward critical spatial thinking in the social sciences and humanities. *GeoJournal*. 75(1), 3–13, DOI:10.1007/s10708-010-9340-3
- Goodchild, M. (2011). Spatial Thinking and the GIS User Interface. *Procedia Social and Behavioral Sciences* 21 (2011) 3–9.
- Granell Canut, C., Gould Carlson, M., Manso Callejo, M.A., Bernabé Poveda, M.A. (2009). "Spatial Data Infrastructures" In *Handbook of Research on Geoinformatics*. Information Science Reference. Encyclopaedia of Geoinformatic. H.Karimi & Rita de Cassia Veiga Marriott (ed). Hershey (PE) USA.
- Gryl, I., Jekel, T. and Donert, K. (2010). GI & Spatial Citizenship. In T. Jekel, A. Koller, K. Donert and R. Vogler, (Eds.) *Learning with Geoinformation V* (pp. 2-11). Berlin, Germany: Wichmann.
- Hagevik, R.A. (2003). The effects of online science instruction using geographic information systems to foster inquiry learning of teachers and middle school science students. (Dissertation under the direction of John E. Penick and Hugh A. Devine) <http://www.lib.ncsu.edu/resolver/1840.16/4389>
- Haklay M. (2012). Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation. In *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice*, ed. D. Sui, S. Elwood and M. Goodchild, pp. 105–122. New York: Springer.
- Hall-Wallace, M. K., McAuliffe, C.M. (2002). Design, implementation, and evaluation of GIS-based learning materials in an introductory geoscience course. *Journal of Geoscience Education* 50: 5-14.
- Harvey, F. (2014). A world without GIS? Post-GIS futures for the new millennium. *Geographia Polonica*, 87(2), pp.241-250.
- Hespanha, S.R., Goodchild, F., Janelle, D.G. (2009). Spatial thinking and technologies in the undergraduate social science classroom. *Journal of Geography in Higher Education*, 33(S1), pp.S17-S27.



- Houtsonen, L., Mäki, S., Riihelä, J., Toivonen, T., Tulivuori, J. (2014). Paikkaoppi: A Web based learning environment for Finnish Schools. In *Innovative Learning Geography in Europe: New Challenges for the 21st Century*, ed R. De Miguel and K. Donert, pp. 89–100. Newcastle upon Tyne: Cambridge Scholars Publishing.
- Huynh, N. T. (2009). "The Role of Geospatial Thinking and Geographic Skills in Effective Problem Solving with GIS: K-16 Education". *Theses and Dissertations (Comprehensive)*. Paper 1078.
- Huynh, N.T., Sharpe, B. (2013). An Assessment Instrument to Measure Geospatial Thinking Expertise, *Journal of Geography*, 112:1, 3-17. <http://dx.doi.org/10.1080/00221341.2012.682227>
- Jo, I., Bednarz, S.W. (2009). Evaluating geography textbook questions from a spatial perspective: Using concepts of space, tools of representation, and cognitive processes to evaluate spatiality. *Journal of Geography* 108:4–13.
- Jo, I., Bednarz, S.W., Metoyer, S. (2010). Selecting and designing questions to facilitate spatial thinking. *The Geography Teacher* 7 (2): 49–55.
- Jo, I., Bednarz, S.W. (2014). Dispositions Toward Teaching Spatial Thinking Through Geography: Conceptualization and an Exemplar Assessment, *Journal of Geography*, 113:5, 198-207, DOI: 10.1080/00221341.2014.881409
- Johnson, A., Sullivan, D. (2010). Geospatial Education at U.S. Community Colleges: Background, Challenges, and Opportunities, *URISA Journal* • Vol. 22, No. 2 • 2010, pp.5-13. Kerski, 2010
- Joint Committee on Geographic Education (1984). *Guidelines for Geographic Education: Elementary and Secondary Schools*. Washington DC, 28 p.
- Kemp, K.K., Goodchild, M.F., Dodson, R.F. (1992). Teaching GIS in geography. *Professional Geographer* 44: 181-191.
- Kerski, J. (2003). The implementation and Effectiveness of Geographic Information Systems Technology and Methods in Secondary Education, *Journal of Geography (National Council for Geographic Education)* 102, 128-137.
- Kerski, J. J. (2008a). The role of GIS in Digital Earth education, *International Journal of Digital Earth*, 1: 4, 326-346.
- Kerski, J. (2008b). Developing Spatial Thinking Skills in Education and Society. *ArcWatch* 2008, ESRI. <http://www.esri.com/news/arcwatch/0108/spatial-thinking.html>
- Kerski, J.J., Demirci, A., Milson, A.J. (2013). The Global Landscape of GIS in Secondary Education, *Journal of Geography*, 112:6, 232-247.
- Kerski, J.J. (2015). Understanding Data: It is Critical! <https://spatialreserves.wordpress.com/2015/11/22/understanding-your-data-it-is-critical/>
- Kim, M., Bednarz, R. (2013). Development of critical spatial thinking through GIS learning. *Journal of Geography in Higher Education* 37(3):350-366.
- King, H. (2006), Understanding spatial literacy: cognitive and curriculum perspectives, *Planet*, 17: 26-28
- Kolb, D. A. (1984). *Experiential Learning: Experience As the Source of Learning and Development*. Engelwood Cliffs, New Jersey: Prentice-Hall.



- Kolvoord, B. (2012). Integrating geospatial technologies and secondary student projects: the geospatial semester. *Didáctica Geográfica* 13: 57-67.
- Koutsopoulos, K. (2010) Teaching Geography – Instructing with GIS and about GIS, Using GeoInformation in European Geography education, 1-19
- Koutsopoulos, C.K. (2011). Changing Paradigms of Geography. *European Journal of Geography*, 1, 54-75.
- Koutsopoulos, C.K., Kotsanis, Y.C. (2014). School on Cloud: Towards a paradigm shift. *Themes in Science and Technology Education*, 7(1), 47-62,  
<http://earthlab.uoi.gr/theste/index.php/theste/article/view/147/96>
- Lázaro, M.L., González, M.J., Lozano, M.J. (2008). "Google Earth and ArcGIS Explorer in Geographical Education", in Jekel T, Koller A and Donert K (eds.) *Learning with Geoinformation III - Lernen mit Geoinformation III*. Wickmann, pp. 95-105.
- Lázaro y Torres, M.L. (Coord) et al. (2015). *Aprender Geografía con la Web 2.0 a través de la evolución de los paisajes agrarios de España*. Manual. Universidad Complutense de Madrid, Madrid.
- Lázaro y Torres, M.L. de, Álvarez Otero, J. y González González, M.J. (2015) *Aprender geografía de España empleando SignA*, En Sebastiá, R. y Tonda, M.E. *Investigar para innovar en la enseñanza de la Geografía*. pp.25-39.
- Lázaro y Torres, M.L., Álvarez, S., González, M.J. (2016). Geodatos y paisaje: De la nube al aula universitaria. *Boletín de la Asociación de Geógrafos Españoles* 70, pp.371-391.
- Lázaro y Torres, M.L, De Miguel, R., Buzo Sánchez, I. (2016). Outdoor learning and geography on the cloud: A challenge for the European network "School on the Cloud". *The International Journal of Technologies in Learning*. Commond Ground Publishing.
- Lee, J. (2005). *Effect of GIS Learning on Spatial Ability*. Ph.D. diss., Texas A&M University, College Station.
- Lee, J., Bednarz, R. (2005). Video analysis of map-drawing strategies. *Journal of Geography* 104: 211-221.
- Lee, J., Bednarz, R. (2009). Effect of GIS Learning on Spatial Thinking, *Journal of Geography in Higher Education*, 33:2, 183-198, DOI: 10.1080/03098260802276714
- Lee, J., Bednarz, R. (2012). Components of Spatial Thinking: Evidence from a Spatial Thinking Ability Test, *Journal of Geography*, 111:1, 15-26, DOI: 10.1080/00221341.2011.583262
- Liben, L.S. (2006). Education for Spatial Thinking. In: Renninger, A.K., Sigel, I.E., *Handbook of Child Psychology*. Child Psychology in Practice, vol. 4, New Jersey: John Wiley & Sons, Inc.
- Liu, S., Zhu, X. (2008). Designing a Structured and Interactive Learning Environment Based on GIS for Secondary Geography Education, *Journal of Geography* 107: 12–19.
- Liu, Y., Bui, E.N., Chang, C.-H., Lossman, H.G. (2010). PBL-GIS in secondary geography education: Does it result in higher-order learning outcomes? *Journal of Geography* 109: 150-158.
- Linn, M.C., Petersen, A.C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development* 56: 1479- 1498.

Linn, S., Kerski, J., Wither, S. (2005). Development of evaluation tools for GIS: How does GIS affect student learning? *International Research in Geographical and Environmental Education* 14: 217-222.

Lobben, A., Lawrence, M. (2014). Synthesized Model of Geospatial Thinking, *The Professional Geographer*, DOI: 10.1080/00330124.2014.935155

McGee, M.G. (1979). *Human Spatial Abilities: Sources of Sex Differences*. New York: Praeger.

Michel, E., Hof, A. (2013). Promoting Spatial Thinking and Learning with Mobile Field Trips and eGeo-Riddles, *GI\_Forum 2013: Creating the GISociety* (Eds. Jekel, T., Car, A., Strobl, J., Griesebner, G.), Wichmann Verlag Berlin, 378-387. doi:10.1553/giscience2013s378.

Miller, J., Keller, P., Yore, L.D. (2005). Suggested Geographic Information Literacy for K-12, *International Research in Geographical and Environmental Education* Vol. 14, No. 4.

Milson, A. J. (2011). SIG en la Nube: WebSIG para la enseñanza de la Geografía. *Didáctica Geográfica [En línea]* Murcia: Grupo de Didáctica de la Geografía de la Asociación de Geógrafos Españoles, 12

<http://www.didacticageografica.es/index.php/didacticageografica/article/view/61/61>

Milson, A.J., Kerski, J., Demirci, A. (2012). *The World at their Fingertips: International Perspectives on Teaching and Learning with GIS in Secondary Schools*. New York: Springer.

Milson, J.M. et al. (2012). *International perspectives on teaching and learning with GIS in secondary schools*, Springer Science + Business Media B.V., New York – Heidelberg, 353 p.

Mohan, A., Mohan, L. (2013). Spatial thinking about maps: Development of concepts and skills across the early school years. Report prepared for National Geographic Education Programs.

Mohan, L., Mohan, A., Uttal, D. (2014). Research on Thinking and Learning with Maps and Geospatial Technologies. In M. Solem, N. T. Huynh, and R. Boehm, (Eds.), *Learning Progressions for Maps, Geospatial Technology, and Spatial Thinking: A Research Handbook* (pp. 9-21). Washington, D.C.: Association of American Geographers.

Moreno Jiménez, A. (2013). Entendimiento y naturaleza de la científicidad geotecnológica: una aproximación desde el pragmatismo epistemológico. *Investigaciones Geográficas* nº 60 (julio-diciembre 2013), 05 - 36. DOI: 10.14198/INGEO2013.60.0

National Research Council (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. National Academies Press.

National Academy of Sciences (2006). *Learning to Think Spatially-GIS Across the K-12 Curriculum*. Washington, D.C.: National Academy of Sciences.

NAEP Geography Consensus project (2010). *Geography Framework for the 2010 National Assessment of Educational Progress*, U.S. Department of Education, Washington D.C., 72 p. <http://www.nagb.org/content/nagb/assets/documents/publications/frameworks/gframework2010.pdf>

Newcombe, N.S, Frick, A. (2010). Early Education for Spatial Intelligence: Why, What, and How, *Mind, Brain, and Education*, DOI: 10.1111/j.1751-228X.2010.01089.x

Nielsen, C.P., Oberle, A., Sugumaran, R. (2011). Implementing a high school level geospatial technologies and spatial thinking course. *Journal of Geography*, 110(2), pp.60-69.

Patterson, M. W., Reeve, K. , Page, D. (2003). Integrating geographic information systems into the secondary curricula. *Journal of Geography* 102: 275-281.

Pellegrino, J.W., Kail, R. (1982). Process analyses of spatial aptitude. In R. J. Sternberg (Ed), *Advances in the psychology of human intelligence* (Vol. 1, pp. 311-365). Hillsdale, NJ: Lawrence Erlbaum Associates.

Pellegrino, J. W., Alderton, D.L., Shute, V. J. (1983). "Understanding Spatial Ability." *Educational Psychologist* 19 (November 1983): 239-253.

Perdue, N., Lobben, A. (2013). The Challenges of Testing Spatial Thinking Skills with Participants who are Blind or Partially Sighted. Sharing knowledge, In José Jesús Reyes Nuñez. Sharing knowledge. Joint ICA Symposium. Event organized within the activities previous to the 26th International Cartographic Conference. Department of Cartography and Geoinformatics, Eötvös Loránd University, Budapest.

Potti, H., Sevilla, C., Abad, P., Rodríguez, A. (2011). SignA: Sistema de Información Geográfica Nacional. La puerta de acceso al Nodo IDE del IGN. Instituto Geográfico Nacional. Recursos. Disponible en: <http://www.ign.es/ign/resources/actividades/sig/SignA.pdf>

Quinn, P., Doran, M., Papafragou, A. (2011). Does changing the reference frame affect infant categorization of the spatial relation BETWEEN?, *Journal of Experimental Child Psychology*, DOI: 10.1016/j.jecp.2010.10.001.

Robson, S. (2012). *Developing Thinking and Understanding in Young Children: An Introduction for Students*. New York: Routledge

Roche, S. (2014). Geographic Information Science I: Why does a smart city need to be spatially enabled? *Progress in Human Geography* 38 (5): 703–711.

Russel, M. (2013). "Beyond 'I Agree': The Instructor's Role in Facilitating Critical Thinking in Online Courses. *The International Journal of Technologies in Learning*, 19. <http://thelearner.com/>, pp. 17-30.

Solem, M., Huynh, N.T., Boehm, R. (eds.) (2014). *Learning Progressions for Maps, Geospatial Technology, and Spatial Thinking: A Research Handbook*. Washington, DC: Association of American Geographers.

Sanders, L.R. et al. (2002). Electronic mapping in Education, *Journal of Research on Technology in Education*, Vol.34, No.2, 91-1009

Self, C.M., Gopal, S., Golledge, R.G., Fenstermaker, S. (1992). Gender-related differences in spatial abilities. *Progress in Human Geography* 16: 315-342.

Self, C.M., Golledge, R.G. (1994). Sex-related differences in spatial ability: What every geography educators should know. *Journal of Geography* 93: 234-243.

Scholz, M.A., Huynh, N.T., Brysch, C.P., Scholz, R.W. (2014). An evaluation of university world geography textbook questions for components of spatial thinking. *Journal of Geography*, 113(5), pp.208-219.

Schulze, U., Gryl, I., Kanwischer, D. (2014). Spatial Citizenship – Creating a Curriculum for Teacher Education. In R. Vogler, A. Car, J. Strobl and G. Griesebner, (Eds.), *GI\_Forum 2014. Geospatial Innovation for Society* (pp. 230 – 241). Berlin, Germany: Wichmann.

- Schultz, R.B., Kerski, J., Patterson, T.C. (2008). The use of virtual globes as a spatial teaching tool with suggestions for metadata standards. *Journal of Geography*, 107(1), pp.27-34.
- Shin, E.E., Milson, A.J., Smith, T.J. (2015): Future Teachers' Spatial Thinking Skills and Attitudes, *Journal of Geography*, DOI: 10.1080/00221341.2015.1100654
- Solem, M., Huynh, N.T., Boehm, R. (2014). Learning Progressions for Maps, Geospatial Technology, and Spatial Thinking: A Research Handbook, National Center for Research in Geography Education, Association of American Geographers.
- Stoltman, J.P., De Chano, L. (2003). Continuity and change in geography education Learning and teaching. In R. Gerber (Ed.) *International handbook on geographical education*. Dordrecht Kluwer Academic Publishers.
- Stump, H., Haldimann, M. (1997) Spatial ability and academic success of sixth grade students at international schools, *School Psychology Internacional*, 18, 3: 245-259.
- Sui, D. Z. (1995). A pedagogic framework to link GIS to the intellectual core of geography. *Journal of Geography* 94: 578-591.
- Thomson, D. (1991). GIS – A view from the other (dark) side: the perspective of an instructor of Introductory Geography Courses at University Level, *Cartographica*, Vol. 28, N° 3, 55-64
- Tschirner, S., O'Brien, M. (2006). GIS into schools: developing a secondary GIS curriculum, <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.100.4843&rep=rep1&type=pdf>
- Tsou, M.H., Yanow, K. (2010). Enhancing General Education with Geographic Information Science and Spatial Literacy., *URISA Journal* • Vol. 22, No. 2 • 2010, pp. 45-55
- Van Leeuwen, W.S., Scholten, H.J. (2009). Spatial literacy: the ABC of the (X,Y,Z). The five senses of GIS in education, *Global Spatial Data Infrastructure Association*, <http://www.gsdi.org/gsdi11/papers/pdf/186.pdf>
- Wannapa, W., Supol, D. (2012). Human Resource. Management and Organizational Innovation. In: *The Business Review*, Vol. 19(2), pp.210-215.
- Wakabayashi, Y., Ishikawa, T. (2011). Spatial thinking in geographic information science: a review of past studies and prospects for the future. *Procedia Social and Behavioral Sciences* 21, 304–313.
- Wolodtschenko (2012) On the new generation of digital mini-atlases. *Proceedings-AutoCarto 2012 – Columbus, Ohio, USA – September 16-18, 2012*. [http://www.cartogis.org/docs/proceedings/2012/Wolodtschenko\\_AutoCarto2012.pdf](http://www.cartogis.org/docs/proceedings/2012/Wolodtschenko_AutoCarto2012.pdf)
- Woloszynska, E., Carlos, V., Carvoeiras, L., Cosac, M., De Lazaro, M., De Miguel, R., De Mira, H., Lambrinos, N., Lang, B., Linder-Fally, M., Martinha, C., Schmeinck, D, Silva, D., Zwartjes, L. (2013), Teaching with Digital-Earth. Guidance for teacher trainers, Digital-Earth.eu network, [www.digital-earth.eu](http://www.digital-earth.eu)
- Zwartjes, L. (2014). The need for a learning line for spatial thinking using GIS in education. In R. de Miguel and K. Donert, (Eds.), *Innovative Learning Geography. New challenges for the 21st Century* (pp. 39-63). Newcastle-upon-Tyne: Cambridge Scholars Publishing.
- Zwartjes, L. (2012). Creating a learning line in education, GIS-education: Where are the boundaries? - 8th European GIS Education Seminar proceedings (Hubeau, M., de Bakker, M., Toppen, F., Reinhardt, W., Steenberghen, T., Van Orshoven, J. Eds.). EUGISES, Leuven, <http://ees.kuleuven.be/eugises12/eugises12-seminar-proceedings.pdf>

