LITERATURE REVIEW ON SPATIAL THINKING

Luc Zwartjes
Maria Luisa de Lázaro
Karl Donert
Isaac Buzo Sánchez
Rafael De Miguel González
Elżbieta Wóloszyńska-Wiśniewska

Funded by the Erasmus+ Programme of the European Union
Content
1 BACKGROUND .......................................................................................................................... 3
2 GI-LEARNER PROJECT .......................................................................................................... 6
3 WHAT IS SPATIAL THINKING .................................................................................................. 7
4 BACKGROUND OF SPATIAL THINKING ............................................................................... 10
5 SPATIAL THINKING TO GEOSPATIAL CRITICAL THINKING ........................................... 14
  5.1 Spatial thinking – critical thinking ..................................................................................... 14
  5.2 Geospatial critical thinking ............................................................................................... 15
  5.3 Participation and spatial citizenship ................................................................................... 18
6 INTEGRATING GIS AS TOOL FOR GEOSPATIAL CRITICAL THINKING ................................ 20
  6.1 GIS in education ................................................................................................................ 20
  6.2 Integrating geospatial thinking in GIScience for secondary school students using GIS .... 27
  6.3 Creating GIS learning outcomes through education ......................................................... 29
  6.4 Some initiatives on geospatial critical smart thinking for students at school .................. 32
7 TAXONOMY INITIATIVES TO EVALUATE SPATIAL THINKING COMPONENTS .................. 34
8 A LEARNING PROGRESSION LINE ON SPATIAL THINKING ........................................... 37
  8.1 Learning progression .......................................................................................................... 37
  8.2 Learning line ...................................................................................................................... 37
  8.3 A draft learning line on geospatial thinking ..................................................................... 39
9 CONCLUSIONS ......................................................................................................................... 43
10 REFERENCES ............................................................................................................................ 44
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 graphicity, 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).

![Spatial Thinking dimensions and related terms according to NRC, 2006. Drawn by: Michel & Hof (2013)](image)

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 21st 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.

GERSMEHL 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)**

<table>
<thead>
<tr>
<th>Location — Where is this place?</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Conditions (Site) - What is at this place?</td>
</tr>
<tr>
<td>b. Connections (Situation) - How is this place linked to other places?</td>
</tr>
</tbody>
</table>

**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)*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Location</td>
<td>Location</td>
<td>Location</td>
</tr>
<tr>
<td>Network</td>
<td>Network</td>
<td>Link, (network)</td>
<td></td>
</tr>
<tr>
<td>Aura</td>
<td>Neighborhood</td>
<td>Area, cluster, (social region)</td>
<td>Buffer</td>
</tr>
<tr>
<td>Region</td>
<td>and region</td>
<td>Central place, (hierarchical order)</td>
<td></td>
</tr>
<tr>
<td>Hierarchy</td>
<td></td>
<td></td>
<td>Change, growth</td>
</tr>
<tr>
<td>Transition</td>
<td>Pattern</td>
<td>Interpolation, (similarity, correlation)</td>
<td>Arrangement, distribution</td>
</tr>
<tr>
<td>Association</td>
<td>Spatial dependence/ heterogeneity</td>
<td>Object, field</td>
<td>Identity, space-time</td>
</tr>
<tr>
<td>Objects and fields</td>
<td>Distance</td>
<td>Identity, (occurrences)</td>
<td></td>
</tr>
<tr>
<td>Scale</td>
<td>Granularity</td>
<td>(Data and representation)</td>
<td>Scale</td>
</tr>
<tr>
<td>Event</td>
<td>Accuracy</td>
<td>(Time–space context)</td>
<td></td>
</tr>
<tr>
<td>Meaning</td>
<td>Value</td>
<td>(Values)</td>
<td></td>
</tr>
<tr>
<td>Comparison</td>
<td></td>
<td>(Comparisons)</td>
<td></td>
</tr>
<tr>
<td>Analogy</td>
<td></td>
<td>(Similarity)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overlays</td>
<td>(Map comparisons)</td>
<td></td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concepts of Space</strong></td>
<td><strong>Spatial Primitives</strong></td>
<td><strong>Location</strong></td>
<td><strong>Visualization</strong></td>
<td>Ability to mentally manipulate, rotate, twist or invert two- or three-dimensional visual stimuli.</td>
</tr>
<tr>
<td>Primitives of identity</td>
<td>Identity/Name</td>
<td>Conditions</td>
<td>Orientation</td>
<td>Ability to imagine how a configuration would appear if viewed from a different orientation or perspective.</td>
</tr>
<tr>
<td>Spatial relations</td>
<td>Location</td>
<td>Connections</td>
<td>Spatial Relations</td>
<td>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.</td>
</tr>
<tr>
<td><strong>Tools of Representation</strong></td>
<td>Magnitude</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal</td>
<td>Time/Duration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>External</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Processes of Reasoning</strong></td>
<td><strong>Simple Spatial Relationships</strong></td>
<td><strong>Modes of Spatial Thinking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extracting spatial structures</td>
<td>Distance</td>
<td>Comparison</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performing spatial transformation</td>
<td>Direction</td>
<td>Region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing functional inferences</td>
<td>Connectivity and linkage</td>
<td>Hierarchy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Movement</td>
<td>Transition</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transition</td>
<td>Analogy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boundaries</td>
<td>Pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Region</td>
<td>Spatial Association</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reference Frame</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arrangement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjacency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enclosure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Complex Relationships</strong></td>
<td><strong>Spatio-Temporal Thinking</strong></td>
<td><strong>Spatial Models</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>Change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pattern</td>
<td>Movement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dispersion/Clustering</td>
<td>Diffusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>Domination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diffusion</td>
<td>Hierarchy/Network</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominance</td>
<td>Association</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overlay/Layer</td>
<td>Gradient/Profile/Relief</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scale</td>
<td>Projection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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)

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

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 (HUYNH 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)

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>GIScience experience results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbott Albert and Golledge</td>
<td>2001</td>
<td>There are not many differences between students using GIS and those who do not.</td>
</tr>
<tr>
<td></td>
<td>1999</td>
<td></td>
</tr>
<tr>
<td>Kerski</td>
<td>2000</td>
<td>Better results and skills to encapsulate, identify and discover territorial elements.</td>
</tr>
<tr>
<td>Hagevik</td>
<td>2003</td>
<td>It develops visualization skills and spatial territorial thinking.</td>
</tr>
<tr>
<td>Patterson, Reeve and Page</td>
<td>2003</td>
<td>Can develop students’ critical spatial thinking (many other authors agree: Wigglesworth, 2003; Liu and Zhu, 2008; Milson and Curtis, 2009).</td>
</tr>
<tr>
<td>Lázaro and González</td>
<td>2005</td>
<td>The potential of GIS tools for learning is coming</td>
</tr>
<tr>
<td>National Research Council/ Committee on Support for Thinking Spatially</td>
<td>2006</td>
<td>GIS had a clearly demonstrated potential as a support system for spatial thinking.</td>
</tr>
<tr>
<td>Kidman and Palmer</td>
<td>2006</td>
<td>The technology is there but the teaching is yet to catch up.</td>
</tr>
<tr>
<td>Demirıcı</td>
<td>2009</td>
<td>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.</td>
</tr>
<tr>
<td>Li et al.</td>
<td>2010</td>
<td>GIS and PBL develop analytical and evaluation skills of students.</td>
</tr>
<tr>
<td>Favier and Van der Schee</td>
<td>2012</td>
<td>Improve learning based on research projects, although teacher and student training is necessary to achieve learning tasks.</td>
</tr>
<tr>
<td>Kim and Bednarz</td>
<td>2013</td>
<td>Improve critical spatial thinking that curricula promote.</td>
</tr>
<tr>
<td>Buzo</td>
<td>2014</td>
<td>Students get actively involved in the learning process using</td>
</tr>
</tbody>
</table>
technology, opening a different window to the world of knowledge and digital skills.

<table>
<thead>
<tr>
<th>De Miguel</th>
<th>2014</th>
<th>Improve critical thinking, motivation and functionality of learning tools.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esteves H.M. &amp;</td>
<td>2015</td>
<td>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.</td>
</tr>
</tbody>
</table>

### 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 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 geomedia construction; recognition of specific representations; comparison of geomedia
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)](image)

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)](image)

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

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

<table>
<thead>
<tr>
<th>Item #</th>
<th>Test items by dimension</th>
<th>Factor loading (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I tend to see patterns among things, for example, an arrangement of tables in a restaurant or cars in a parking lot.</td>
<td>.28 (.07)</td>
</tr>
<tr>
<td>2</td>
<td>I tend to see and/or search for regularities in everyday life when viewing objects or phenomena.</td>
<td>.31 (.07)</td>
</tr>
<tr>
<td>3</td>
<td>I do not pay attention to reading and interpreting spatial patterns such as locations of cars in a parking lot.</td>
<td>.59 (.07)</td>
</tr>
<tr>
<td>4</td>
<td>When I use maps to find a route, I tend to notice overall patterns in the road network.</td>
<td>.66 (.08)</td>
</tr>
<tr>
<td>5</td>
<td>I am curious about patterns in information or data, that is, where things are and why they are where they are.</td>
<td>.63 (.07)</td>
</tr>
<tr>
<td>6</td>
<td>When I use maps showing things such as population density, election results, or highways, I try to recognize patterns.</td>
<td>.67 (.07)</td>
</tr>
<tr>
<td>7</td>
<td>I rarely use spatial vocabulary such as location, direction, diffusion, and network.</td>
<td>.82 (.06)</td>
</tr>
<tr>
<td>8</td>
<td>I use spatial terms such as scale, distribution, pattern, and arrangement.</td>
<td>.80 (.06)</td>
</tr>
<tr>
<td>9</td>
<td>Using spatial terms enable me to describe certain things more efficiently and effectively.</td>
<td>.87 (.06)</td>
</tr>
<tr>
<td>10</td>
<td>I have difficulty in describing patterns using spatial terms, such as patterns in bus routes or in the weather.</td>
<td>.44 (.06)</td>
</tr>
<tr>
<td>11</td>
<td>I tend to use spatial terms such as location, pattern, or diffusion to describe phenomena.</td>
<td>.76 (.07)</td>
</tr>
<tr>
<td>12</td>
<td>When I am thinking about a complex idea, I use diagrams, maps, and/or graphics to help me understand.</td>
<td>.63 (.07)</td>
</tr>
<tr>
<td>13</td>
<td>It is difficult for me to construct diagrams or maps to communicate or analyze a problem.</td>
<td>.62 (.07)</td>
</tr>
<tr>
<td>14</td>
<td>When a problem is given in written or oral form, I try to transform it into visual or graphic representation.</td>
<td>.48 (.09)</td>
</tr>
<tr>
<td>15</td>
<td>When I assemble something such as furniture, a bicycle, or a computer, written instructions are more helpful to me than pictorial instructions.</td>
<td>.20 (.08)</td>
</tr>
<tr>
<td>16</td>
<td>I find that graphs, charts, or maps help me learn new concepts.</td>
<td>.47 (.06)</td>
</tr>
<tr>
<td>17</td>
<td>It is helpful for me to visualize physical phenomena such as hurricanes or weather fronts to understand them.</td>
<td>.56 (.06)</td>
</tr>
<tr>
<td>18</td>
<td>I like to support my arguments/presentations using maps and diagrams.</td>
<td>.80 (.06)</td>
</tr>
<tr>
<td>19</td>
<td>I like to study data or information with the help of graphics such as charts or diagrams.</td>
<td>.85 (.06)</td>
</tr>
<tr>
<td>20</td>
<td>When trying to solve some types of problems, I tend to consider location and other spatial factors.</td>
<td>.54 (.07)</td>
</tr>
<tr>
<td>21</td>
<td>I have difficulty in explaining spatial concepts such as scale and map projection to my friends.</td>
<td>.61 (.06)</td>
</tr>
<tr>
<td>22</td>
<td>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.</td>
<td>.49 (.07)</td>
</tr>
<tr>
<td>23</td>
<td>Spatial concepts, such as location and scale, do not help me solve problems.</td>
<td>.60 (.06)</td>
</tr>
<tr>
<td>24</td>
<td>I use maps and atlases (including digital versions) frequently.</td>
<td>.77 (.07)</td>
</tr>
<tr>
<td>25</td>
<td>I do not like using maps and atlases (including digital versions).</td>
<td>.81 (.06)</td>
</tr>
<tr>
<td>26</td>
<td>I enjoy looking at maps and exploring with mapping software such as Google Earth and GIS.</td>
<td>.66 (.06)</td>
</tr>
<tr>
<td>27</td>
<td>Activities that use maps are difficult and discourage me.</td>
<td>.66 (.06)</td>
</tr>
<tr>
<td>28</td>
<td>I like to use spatial tools such as maps, Google Earth, or GPS.</td>
<td>.47 (.09)</td>
</tr>
</tbody>
</table>

Source: Kim (2011, 107–126)

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
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).

![GIS Conceptual Framework](image)

**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.

![Table: Implications for GIS Instructional Approaches](image)

**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).
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 todays and tomorrows 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 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 geomedia 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 primordially 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.

![Diagram of Geo-media](image)

**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\(^1\), 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

---

\(^1\) 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:
  o Being able to work with others – teamwork
  o 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
  o Find significant locations (their home, school or town) on a virtual globe
  o Pan, zoom, orientate
  o Make measurements
  o Use the layers to focus on specific features
  o 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
  o Display information on maps
  o Create own maps
  o Communicate cartographic information
• Understand the construction of digital maps as a representation of the real world
  o The power of maps (reliability of data, classification and colour schemes)
  o Topology: points, lines, polygons
  o Layers
  o 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/geospatialssemester), 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)](Image)
Table 10: Spatial projects in IES San Roque School (Buzo, 2015)

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

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 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)](image-url)
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)](image-url)

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)

<table>
<thead>
<tr>
<th>Component 1: Concepts of Space</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nonspatial</strong>: No spatial component in the question.</td>
</tr>
<tr>
<td><strong>Spatial Primitives</strong>: the lowest level concept of space, involves the concepts of location, place-specific identity, and/or magnitude.</td>
</tr>
<tr>
<td><strong>Simple-Spatial</strong>: 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.</td>
</tr>
</tbody>
</table>
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)*

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

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 MOOLENBOEK & 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)](image)

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

<table>
<thead>
<tr>
<th>Competence Areas</th>
<th>Primary 6 – 10 y</th>
<th>Lower Secondary 11 – 14 y (In addition to 6-10 y)</th>
<th>Upper Secondary 15 – 18 y (In addition to 11-14 y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>understanding / analysing digital geomedia</td>
<td>reading, orientating, combining, interpreting, measuring, comparing, querying</td>
<td>geo processing network analysis spatial analysis</td>
<td></td>
</tr>
<tr>
<td>producing and communicating digital geomedia</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>critical use / awareness of digital geomedia in everyday life</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>geographical technology: hardware &amp; tools</td>
<td>GPS, digital maps, virtual globes web mapping</td>
<td>3D representations of the world (DEM) satellite images open geodata online, desktop and mobile GIS</td>
<td></td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Upper anchor</th>
<th>Lower anchor</th>
</tr>
</thead>
</table>
| Spatial Aspects of Conflict | • 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  
• 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 | • The concepts and skills the learning progression will encompass (table 16)  
• determine the age that would make the most sense for the lower anchor of the progression (table 17) |

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

<table>
<thead>
<tr>
<th>Spatial Concepts</th>
<th>Student Understandings and Possible Misconceptions and Challenges</th>
<th>Ages 3-6 (Pre-K through Grade 1)</th>
<th>Ages 7-9 (Grades 2-4)</th>
<th>Ages 10-12 (Grades 5 and 6)</th>
</tr>
</thead>
</table>
| 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.  
Studies of Interest: Blades and Spencer 1990; Blaustein and Aronoff 1979; Downs, Liben, and Dagg 1998; Hatie and Vatisty藤 1995; Liben 2003; Liben and Downs 1995; Presson 1982; Sadow, Shea, Blades, and Spencer; and Blaustein 1996 | Students can accurately locate places and landscape features on a map, but perform better with familiar locations as opposed to foreign locations. Map alignment issues also improve at this age. However, students inconsistently use landmarks to verify locations.  
Studies of Interest: Blaustein and Shea 1971; Golledge, Batterby, and Marsh 2003b; Kasten and Liben 2010, 2007 | Students need to be primed to use all the resources available to determine locations, and encouraged self-exploration of decisions, to cue thinking more about landmarks, distances, and directions. Students do not readily use map scales, metric distance, 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.  
Studies of Interest: Blaustein and Shea 1971; Golledge and Trimmer 1997; Liben 2008; Liben and Downs 1993; Trettler et al. 2008 |
| 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).  
Studies of Interest: Golledge, Batterby, and Marsh 2003b; Mc 1999; Rousseau, Palmer, and Noel 2004 | 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 distance, but some need to learn cardinal directions.  
Studies of Interest: Kasten and Liben 2010 | |
| 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.  
Studies of Interest: Blades, Sadow, and Spencer 1995; Blades and Spencer 1987; Liben 2003; Liben and Downs 1992; Roland, Cusset, and Campbell 1993 | 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.  
Studies of Interest: Bell 2000; Liben 2008; Kasten and Liben 2010; Newcombe and Frick 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).  
Studies of Interest: Newcombe and Frick 2010; Newcombe and Hatie and Vatisty藤 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.  
Studies of Interest: Bell 2000; Liben 2008; Kasten 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 & the size of a school depicted on a map.  
Studies of Interest: Liben 2008; Uttal 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.  
Studies of Interest: Bell 2000; Liben 2008; Kasten and Liben 2010; Newcombe and Frick 2010 | |
| 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).  
Studies of Interest: Liben 2008, 2009; Myers and Liben 2008 | During this age, students transition between iconic/world symbols to abstract symbols, but they still make significant errors; explicit guidance needed on what symbols mean.  
Studies of Interest: Golledge, Batterby, and Marsh 2003b; Liben 2009, 2008; Myers and Liben 2008 | Students can use abstract symbols and understand symbols do not always "look like" the referent.  
Studies of Interest: Golledge, Batterby, and Marsh 2003b; Liben 2009, 2008; Myers and Liben 2008 |
| Hierarchies | Concept of hierarchy (or nesting) is not well established intuitively with this age group, but can possibly be introduced with close guidance.  
Studies of Interest: Lovas 2008 | About half of all 4th grade students incidentally understand the concept of overlay without formal instruction. Guidance using map overlays is 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.  
Studies of Interest: Batterby, Golledge, and March 2006 | |
| Overlay and Other Complex Spatial Tasks | | | |

GI Learner 41
Table 17: Determining the spatial concepts of the lower anchor in table 15 by grade (Solem et al., 2014)

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


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


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


