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The GI-Learner Approach: Learning Lines for Geospatial Thinking in Secondary Schools

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Abstract

This paper introduces basic considerations that inform education for geospatial thinking, as proposed in the KA2 Erasmus Plus GI-Learner project. It reports on some initial state-of-the-art activities of the project, presents a list of GI-Learner competences based on a broad literature review and establishes a roadmap for future support activities for geospatial learning.

Keywords:

spatial thinking, secondary education, teacher training

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 the near ubiquitous availability of tools like GPS and car navigation systems, the general public has started to become aware of some of the potential of interfaces that deliver spatial data.

Space and location make spatial thinking a distinct, basic and essential skill that can and should be learned in school education, alongside others like language, mathematical and scientific skills The goal of the GI-Learner project 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:

i) address key internal issues related to GIS implementation: teacher training, availability of user-friendly software and of ICT equipment in schools
ii) use a "community of learners" approach

iii) establish GIScience in school curricula, making sure that it is aligned with significant general learning goals like graphicacy, critical thinking and citizenship.

In terms of the first two recommendations, considerable progress has already been made. For example, there are now more training materials for teachers available through 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 may even be asked bring their own devices, data is more readily available, and web-based platforms have reduced or eliminated software costs.

GIS expertise is being widely shared. The digital-earth.eu network launched "Centres of Excellence" in 15 European countries in 2012 (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 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 examples of good practice and organizing sessions with teachers. However, there is still a need for much more training, additional learning and teaching materials, more examples of good practice, and a comprehensive and well-structured compilation of digital-earth tools.

The institutionalization of geo-technology and geo-media into secondary school curricula remains a goal yet to be achieved in almost all countries, despite the development of:

i) benchmarks (Herodot, 2009; Lindner-Fally & Zwartjes, 2012), intended to provide a rationale and recommendations on the implementation of a GI curriculum in schools, with assistance for teacher trainers, teachers and headteachers, but also advice for policy and decision makers
ii) competence models (SchulzE et al., 2012, 2013, 2015; GRYL et al., 2013)
iii) teacher guidance (Zwartjes, 2014), helping teachers to select suitable tools to use, based on curricula, abilities of their students and their own capabilities.
iv) innovative projects such as iGuess, SPACIT, EduGIS Academy, I-Use.

GI-Learner aims to respond to this by the development of a GIScience learning line for secondary schools, so that the integration of spatial thinking can take place. This implies translating spatial and other competences, taking into account the age and capabilities of students, into real learning objectives. Establishing GIScience firmly in the school curriculum will increase spatial-thinking education activities and help produce geospatially literate citizens and the workforce we need now and for the future.

2 GI-Learner project

GI-Learner (http://www.gilearner.eu) is a project supported by Key Action 2 of the Erasmus Plus education programme. It is a three-year project, which started in December 2015, with seven partners from five European countries. It aims to help teachers implement learning lines for spatial thinking in secondary schools, using GIScience. In order to do this, the project:

1) summarizes the most important literature on learning lines and spatial thinking
2) scans curricula in partner countries to identify opportunities to introduce spatial thinking and GIScience
3) defines geospatial-thinking competencies
4) develops an evaluative tool to analyse the impact of the learning lines on geospatial thinking
5) creates initial draft learning lines, translating them into learning objectives, and teaching and learning materials for the school 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. A diagnostic tool will also be developed, tested, assessed and revised. The final version of the GI-Learner learning outcomes will then be written and published. Further materials for learning lines will then be developed for year groups K8 and K11 in the second year of the project and K9 and K12 and third year. Finally, a publication with guidelines for suggested inclusion of GIScience into national curricula will be produced.

GI-Learner will also 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 of the target groups in terms of their age, gender, ethnicity or other aspects. The specific geospatial abilities to be examined can be selected, whether geospatial-thinking ability is to be evaluated in a holistic manner or in a partial way.

3 Learning lines

Lindner-Fally & Zwartjes (2012) defined a learning line as the construction of knowledge and skills throughout the whole curriculum. It should reflect a growing level of complexity, ranging from easy (basic skills and knowledge) to difficult, as illustrated in the Flemish curriculum (Leerplancommissie Aardrijkskunde, 2010) for secondary geography (Table 1).

Table 1: Learning lines in the Flemish geography curriculum for secondary education (Lindner-Fally & Zwartjes, 2012)

Learning lines	Fieldwork	Working with images	Working with maps	Working with statistics	Creation of knowledge
Level 1	Perception – knowledge of facts				
Level 2	Analysis – selection of relevant geographic information				
Level 3	Structure – looking for complex connections and relationships				
Level 4	Application – critical thinking and problem solving				

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

Van Moolenbroek & Boersma (2013) describe the elaboration of a learning line for biology education, using a "concept-context" approach for selecting learning goals and organizing knowledge. The approach related scientific concepts to contexts, thereby improving engagement with the science curriculum by selecting contexts that were relevant for the students. With this they integrated a problem-posing approach that explicitly takes a learner's point of view.

Perdue & Lobben (2013) proposed a spatial-thinking framework and hypothesized that certain spatial-thinking skills are of a higher order than others and build upon previous, less complex skills (Figure 1). So, in the example shown, regional identification is conceptualized as a high-level skill achieved through the accumulation of boundary, proximity, classification and clustering skills.

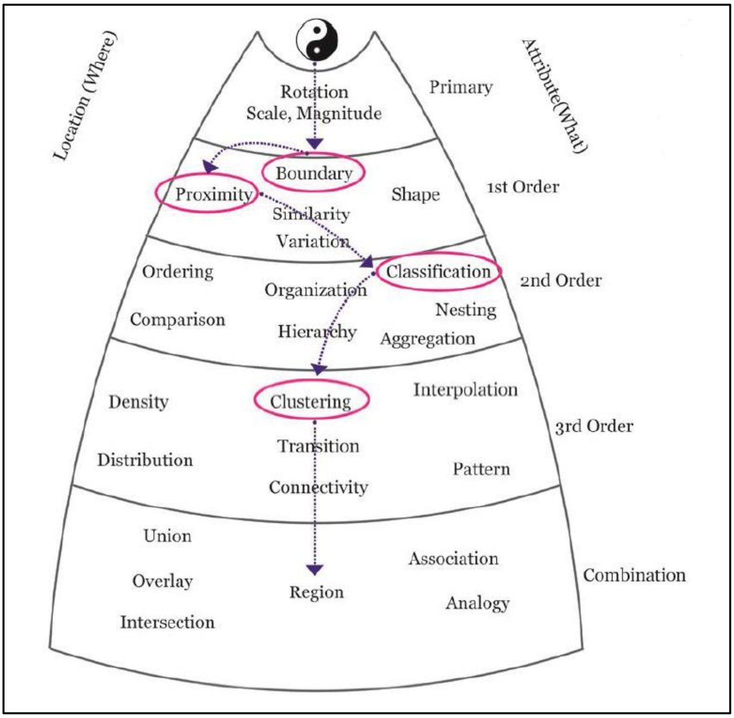

Figure 1: Spatial-thinking framework (perdue & lobben, 2013)

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

4 Dimensions, modes and frameworks of spatial thinking

Spatial thinking is a distinct form of thinking, which helps people to visualize relationships between and among spatial phenomena (Stoltman & De Chano, 2003). It strengthens students' abilities to conduct scientific inquiry and engage in problem solving. Lee and Bednarz (2009) described 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. Bednarz & Lee (2011) confirmed that spatial thinking is not a single ability but comprises a collection of different skills.

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, literacy and basic mathematics. Students need to know the building blocks of spatial thinking. There have been many attempts to analyse, organize, classify and define these, and the remainder of this section examines some of the key literature.

Gersmehl & Gersmehl (2006; 2007; 2011) reviewed neuroscience research, observing how different areas of the brain are related to the kinds of "thinking" that appear to be done. They suggested that long-lasting learning of geographic information is more likely to occur when lessons are explicitly designed so that students perform spatial tasks. They proposed eight modes of spatial thinking (Table 2). They confirmed that students would greatly benefit if spatial-thinking skills were more prominently placed in the school curriculum, and concluded that several brain regions appear to be devoted to doing specific kinds of thinking – about locations and spatial relationships.

Table 2: Modes of Spatial Thinking (adapted from Gersmehl & Gersmehl, 2011)

Location — Where is this place? a. Conditions (Site) - What is at this place? b. Connections (Situation) - How is this place linked to other places? **Eight aspects of Spatial Thinking** (an example of a concrete activity) 1. **Spatial comparison** – similarities and differences between places 2. **Spatial influence** (Aura) – the effect of a place on the surrounding areas 3. **Spatial groups** (Region) – regions of similar places 4. **Spatial transition** – changes taking place 5. **Spatial hierarchy** – where and how does a place fit in 6. **Spatial** analogies – places with similar situations 7. **Spatial patterns** – how features are arranged 8. **Spatial associations** (correlations) – possible causal relationships **Spatio-temporal thinking** - How do spatial features and conditions change over time?

The National Research Council (NRC, 2006) defined spatial thinking as a collection of cognitive skills, comprising knowing concepts of space, using tools of representation, and reasoning processes (Figure 2). the national academy of sciences (2006) proposed five skills sets: asking geographic questions, acquiring geographic information, organizing geographic information, analysing geographic information, and answering geographic questions.

The Committee On Support For Thinking Spatially (2006) suggested that spatial thinking involves three component tasks: extracting spatial structures, performing spatial transformations, and drawing functional inferences. Representations are used to help us remember, understand, reason and communicate about the properties of and relations between objects represented in space.

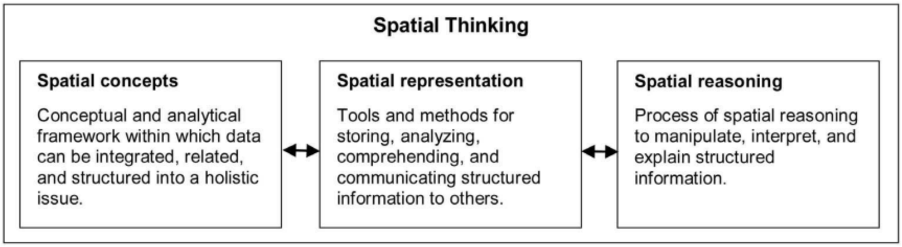

Figure 2: Spatial Thinking: dimensions and related terms (Michel & Hof, 2013)

Many interpretations of spatial thinking have sought to establish hierarchical classifications. Kim & Bednarz (2013) examined spatial habits of mind. These are the broadest learning outcomes, which are based mainly on ways of thinking. They identified five spatial sub-dimensions: pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use (Table 3); they also described basic and extension modes.

Table 3: Five spatial habits of mind (adapted from Kim & Bednarz, 2013)

Pattern Recognition	students should be taught and encouraged to foster their spatial habits to recognize patterns in their everyday life	extension: recognize, describe and predict spatial patterns
Spatial Description	Students can use spatial vocabulary proficiently	extension: a more advanced spatial lexicon, and more frequent use of spatial vocabulary
Visualization	Students increase understanding through the aid of graphic representations	extension: enhance comprehension by converting the information into visual representations; understand the benefit and power of graphic representations
Spatial Concept Use	Students use or apply spatial concepts to understand and perform various tasks	extension: employ spatial concepts to understand surroundings

Spatial Tool Use	Students use spatial representations and tools to support spatial thinking; exposure to tools helps understand space and develop spatial cognition	extension: use spatial tools to solve problems

Newcombe and Shipley (2015) identified five classes of spatial skills, on which they carried out research in order to classify different spatial abilities. They identified an intrinsic-static skill (disembedding), two intrinsic-dynamic skills (spatial visualization and mental rotation), an extrinsic-static skill (spatial perception), and an extrinsic-dynamic skill (perspective taking).

Jarvis (2011) considers the term "spatial thinking" to be a very broad subject but integral to the process of spatial literacy acquisition. Fostering an ability to make the links between space, representation and reasoning (or to think spatially) is central to spatial literacy. She examines the process of spatial literacy acquisition, derived from spatial thinking, based on on three components – abilities, strategies and knowledge. She offers a meta-level spatial framework for GIScience that includes (i) representations: the properties of entities; (ii) comparisons: relations between static entities; (iii) comparisons: relations between dynamic entities; (iv) transformations of representations of entities; (v) complex spatial reasoning: combining components to solve problems.

Cook et al. (2014) add a strategic domain to spatial thinking, applying it to the need for planning or developing programmes designed to achieve future goals. They say that developing a strategy enables the design of approaches that can help meet future challenges. Their approach specifies preparation and anticipation to reach an ideal, but possible, state.

Jo & Bednarz (2009) developed a taxonomy to evaluate different components of spatial thinking in the curriculum, textbooks, lesson plans and other educational materials. Jo et al. (2010) used this taxonomy to examine questioning in spatial thinking as part of everyday teaching practice and applied it to the pedagogical strategy of questioning in both texts and as part of classroom activities. Their taxonomy 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. They make the case that a spatial thinking taxonomy 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 with regards to its use of spatial concepts and the cognitive processes required.

Scholz et al. (2014) used JO et al's (2010) system to identify the level and type of spatial thinking found in textbook questions (Table 4). They suggested a simplified taxonomy for evaluating materials, integrating all three components.

Table 4: Three components of spatial thinking in questions (adapted from Scholz et al., 2014)

Component 1: Concepts of Space
Nonspatial: No spatial component in the question.
Spatial Primitives: the lowest level concept of space, involves the concepts of location and place-specific identity and/or magnitude.
Simple-Spatial: A higher-level concept of space, based on concepts and distributions, including distance, direction, connection and linkage, movement, transition, boundary, region, shape, reference frame, arrangement, adjacency and enclosure.
Complex-Spatial: The highest-level concept of space, based on high-order derived concepts, 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
This component evaluates the cognitive level of the question.
Input: The lowest level – receiving of information; 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.

This section has not attempted 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 or virtual, individual or collective, intuitive or taught.

Based on this review, ten GI-Learner geospatial thinking competences are proposed by the project team:

- Critically read and interpret cartographic and other visualizations 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 inter-relationships
- Synthesise meaning from analysis
- Reflect, and act on the basis of knowledge.

5 Some domains connected with spatial thinking

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, some areas of Mathematics, and History (LAMBRINOS & ASIKLARI, 2014). 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.

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.

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. They argue that concepts of space and place, and space and time should therefore be central themes in education, as part of a fundamental shift from disciplinary to multidisciplinary systems. The term "critical" describes 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. Goodchild & Janelle suggest that critical spatial thinkers will be able to recognize and understand the assumptions and limitations underlying spatial data, its representation, and the reasoning associated with it. Spatial technologies are perceived as an essential, integrating element that cut across disciplines through the use of common language and concepts (BARNIKEL & PLOETZ, 2015).

Criticality is central to engagement, participation and action; it is directly related to concepts of spatial citizenship (GRYL et al., 2010; GRYL & JEKEL, 2012). The concept of spatial citizenship was developed as an aspect of "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 are used in a spatial citizenship context to help acquire instrumental knowledge and find solutions to problems, and to understand more complex issues. Web 2.0 developments actively promote the importance of geo-participation and geo-communication (GRYL, 2012).

Schulze et al. (2012) analysed major dimensions connected with spatial thinking during the Spatial Citizenship project. They extracted and described seven interconnected competencies, namely critical thinking, geography, GIS knowledge and skills, problem solving, spatial thinking, teamwork and collaboration, and visualization and communication (Table 5).

Table 5: Domains connected with spatial thinking (SchulzE et al., 2013)

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

6 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 require additional attention to be paid to spatial thinking in teacher-training courses.

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References

Barnikel, f. & Ploetz, R., 2015. The acquisition of spatial competence – fast and easy multidisciplinary learning with an online GIS. European Journal of Geography, 6 (2), 6-14

Bednarz, S. W. & van der Schee, J., 2006. Europe and the United States: the implementation of geographic information systems in secondary education in two contexts. Technology, Pedagogy and Education, 15 (2), 191-205

Bednarz, R. & Lee, J., 2011. The components of spatial thinking: empirical evidence. Procedia Social and Behavioral Sciences 21, 103-107

Bloemen, h. & Naaijkens, A., January 2014. Designing a (continuous) learning line for literary translation. In Second International Conference on Research into the Didactics of Translation: Book of Abstracts (pp. 36-36). PACTE group, https://lirias.kuleuven.be/handle/123456789/489288

Charcharos, C., Tomai, E., & Kokla, M,. 2015. Assessing spatial thinking ability. GEOTHNK International Closing Conference, Athens, Greece, 7 November 2015, https://www.academia.edu/20584709/Assessing_Spatial_Thinking_Ability

Committee on Support for Thinking Spatially, 2006. Learning to Think Spatially, Washington, DC: National Academies Press

Cook, C.N., Inayatullah, S., Burgman, M.A., Sutherland, W.J. & Wintle, B.A., 2014. Strategic foresight: how planning for the unpredictable can improve environmental decision-making. Trends in Ecology & Evolution, 29(9), 531-541

Donert, K., 2015. Digital earth – digital world: strategies for geospatial technologies in twenty-first century education. In: Solari, O.M., Demirci, A. and van der Schee, J., Geospatial Technologies and Geography Education in a Changing World, 195-204. [city?,] Japan: Springer

Gersmehl, P.J. & Gersmehl, C.A., 2006. Wanted: a concise list of neurologically defensible and assessable spatial-thinking skills. Research in Geography Education, 8, 5-38

Gersmehl, P.J. & Gersmehl, C.A., 2007. Spatial thinking by young children: eurologic evidence for early development and "educability". Journal of Geography, 106(5), 181-191

Gersmehl, P.J. & Gersmehl, C.A., 2011. Spatial thinking: where pedagogy meets neurocience. Problems of Education in the 21st Century, 27, 48-66

Goodchild, M., 2006. The Fourth R? Rethinking GIS Education, ArcNews Fall 2006.

Goodchild, M.F. & Janelle, D.G., 2010. Toward critical spatial thinking in the social sciences and humanities. GeoJournal, 75(1), 3-13

Gryl, I., 2012. A web of challenges and opportunities. New research and praxis in Geography education in view of current Web technologies. European Journal of Geography, 3, 33-43

Gryl, I., Jekel, T. & Donert, K., 2010. GI & spatial citizenship. In Jekel, T., Koller, A., Donert, K. & R. Vogler (eds.), Learning with Geoinformation V, Berlin: Wichmann, 2-11

Gryl, i. & Jekel, T., 2012. Re-centering GI in secondary education. Towards a spatial citizenship approach. Cartographica, 47(1), 18-28

Gryl, I., Schulze, U. & Kanwischer, D., 2013. Spatial citizenship: the concept of competence. GI_Forum 2013: Creating the GISociety – Conference Proceedings, 282-293, http://hw.oeaw.ac.at/0xc1aa500e_0x002e6e6c.pdf

HERODOT, 2009. Benchmarks in Geography, HERODOT Network for Geography in Higher Education, http://www.herodot.net/geography-benchmark.html
Jarvis, C.H., 2011. Spatial literacy and the postgraduate GIS curriculum. Procedia-Social and Behavioral Sciences, 21, 294-299
Jo, I., & Bednarz, S. W., 2009. Evaluating geography textbook questions from a spatial perspective: using concepts of space, tools of representation, and cognitive processes to evaluate spatiality. Journal of Geography, 108, 4-13
Jo, I., Bednarz, S. & Metoyer, S., 2010. Selecting and designing questions to facilitate spatial thinking. The Geography Teacher, 7(2), 49-55
Kerski, J., 2008. Developing Spatial Thinking Skills in Education and Society. ArcWatch 2008, ESRI. http://www.esri.com/news/arcwatch/0108/spatial-thinking.html
Kim, M. and Bednarz, R., 2013. Development of critical spatial thinking through GIS learning. Journal of Geography in Higher Education, 37(3), 350-366
Koutsopoulos, C. K., & Kotsanis, Y. C., 2014. School on cloud: towards a paradigm shift. Themes in Science and Technology Education, 7(1), 47-62, http://earthlab.uoi.gr/theste/index.php/theste/article/view/147/96
Lambrinos, N. & Asiklari, F., 2014. The introduction of GIS and GPS through local history teaching in primary school. European Journal of Geography, 5(1), 32-47
Lee, J. & Bednarz, R. 2009. Effect of GIS learning on spatial thinking. Journal of Geography in Higher Education, 33(2), 183-198
Leerplancommissie Aardrijkskunde, 2010. Aardrijkskunde Tweede Graad ASO, VVKSO, Brussels, http://ond.vvkso-ict.com/vvksomainnieuw/document.asp?DocID=2431
Lindner-Fally, M. & Zwartjes, L., 2012. Learning and teaching with Digital Earth – teacher training and education in Europe. In: Jekel, T., Car, A., Strobl, J. & Griesebner, G. (eds.), GI_Forum 2012: Geovisualization, Society and Learning, 272-282, http://gispoint.de/fileadmin/user_upload/paper_gis_open/537521027.pdf
Michel, E. & Hof, A., 2013, Promoting spatial thinking and learning with mobile field trips and eGeo-riddles. In Jekel, T., Car, A., Strobl, J., Griesebner, G. (eds.), GI_Forum 2013: Creating the GISociety, Berlin: Wichmann, 378-387
National Academy of Sciences, 2006. Learning to Think Spatially – GIS Across the K-12 Curriculum. Washington, DC: National Academy of Sciences.
Newcombe, N.S. & Shipley, T.F., 2015. Thinking about spatial thinking: new typology, new assessments. In: Gero, J.S. (ed.), Studying Visual and Spatial Reasoning for Design Creativity, 179-192. Doordrecht: Springer
NRC, 2006. Learning to think spatially: GIS as a support system in the K-12 curriculum. Washington, DC: National Academies Press
Perdue, N. and Lobben, A., 2013. The challenges of testing spatial thinking skills with participants who are blind or partially sighted. Sharing knowledge, In: Reyes Nuñez J. J.. Sharing Knowledge. Joint ICA Symposium, http://lazarus.elte.hu/ccc/2013icc/skproceedings.pdf#page=112
Scholz, M.A., Huynh, N.T., Brysch, C.P. & Scholz, R.W., 2014. An evaluation of university world geography textbook questions for components of spatial thinking. Journal of Geography, 113(5), 208-219
Schulze, U., Gryl, I., & Kanwischer, D., 2012. A Competence Model for Spatial Citizenship education, SPACIT Project, http://www.spatialcitizenship.org/media/WP2_report_D2_1-final_.pdf
Schulze, U., Kanwischer, D. and Reudenbach, C., 2013. Essential competences for GIS learning in higher education: a synthesis of international curricular documents in the GIS&T domain. Journal of Geography in Higher Education, 37(2), 257-275
Schulze, U., Gryl, I., & Kanwischer, D., 2014. Spatial citizenship: creating a curriculum for teacher education. In: Vogler R., Car. A., Strobl J. & Griesebner G. (eds.), Geospatial Innovation for Society, Berlin: Wichmann, 230-241

Schultz, U., Gryl, I. & Kanwischer, D., 2015. Spatial citizenship education and digital geomedia: composing competences for teacher education and training. Journal of Geography in Higher Education, 39(3), 369-385

Shin, E.E., Milson, A.J. & Smith, T.J., 2015. Future teachers' spatial thinking skills and attitudes. Journal of Geography, 115, 4, 1-8.

Stoltman, J., & De Chano, L., 2003. Continuity and change in geography education: learning and teaching. In R. Gerber (ed.), International Handbook on Geographical Education, Dordrecht: Kluwer, 115-137

Tsou, M.H. & Yanow, K., 2010. Enhancing general education with geographic information science and spatial literacy, URISA Journal, 22 ,2, 45-55

Van Moolenbroek, A., & Boersma, K., 2013. Behavioural biology: developing a learning and teaching strategy in upper secondary education. In T. Plomp & N. Nieveen (eds.), Educational Design Research – Part B: Illustrative Cases, 601-617. Enschede, The Netherlands: SLO, http://www.vanmoolenbroek.nl/wp-content/uploads/2015/01/Ch29.pdf

Young, M., 2010. Alternative educational futures for a knowledge society. European Educational Research Journal, 9(1), 1-12

Zwartjes, L., 2014. The need for a learning line for spatial thinking using GIS in education, In de Miguel González, R. & Donert K. (eds.), Innovative Learning Geography in Europe: New Challenge for the 21st Century, 39-62, Newcastle: Cambridge Scholars Publishing