GI-Learner: a project to develop geospatial thinking learning lines in secondary schools

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Abstract

This paper introduces the KA2 Erasmus Plus project GI-Learner, which has been funded by the European Commission from 2015-2018. It reports on the initial state-of-the-art activities of the project, presents a list of GI-Learner competences and establishes a roadmap for the future of the project.

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:

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

In terms of the first two recommendations considerable progress has already been made, for example there have been more training opportunities for teachers as the EduGIS Academy (http://www.edugis.pl/en/), iGuess (http://www.iguess.eu), I-Use (http://www.i-use.eu) and SPACIT (http://www.spatialcitizenship.org) projects, schools nowadays generally have better ICT equipment, pupils are asked bring their own devices, data is more freely available and Web-based platforms have reduced costs. The digital-earth.eu network launched ‘Centres of Excellence’ in 15 European countries (http://www.digital-earth-edu.net). The Geo For All imitative 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:

i) 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
ii) competence models (SCHULZE et al., 2012, 2013, 2015, GRYL et al. 2013),
iii) teacher guidance (ZWARTJES, 2014) whereby teachers can select suitable tools to use, based on curricula, abilities of their students and their own capabilities and
iv) 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.

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:

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 analyze the impact of the learning lines on geospatial thinking and
5) 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 Learning lines

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 (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 – look for complex connections and relationships				
Level 4	Application – thinking problem solving				

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

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

PERDUE et al. (2013) proposed a spatial thinking framework and hypothesized that certain spatial thinking skills are higher order than others and build upon previous, less complex skills (Figure 1). 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.

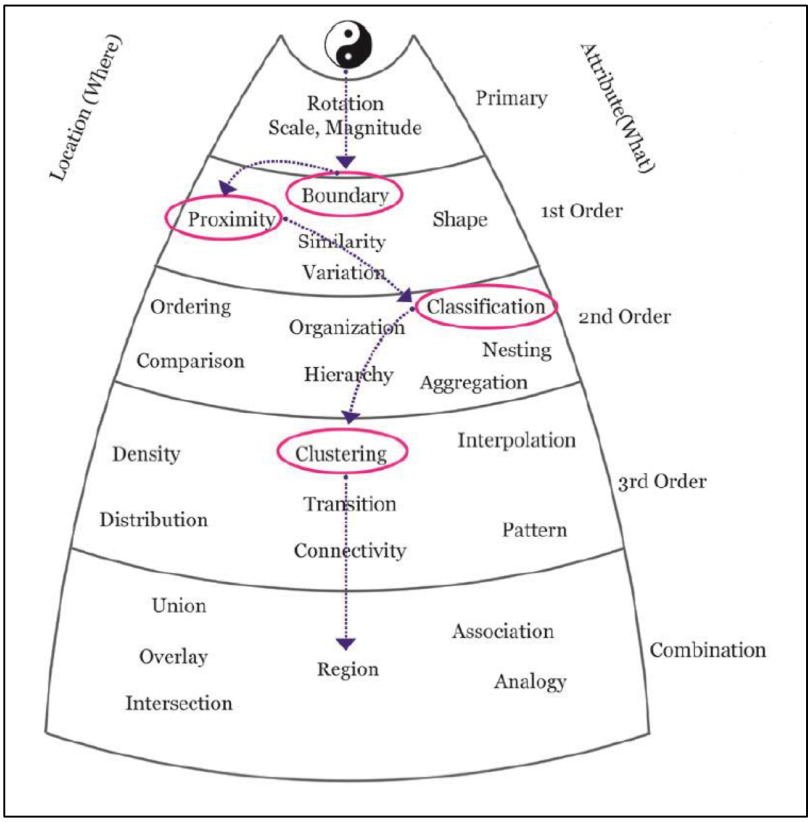

Figure 1: Spatial thinking framework (PERDUE, 2013)

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

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, engage in problem solving and think spatially. 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 spatial thinking is not a single ability but comprised of 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 and mathematics. Students need to know the building blocks of spatial thinking. There have been many attempts to analyse, organise, classify and define them. The remainder of this section examines some of the key literature.

GERSMEHL & GERSMEHL (2006; 2007; 2011) reviewed neuroscience research observing how areas of the brain are related to the kinds of "thinking" that appear to be done. They suggested 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 AND GERSMEHL, 2011)

Location — Where is this place?
a. Conditions (Site) - What is at this place?
b. Connections (Situation) - How is this place linked to other places?

Eight aspects of Spatial Thinking (an example of a concrete activity)
1. **Spatial comparison** – similarities and differences between places
2. **Spatial influence** (Aura) – the effect of a lace 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 comprised of 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; analyzing geographic information; and answering geographic questions.

The COMMITTEE ON SUPPORT FOR THINKING SPATIALLY (2006) suggested spatial thinking involves breaking the process down into 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.

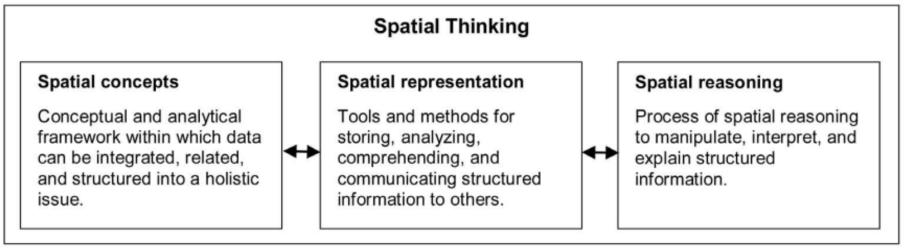

Figure 2: Spatial Thinking dimensions and related terms (MICHEL & HOF, 2013)

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 mainly based on ways of thinking. They identified five spatial sub-dimensions: pattern recognition, spatial description, visualization, spatial concept use, and spatial tool use (Table 3) and 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 graphical 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: spatial thinkers using spatial tools to solve problems

NEWCOMBE AND SHIPLEY (2015) identified five classes of spatial skills on which research was done to classify spatial abilities. They identified an intrinsic-static skill (disembedding), two intrinsic-dynamic skills (spatial visualization and mental rotation), a extrinsic-static skill (spatial perception) and a 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 dependant on three components, abilities, strategies and knowledge. She offers a meta-level framework for GIScience in terms of the types of representations, transformations and complex thinking. It 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 and v) complex spatial reasoning: combining components to solve questions.

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

JO & BEDNARZ (2009) developed 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. The 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 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.

SCHOLZ et al. (2014) used this system to identify the level and type of spatial thinking found in textbook questions (Table 4) and 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, 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
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, analyzing information, includes: explaining, analyzing, 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 been 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, ten GI-Learner geospatial thinking competences are proposed by the 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

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 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.

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. 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 and 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.

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 visualisation 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 and 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 applying geographic knowledge and understanding; develop problem-oriented knowledge and skills in GIScience
Spatial Thinking	Fundamentals of spatial understanding, spatial analysis and application; performance of complex spatial analysis and modelling; present complex spatial information
Teamwork and Collaboration	Participate in and use GIS within multidisciplinary teams and environments; cooperate with other specialists; manage and coordinate GIS projects
Visualization and Communication	Represent and visualize of (geo)spatial data; effectively communicate geographic information to different target groups such as researchers, decision-makers and the general public.

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 necessitate that additional attention is paid to spatial thinking in teacher preparation programs.

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