GI Learner,

A project to develop ***geospatial thinking learning lines*** in secondary schools

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1 Background

Geo-ICT is part of the digital economy identified by the European Commission as being vital for innovation, growth, jobs and European competitiveness. As a rapidly growing business sector, there is a clear and growing demand for Geo-ICT know-how (Donert, 2005).

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 to 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 (Schulz E 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 The 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 progression 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).

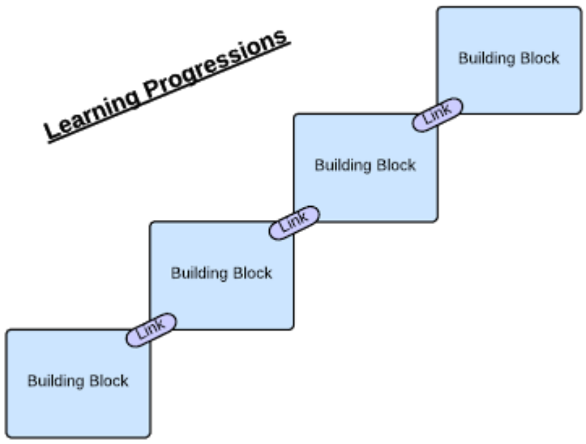


Table 1: Learning lines in the Flemish geography curriculum for secondary education (Lindner-Fally & Zwartjes, 2012)

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.

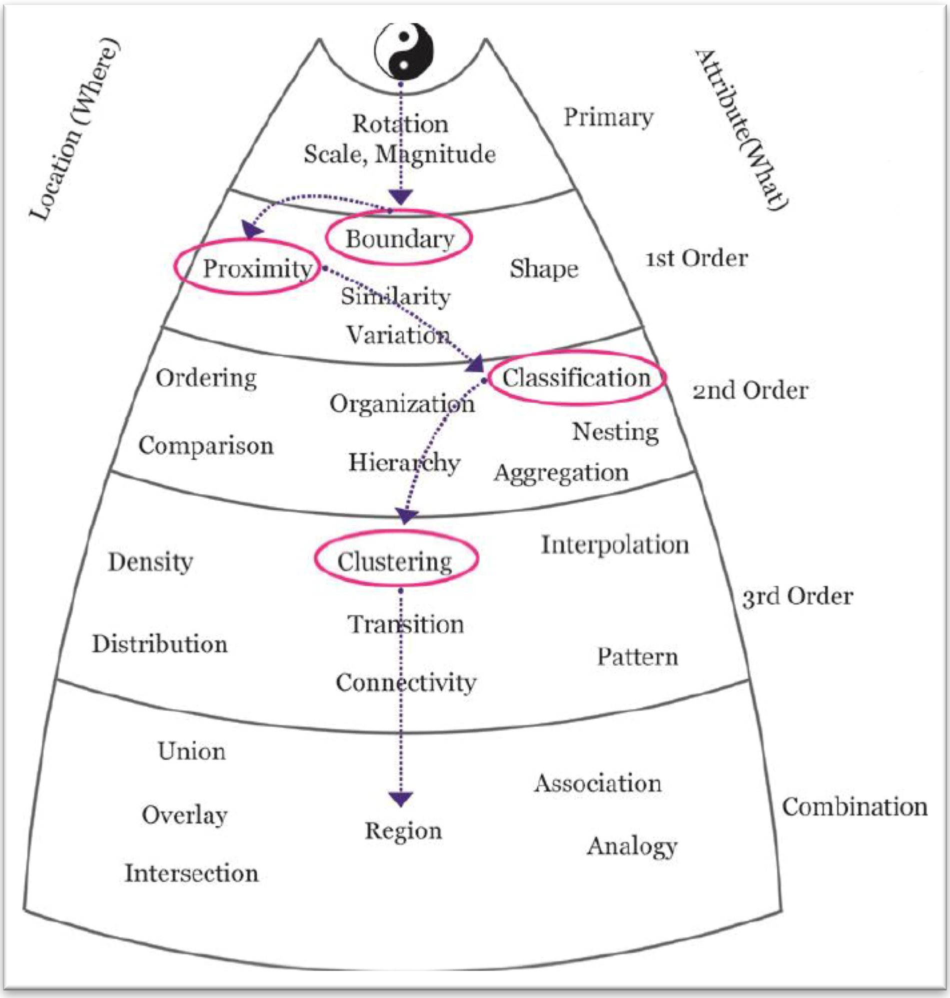
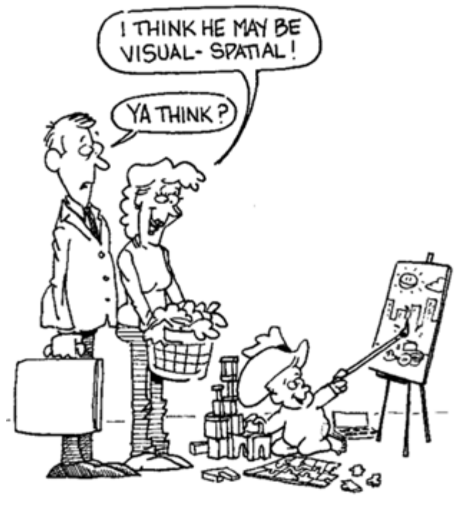


Figure 1: Spatial thinking framework (Perdue, 2013)

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?

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. 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). It is exactly the links among these three that gives spatial thinking its power of versatility and applicability.

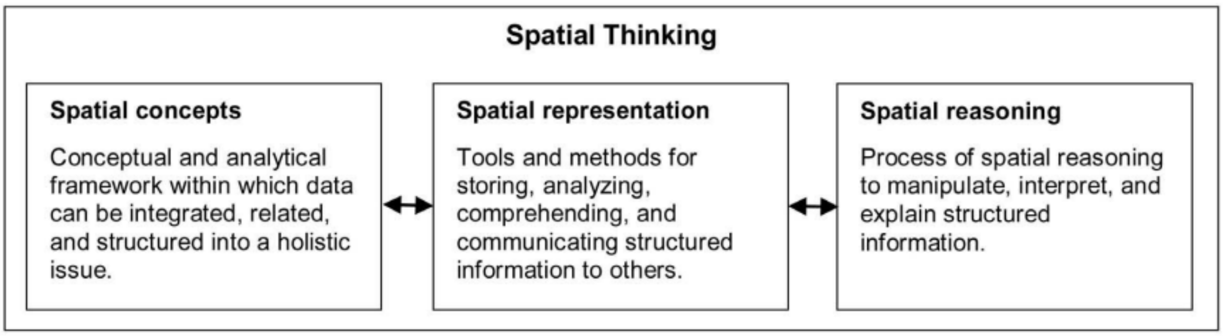


Figure 2: Spatial Thinking dimensions and related terms (Michel & Hof, 2013)

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.

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, each with a progression inside from easy (A) to more elaborated (C).

1 GI-Learner competencies

			K7-8	K9	K10	K11	K12
1	**Critically read, interpret cartographic and other visualisations in different media**	**interpretation**	A	B	C		C
	A: Be able to read maps and other visualisations	Example: use legend, symbology ...					
	B: Be able to interpret maps and other visualisations	Example: use scale, orientation; understand meaning, spatial pattern and context of a map					
	C: Be critically aware of sources of information and their reliability	Example: critically evaluate maps identifying attributes, representations (e.g. inappropriate use of symbology, or stereotyping) and metadata of the maps					
2	**Be aware of geographic information and its representation through GI and GIS.**	**learning about**	A	B	C		C
	A: Recognize geographical (location-based) and non-geographical information	Example: describe GPS, GIS, Internet interfaces; be able to identify geo-referenced information					
	B: Demonstrate that geographical information can be represented in some ways	Example: employ some different representations of information (maps, charts, tables, satellite images...)					
	C: Be critically aware that geographic information can be represented in many different ways	Example: be able to evaluate and apply a variety of GI data representations					
3	**Visually communicate geographic information**	**produce**	A		B		C
	A: Transmit basic geographic information	Example: produce a mental map, be aware of your own position					
	B: Communicate with geographic information in suitable forms	Example: basic map production for a target audience - using old and new media, Share results with target group					
	C: Be able to use GI to exchange in dialogue with others	Example: discuss outcomes like survey results/maps online or in class, referring to a problem in own environment					
4	**Describe and use examples of GI applications in daily life and in society**	**applying**	A	B	C		C
	A: Be aware of GI applications	Example: know about GPS-related/locational (social networking) applications including Google Earth; produce a listing of known GI applications or find them on the internet/cloud					
	B: Use some examples of (daily life) GI applications	Example: problem-solving oriented with GI application like navigating; use an app to read the weather, environmental quality, travel planner					
	C: Evaluate how and why GI applications are useful for society	Example: assess the functionality and use for society of a GI application (emergency services, police, precision agriculture, environmental planning, civil engineering, transport, research) and present the results					

5	**Use (freely available) GI interfaces**	**use**	A	B	C	C
	A: Perform simple geographical tasks with the help of a GI interface	Example: Find your house in a digital earth browser; finding a certain location; measuring the distance between two points by different means; use applications for mobile phones (ex. GPS) to locate a place				
	B: Use more than one GI interface and its features	Example: collect data and compare to set the best route from school to home and back; get a topographical map for a walk				
	C: Effectively solve problems using a wide variety of GI interfaces	Example: Find and use data from various data portals (SDI) to look for the best facilities of a specific region, or for the 'best' place to live using parameters like infrastructure, noise, open spaces, ...				
6	**Carry out own (primary) data capture**	**produce / gathering**	A		B	C
	A: Collect simple data	Example: gather data during fieldwork (coordinates, pictures, comments...) e.g. sound data to analyse impacts of traffic; map attractive places for children in your city				
	B: Compare different qualitative and quantitative data and select an appropriate data gathering approach, tool etc.	Example: when investigating environmental factors choose what data is needed				
	C: Solve issues concerning data gathering and select the most suitable alternative approaches to data capture	Example: design a methodology which explains the data collection for land use change, like how to collect data from different sources and classify them appropriately				
7	**Be able to identify and evaluate (secondary) data**	**use / evaluate**	A		B	C
	A: Locate and obtain data from source maps (different visualisations)	Example: Find and download data on migration and be able to use it				
	B: Acknowledge that there is different quality in data, not everything is useful	Example: Identify multiple data sources for example of population or pollution and be able to assess their level (scale), detail, frequency, accuracy and other considerations; analyse different sources and decide which is the most useful				
	C: Fully assess value / usefulness / quality of data	Example: Use data on climate change from ESA, IPCC compared to Facebook graphs				
8	**Examine interrelationships**	**analyse**		A	B	C
	A: Recognise that items may, or may not, be related (connected) in different ways to one another	Example: recognize simple relationships between things, e.g. heat and sunshine, or city size and traffic jams // inverse relationships // some things are not related				
	B: Demonstrate interrelationships between a variety of factors	Example: changes in environment, influence, connections and hierarchy of ecosystems				
	C: Valuate different relationships and judge causes and effects	Example: Evolution of ecosystems over time is complex and is related to many variables; problem-oriented exploration of interrelationships like: where do my jeans or my mobile phone come from				

9	**Extract new insight from analysis**	**produce**			A	B	C
	A: Read what the analysis says	Example: understand there are different types of climate					
	B: Combine elements from the analysis to make sense of the outcomes	Example: realise that climate is changing					
	C: Assess the analysis in depth, create new meaning and make links to the bigger picture	Example: responding and suggest solutions on climate change					
10	**Reflect and act with knowledge**	**action: decision making / applying in real world**	A		B		C
	A: Recognise the decisions that had to be made	Example: Use geodata to assess which new road system should the local authority build					
	B: Judge implications for individuals and society	Example: conclude there will be winners and losers for each road proposal					
	C: Design future actions to stakeholders - including themselves	Example: develop a campaign to persuade decision makers concerning traffic planning; make a blog or a website with collected and visualized data; write a documented article in a magazine using GI information					

Level of learning over the secondary school curriculum (K7-12)

Competency	K7-8	K9	K10	K11	K12
1	A	B	C		C
2	A	B	C		C
3	A		B		C
4	A	B	C		C
5	A	B	C		C
6	A		B		C
7	A		B		C
8		A	B		C
9			A	B	C
10	A		B		C

2 INTEGRATING GIS AS TOOL FOR GEOSPATIAL CRITICAL THINKING

Mapping can be an effective method for communicating a large volume 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 3): 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 et.al., 2005).

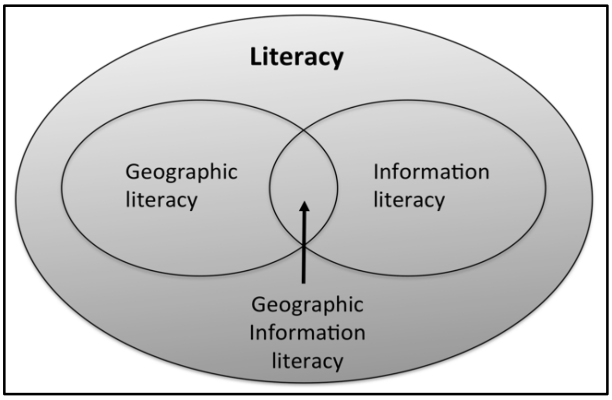


Figure 3: Contextual diagram for geographic information literacy (Miller et.al., 2005)

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. 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 4).

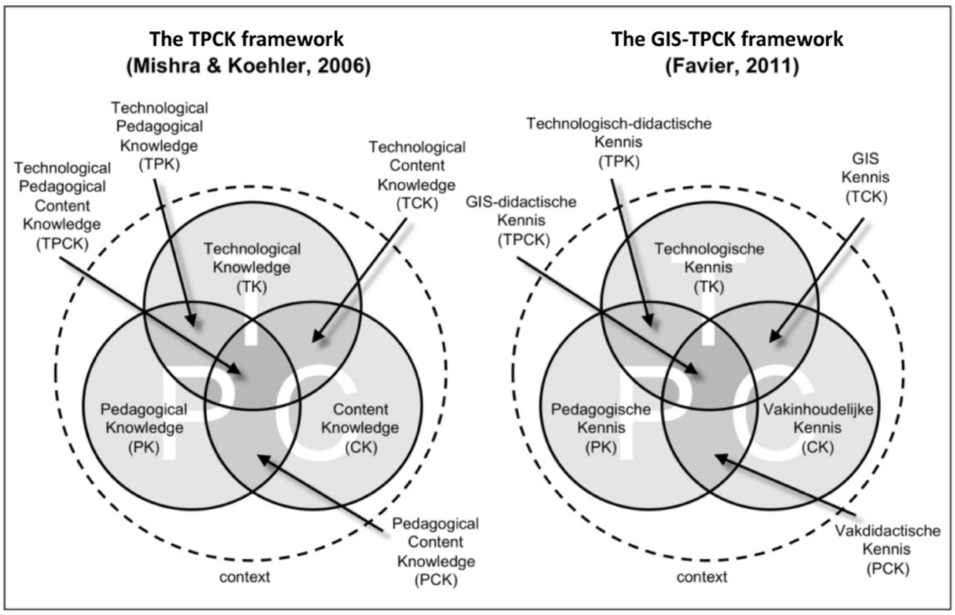


Figure 4: The general TPCK model (left) and the GIS-TPCK framework (Favier et al., 2012)

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.

Favier (2013) describes five ways on how GIS can be integrated in secondary education (Figure 5). Teaching and learning about GIS (number 1 and 3 in the figure) 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.

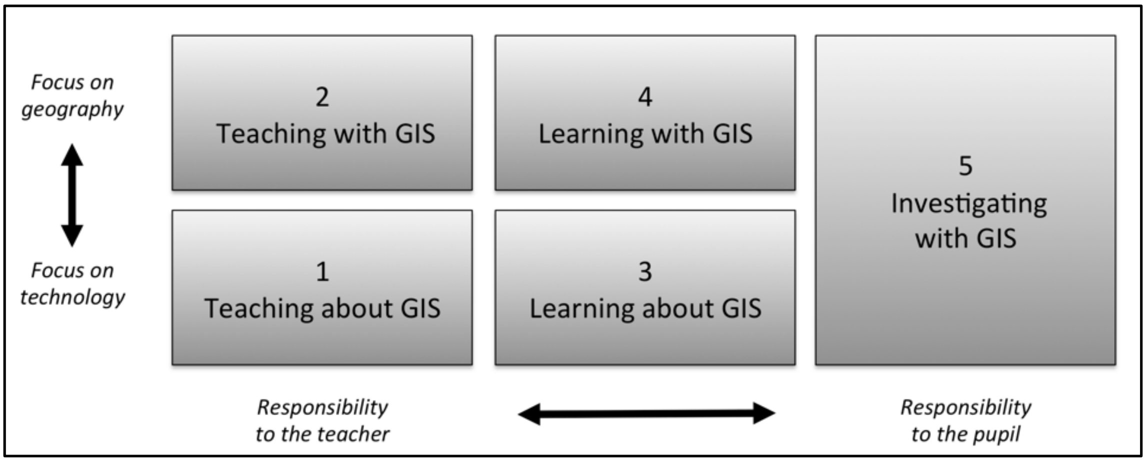


Figure 5: Five ways of integrating GIS in geography education (Favier, 2013)

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.

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