Creating a learning line on spatial thinking in education

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Abstract

Spatial thinking in education should be a fixed value in addition to other such as linguistic and mathematical thinking. It is part of the everyday life. As research showed one of the best tools to introduce spatial thinking in education is geography. It offers al the tools for the three components of geography: skills, subject matter and perspectives.

But nevertheless the introduction and use of GIS in education is not a success. Researchers have described many reasons, among others the lack of education standards on the use of GIS in the curriculum.

Therefore the Digital Earth project creates a benchmark with learning outcomes through the educational curriculum. To make it practical a learning line – including an increasing level of complexity – in using GIS should be developed.

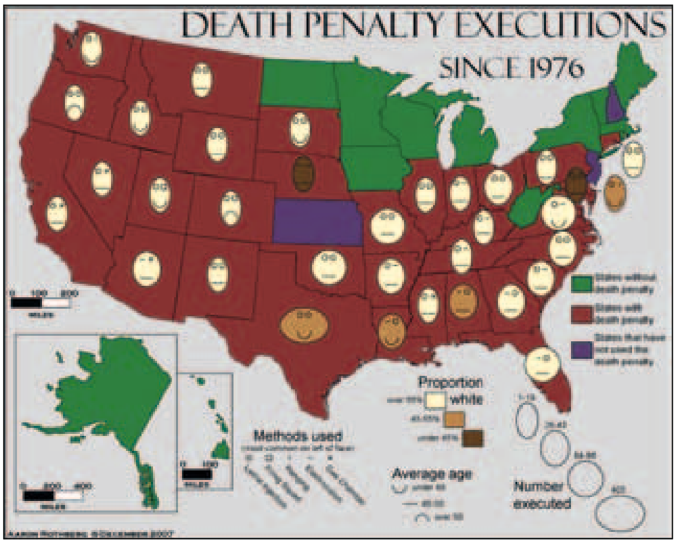
Key words: *GIS, spatial thinking, education, learning outcomes, skills, competences*

1 Spatial thinking in education

Many reports state that spatial thinking in education should be a fixed value in addition to other such as linguistic and mathematical thinking. According to the National Research Council (Down e.o. 2006) thinking spatially enables knowing about:

- space – e.g. different ways of calculating distance, coordinate system
- representation – e.g. effect of projections, principles of graphic design (semiology, Figure 1)
- reasoning – e.g. different ways of thinking about shortest distances, estimate the slope of a hill from a map of contour lines

Figure 1 An incorrect use of semiology can give strange results (source: http://wiki.ead.pucv.cl/index.php/Archivo:02_ejemplo_cartografia_penademuerte_chernoff.jpg)



A spatially literate person has following characteristics:

- He has the habit of mind of thinking spatially – he knows where, when, how and why to think spatially,
- He can practice spatial thinking in an informal way – he has deep and broad knowledge of spatial concepts (such as distance, direction, scale, and arrangement and representation (maps, 3D-models, graphs…),
- He can adopt critical stance to spatial thinking and evaluate quality of spatial data, he can use spatial data to construct, articulate.

Spatial thinking is integral to everyday life. It is the concept of space that makes spatial thinking a distinct form of thinking. We live in a spatial world, we solve spatial problems. Thus it is a basic and essential skill that can and should be learned, besides other skills like language, mathematics and science.

The US Department of Labor developed in 2010 a Geospatial Technology Competency Model (Figure 2), “developed by researching and analyzing publicly available resources, existing skill standards, competency-based curricula and certifications to provide an employer-driven framework of the skills needed for success in geospatial technology.” (United States Department of Labor, 2010)

Figure 2: Geospatial Technology Competency Model
(source: http://www.careeronestop.org/competencymodel/)

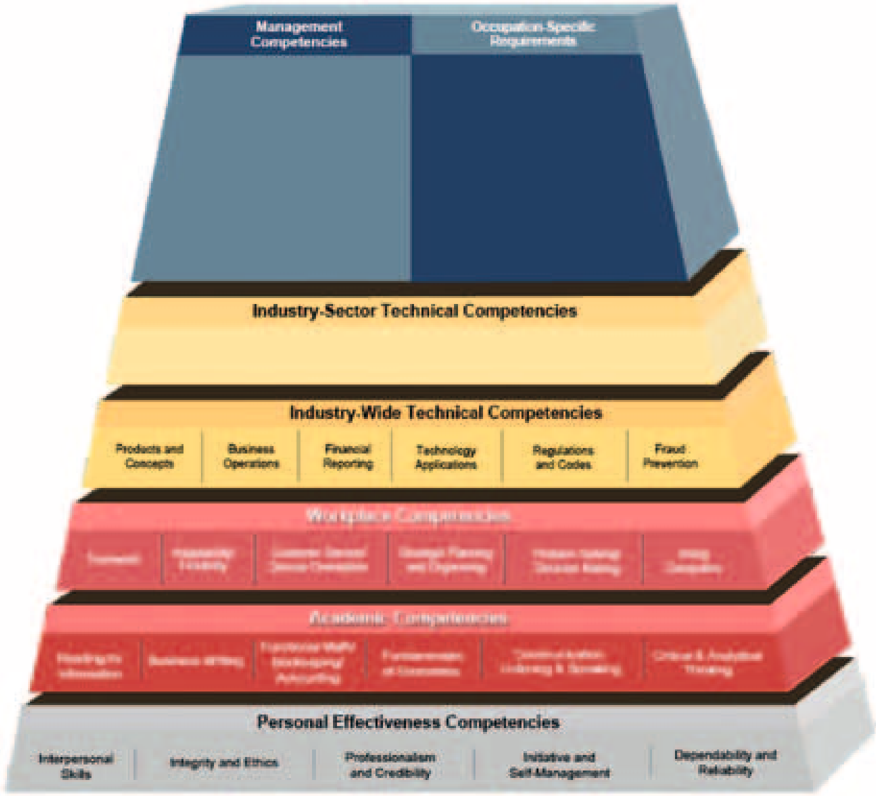


Figure 3: Academic competencies of geography inside the Geospatial Technology Competency Model
(source: http://www.careeronestop.org/competencymodel/)

Geography

Understanding the science of place and space. Knowing how to ask and discover where things are located on the surface of the earth, why they are located where they are, how places differ from one another, and how people interact with the environment.

- **Subject-specific Geographic Knowledge**
  - Human-Environment Interaction: Know and apply geographic information about relationships between nature and society (e.g., pollution from industrial development, economic effects of drought)
  - Regional Geography: Know and apply knowledge of the physical and human geography of a specific country or world region
  - Physical Geography: Know and apply geographic information about the processes that shape physical landscapes; weather, climate and atmospheric processes; ecosystems and ecological processes; and natural hazards
  - Cultural Geography: Know and apply geographic information about culture and cultural processes, including religion, language, ethnicity, diffusion, meaning of landscapes, cultural significance of place
- **Geographic Skills**
  - Geographic Information Systems (GIS): Use GIS to acquire, manage, display, and analyze spatial data in digital form
  - Cartography: Producing, creating, and designing paper or digital maps
  - Field Methods: Use interviews, questionnaires, observations, photography, maps, GPS, GIS, and other techniques to measure geographic information in the field
  - Spatial Statistics: Use quantitative methods to process spatial data for the purpose of making calculations, models, and inferences about space, spatial patterns, and spatial relationships
- **Geographic Perspectives**
  - Spatial Thinking: Identify, explain, and find meaning in spatial patterns and relationships, such as site conditions, how places are similar and different, the influence of a land feature on its neighbors, the nature of transitions between places, how places are linked at local, regional, and/or global scales
  - Global Perspective: Possess and apply knowledge of how people, places, and regions are linked by global networks and processes (e.g., globalization, international trade, immigration, Internet technology, global climate system)
  - Interdisciplinary Perspective: Draw on and synthesize the information, concepts, and methods of the natural and social sciences for geographic research and applications

Competency models offer job seekers or students an opportunity to learn what it takes to enter a particular field. For this competency model at the level of 'Academic Competencies' geography is mentioned as "Understanding the science of place and space. Knowing how to ask and discover where things are located on the surface of the earth, why they are located where they are, how places differ from one another, and how people interact with the environment." (United States Department of Labor, 2010). If we look inside the specifications on level of skills and perspectives two concepts are conspicuously present: GIS and spatial thinking (Figure 3).

2 Linking spatial thinking to the use of GIS

When referring to GIS mostly is mend 'Geographic Information System': a set of computer technologies that allows visualizing and manipulating geodata in an easy visual method. In this paper GIS refers to this definition. But GIS can also be called 'Geographic Information Science' (Goodschild, 1992), thus also involving a way of methods and ways of looking at the world (Milson, 2012), whereby GIS is used to obtain spatial thinking skills.

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

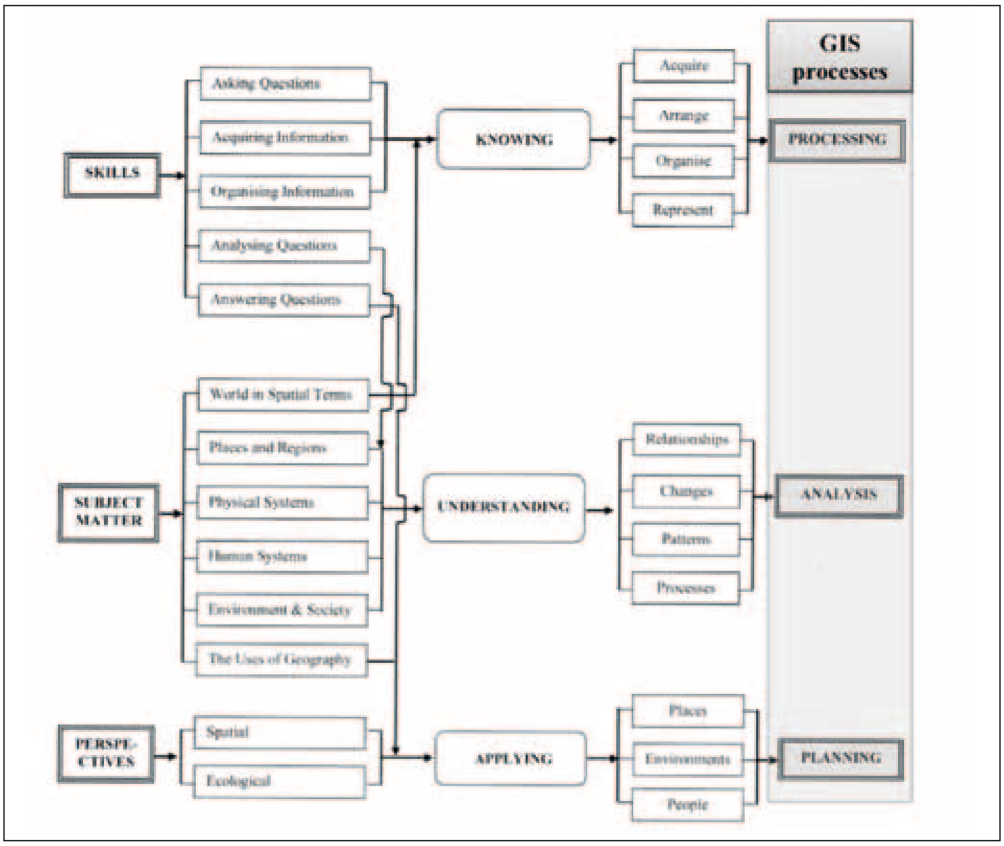
- We can use the powers of GIS to teach geography for it can help us understand our world through both the natural and the man-made manifestations which are the essence of geography
- In teaching with GIS a positive effect can be created on the development of spatial thinking and reasoning.

Thompson (1991) states that GIS is an 'educational delivery system for improving the student's knowledge of the world in which she or he lives.' GIS is able to answer all the questions that knowledge, understanding and application in geography education requires (Koutsopoulos, 2010).

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.

Koutsopoulos (2010) developed a conceptual framework for using GIS. For his idea he uses the Geographic Education Standards Project (GESP, 1994), stating that geography is composed of three components: skills, subject matter and perspectives whereby all three are necessary to be 'geographically informed' and thus should be examined (Figure 4).

Figure 4: Linking the science of geography to GIS (Koutsopoulos, 2010 & own edit)



Geographic skills are a series of tools and techniques, including asking geographic questions, acquire and organize spatial information. The purpose is mainly focused on the level of knowing ("where is it?"), although some questions will lead to the process of understanding ("why is it there?") or even applying ("what if ...?").

The *subject matter* is divided – according to GESP – into six "essential elements". Most of these refer to the process of understanding.

A *geographic perspective* is a lens through which geographers look at the world. It involves the ways that knowledge and understanding can be used to solve geographic problems (process of applying). The specific aspect of geography – linking human and physical systems in a spatial lens – provides everything to solve spatial problems by active participation.

Geographic skills, subject matter and perspective correspond to the processes of knowing, understanding and applying: by "learning the concepts and vocabulary of geography (knowing) students may begin to think about what they mean (understanding) and apply to real problems (applying)" (NAEP Geography Consensus project, 2010).

Knowing is in spatial terms expressed by the questions 'What is it?' and 'Where is it?', in GIS this means processing spatial data.

Understanding is expressed by questions such as: 'Why is it there?', 'What has changed?', 'What is the pattern?', 'What is the interaction?', in GIS this is spatial analysis.

Applying is expressed by the question 'What if ...?' to solve spatial problems, in GIS this means planning.

Koutsopoulos (2010) linked the 3 GIS processes with the questions and the five themes of geography – created by the Joint Committee on Geographic Education (1984): location, place, relationship with places, movement, and region (Figure 5).

Figure 5 A conceptual framework in Instructing with GIS (Koutsopoulos, 2010 & own edit)

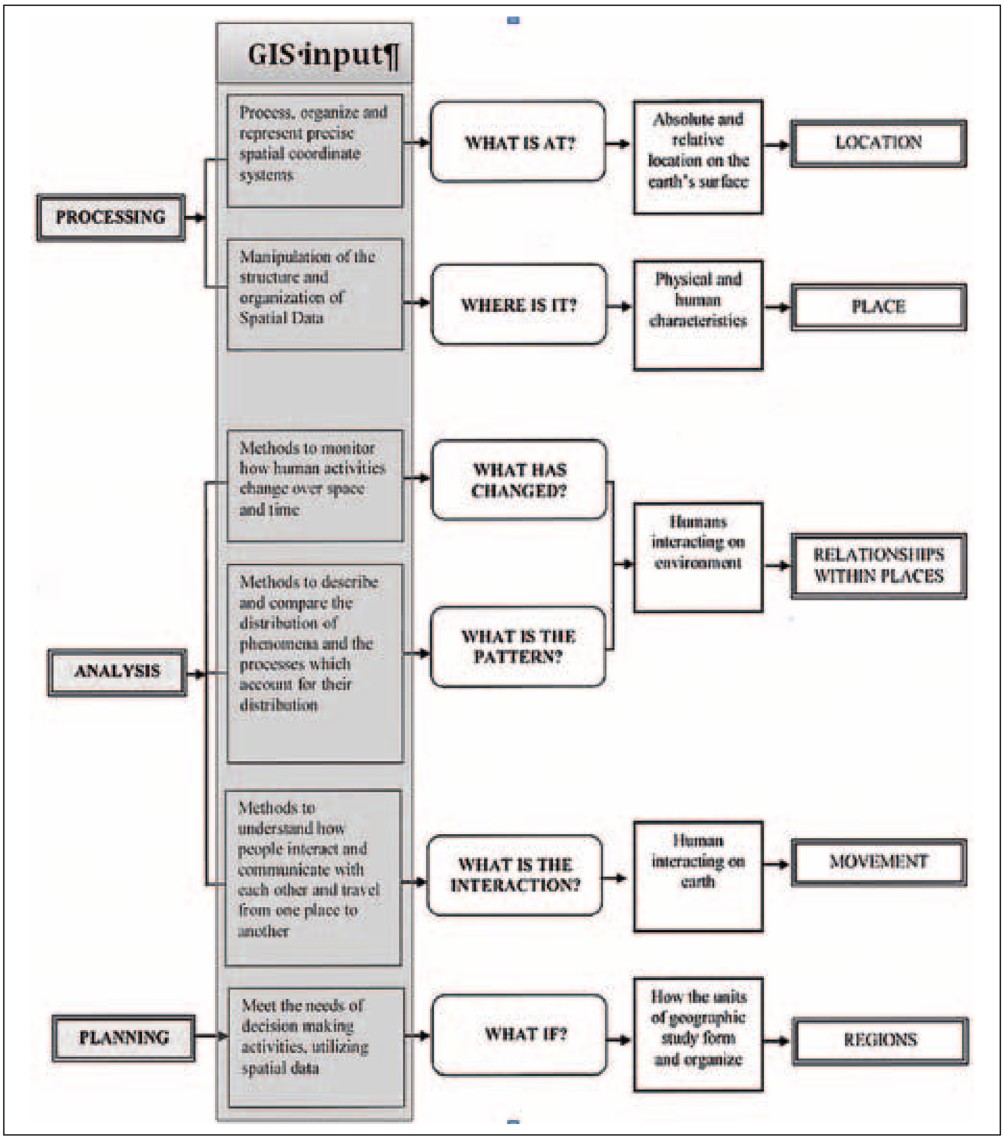


Figure 6: Four schools of thought about the relationship between geography & GIS about the implications for GIS instructional approaches (Kemp. et al, mentioned by Sui, 1995)

Relationship between Geography and GIS	Instructional Focus (education vs. training)	Course Content (technical vs. application)	Format of Delivery (lab vs. lecture)
geography as the home discipline of GIS	education	application	combination of lab and lecture
GIS as a collection of marketable skills	training	technical	lab
GIS as a new tool for spatial science	training	application	lab
GIS as a new discipline	education	technical	lecture

His framework shows very clearly the impact and importance of GIS in answering the questions on the level of the three processes. He results that "GIS can serve as an unique educational tool in which the manipulation, analysis and presentation of spatial data can support the teaching of geography" (Koutsopoulos, 2010).

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

The approach developed by Koutsopoulos follows one of the four GIS schools described by Kemp (1992, quoted in Sui, 1995, Figure 6): GIS as an enabling Technology for Science, arguing that GIS is not an goal in itself but a means to use spatial thinking skills.

In two of the four schools describe their ideal vision for secondary education:

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

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

3 Integrating spatial thinking – using GIS – in education

'Geography educators have justified GIS's introduction using three competing and yet complementary rationales that correspond to GIS's strengths: (1) the educative rationale: GI Science and GIS support the teaching and learning of geography; (2) the place-based rationale: GIS is the ideal tool to use to study geographical problems at a range of scales; and (3) the workplace rationale: GIS is an essential tool for knowledge workers in the twenty-first century. These arguments have not appealed to large numbers of teachers however.' (Bednarz and van der Schee, 2006). According their research the main reasons are:

- in teacher training (pre-service and in-service) GIS is not a core item
- more and more geography is taught by non-geographers, 'this lack of specialist geography teachers means that many teachers have limited pedagogical content knowledge, defined as knowledge about the best way to teach subject matter. The result is that few teachers assigned to teach geography recognize the potential opportunities GIS offers to teach geography content and skills' (Bednarz, van der Schee, 2006).
- the curriculum doesn't include or impede adoption to include GIS
- the availability of free data and software
- the attitude of teachers. 'Innovations that are complex in form and function, hard to grasp and affect multiple aspects of the teaching–learning system are less likely to be implemented'(Bednarz, van der Schee, 2006). It seems difficult to persuade teachers to use new technologies, certainly if they are highly technical demanding.

They made 3 recommendations:

- address the key internal issues related to GIS implementation: teacher training, availability of user friendly software, ICT equipment in schools
- use a community of learners approach.
- institutionalizing GIS into curricula, making sure that it is aligned with significant general learning goals like graphicacy, critical thinking and citizenship skills. The same recommendation was made by The National Academy of science (2006) stated as one of the primordially recommendations the development of spatial thinking standards and curriculum material.

So spatial literacy must start in education, but therefore we need to answer some questions:

- How may GIS be incorporated into existing standard-based instruction in all knowledge domains across school curriculum
- How can cognitive developmental and educational theory be used the develop new versions of GIS that are:
  - age appropriate in their design,
  - age appropriate in their scope and sequence.

The second question is a matter of developing easier to use software with data access. On both fields a lot of progress is made. There are a lot of free GIS viewers or open source full GIS software programs available. Also more and more governments are offering datasets (for free) or provide open access to database servers.

The first question is one of the aims of the Special Interest Groups 3 and 4 of the Digital Earth project: develop goals / learning outcomes for using GIS in education.

4 GIS LEARNING OUTCOMES THROUGH EDUCATION

Figure 6 This benchmark statement has been produced as a result of the digital-earth.eu COMENIUS network SIG 3 (Teacher education and teacher training) meeting in Brugge, Belgium in October 2011 (www.digital-earth.eu)

digital-earth.eu

The **digital-earth.eu** project examines the use of geographic media in schools and teacher education. Geo-media is the visualization of information from different media sources and is concerned with digital content and it's processing based on place, position and location. Many geographic media are widely used for navigation and routing purposes. Cartographic communication has never been so easy to implement, therefore 21st century school education needs to include geo-media into daily work. Innovative approaches to teaching and learning are needed to study environments from local to global scale.

The digital-earth.eu network seeks to provide broad access to resources, promoting innovation and best practice in the implementation of geo-media as a digital learning environment for school learning and teaching. The goal is to raise the profile of learning with digital earth tools and resources. The network encourages the sharing of innovative practices and rewards organizations and individuals displaying 'excellence'.

Special Interest Groups (SIGs) are working on following topics:
1. Resources, technologies and geoinformation
2. Learning and teaching with geo-media and geoinformation
3. Teacher Education and Training in geo-media
4. Curriculum aspects and geo-media.

Developing spatial literacy assumes the availability of digital earth tools, which allow students to interact with geoinformation, to answer questions and critically reflect using a geographic approach. They can also clearly communicate the results to a broader audience.

Therefore, teachers must understand basic geographic concepts and be able to support students' learning needs. Taking in account the different levels of age and education, teachers must be enabled to apply different methods and tools in the respective learning environments. Appropriate evaluation and assessment methodology has to be developed and implemented by Europe's 21st century teachers, teacher educators and trainers.

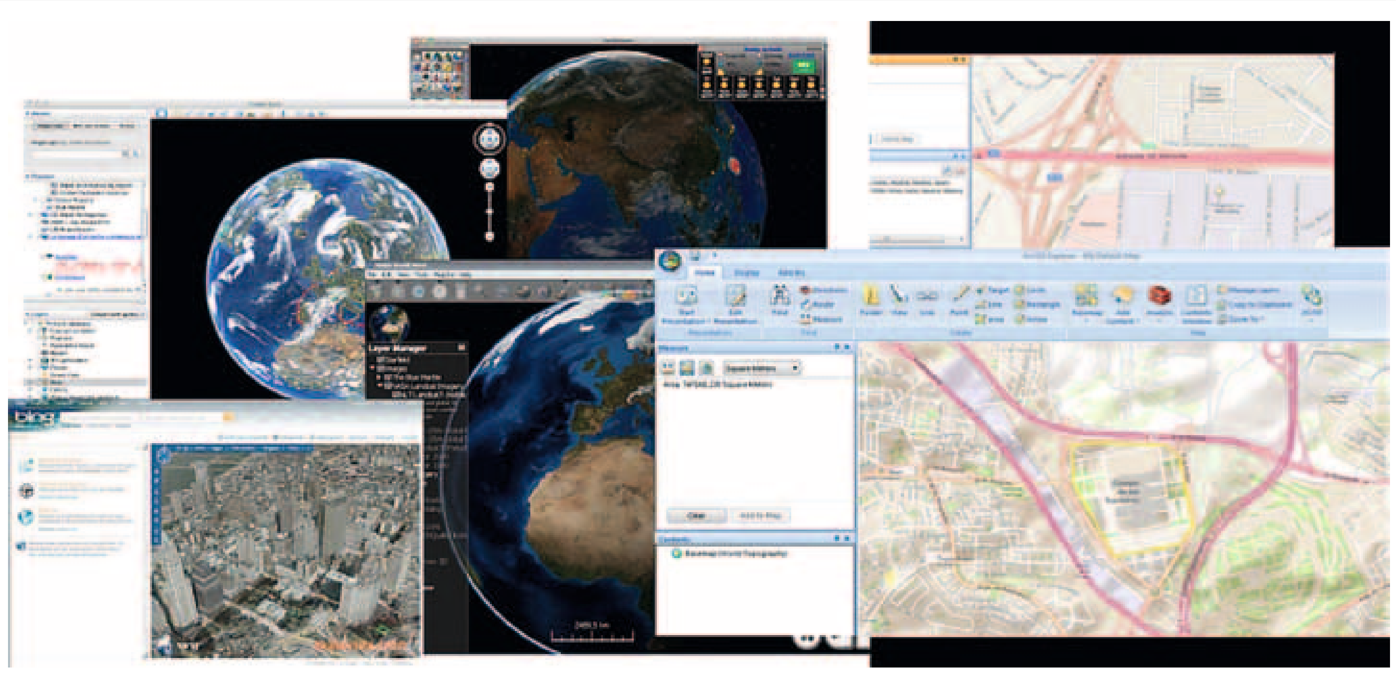
Goals for teacher training and education in Europe
Spatial literacy
Create digital earth citizens that are aware of basic spatial concepts and able to use digital earth tools
Increase active citizenship in spatial decision making
Increase employability opportunities for teachers
Encourage lifelong learning

Competencies
Spatial thinking:
- To know concepts of spatial thinking
- Be able to use tools of spatial representation,
- To apply processes of reasoning (Where is it? Why is it there? What if it was somewhere else? Making informed decisions and defend personal points of view)

Pedagogic and didactical skills for the use of digital earth tools in school
Ability to use spatial skills in real world problem-solving context
Understanding complex and changing interrelationships
Awareness and understanding for the digital earth concept
Ability to use digital earth tools (also technological skills)
Lifelong learning competencies: ability to find training opportunities, time management, planning competency, communication competencies
Being able to identify and evaluate resources
Social learning:
- Being able to work with others – teamwork
- Use professional social networks (virtual and face-to-face)

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

Figure 7 Primary school pupils should be able to work with digital globes and simple GIS-software



Primary school teachers need to be able to enable students (year 1-6) to
Open digital maps and virtual globes on a computer
Indicate the different parts of digital maps/virtual globes (navigation bar, menu, scale, map window, Figure 7)
Interpret symbols on digital maps
Work with digital maps and 3D representations of the world:
- find significant locations (their home, school or town) on a virtual globe
- pan, zoom, orientate
- make measurements
- use the layers to focus on specific features
- update maps

Be aware of generalization levels applied in different zoom levels (e.g. road density)
Access information efficiently and effectively, evaluate information critically and competently (see maps as manipulated representations created by people/organizations with a certain purpose, e.g. classification methods, color schemes, map contents)
Use digital maps and virtual globes for a variety of different purposes

Secondary school (year 7-12)
In addition to the learning outcomes of primary school, secondary school teachers need to enable their students to
Know the digital earth concept and its tools
Understand the basic purpose and application of digital earth to real world problems
Be able to gather and evaluate information
Use advanced digital earth tools for learning (starting with Web-GIS, GIS viewers to GIS software)
Manipulate maps
- Display information on maps
- Create own maps
- Communicate cartographic information

Understand the construction of digital maps as a representation of the real world
- The power of maps (reliability of data, classification and color schemes)
- Topology: points, lines, polygons
- Layers
- Database

Know about the professional use of GIS and other digital earth tools
Gather information from data resources or through fieldwork activities (use GPS devices, mobile applications)
Use digital earth tools for investigation/research
- Interpret content
- Identify and ask significant questions that clarify various points of view and lead to sustainable solutions
- Frame, analyze and synthesize information in order to solve problems and answer questions

5 Creating a learning line in GIS

Taking in account the age and level of complexity the best option is to work with a learning line in education, thus covering at least the six years from age 12 to 18, but even better starting in primary education.

A learning line is defined here as the educational term that refers to the construction of knowledge and skills throughout the whole curriculum. This learning line reflects an increasing level of complexity, ranging from easy (more basic skills and knowledge) to difficult.

Figure 8: Learning lines in the Flemish secondary geography curriculum

Learning lines Levels	Fieldwork	Working with images	Working with maps	Working with statistical material	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	**Apply** – thinking problem solving				

As an example the Flemish geography curriculum (Leerplancommissie Aardrijkskunde, 2010) defines learning lines in the secondary geography curriculum (Figure 8).

Some existing examples

Learning line maps

Level 1: Recognize and name the elements of the legend on the map. Distract the scale.
Level 2: Retrieve from the map those geographic elements that are relevant within a research context.
Level 3: Classify and relate elements on the geographic map.
Level 4: Interpret a map.

Learning line images

Level 1: Describe the image
Level 2: Retrieve from the image those geographic elements that are relevant within a research context
Level 3: Examine the correlation between the different elements by using various techniques (map studies, surveys, statistics ...).
Level 4: Make up a synthesis of the image

When applying the learning line concept to the learning outcomes (described in the previous section) we get this result:

Level 1: **Perception** – being able to work with digital maps and virtual globes:
- Open digital maps and virtual globes on a computer
- Indicate the different parts of digital maps/virtual globes (navigation bar, menu, scale, map window)
- Interpret symbols on digital maps
- Understand the construction of digital maps as a representation of the real world (topology, layers, database)

Level 2: **Analysis** – selection of the relevant geographic information
- Work with digital maps and virtual globes: find locations, pan, zoom, orientate, make measurements
- Access information efficiently and effectively, evaluate information critically and competently
- Be able to gather and evaluate information from data resources or through fieldwork activities
- Interpret content

Level 3: **Structure** – look for complex connections and relationships
- Use digital maps and virtual globes for a variety of different purposes
- Identify and ask significant questions that clarify various points of view and lead to sustainable solutions
- Manipulate maps by creating own maps
- Communicate cartographic information

Level 4: **Apply** – thinking problem solving
- Be aware of generalization levels applied in different zoom levels (e.g. road density)
- Understand the basic purpose and application of digital earth to real world problems
- Use advanced digital earth tools for learning (starting with Web-GIS, GIS viewers to GIS software)
- Frame, analyze and synthesize information in order to solve problems and answer questions

For introduction in the different grades of secondary schools the level would depend of the age, thus grade (figure 9).

Figure 9: Correlation between grade and level

Grade	Age	Level			
		1	2	3	4
1	13 – 14 y				
2	15 – 16 y				
3	17 – 18 y				

Conclusions

Spatial thinking in education should be a fixed value in addition to other such as linguistic and mathematical thinking. Because of its capabilities GIS – Geographic Information System – is inherently an excellent vehicle to obtain the essential spatial thinking skills. The framework developed by Koutsopoulos shows very clearly the impact and importance of GIS in answering the questions on the level knowing, understanding and applying. GIS can serve as a unique educational tool in which the manipulation, analysis and presentation of spatial data can support the teaching of geography.

The introduction of GIS in secondary education is not easy. Most reasons why previous attempts didn't succeed are overruled by recent developments. But the main reason to persuade teachers is the implementation in the curriculum. The benchmark created by the Digital Earth project SIG 3 is a first step. When adding the concept of learning lines we can construct the content depending of the pupil age. With input from others this might lead to a real curriculum reform.

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