GEOTHNK: A Semantic Approach to Spatial Thinking

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Abstract Spatial thinking has lately been acknowledged as an important ability both for sciences and for everyday life. There is a clear need for enhancing spatial thinking in education and engaging both educators and learners in more critical, inquiry-based teaching and learning methods. In this context, GEOTHNK project is a European effort to propose a scientifically grounded, technologically sustainable, and organizationally disruptive framework for the development of learning pathways for enhancing spatial thinking across education sectors and learning environments.

Keywords Knowledge structure · Inquiry-based learning model · Geospatial thinking · Formal and informal education

1 Introduction

Spatial thinking uses the properties of space as a means of solving problems, finding answers, and expressing solutions (National Research Council—NRC 2006). In other words, it uses space for structuring problems, seeking answers, and formulating possible solutions associated with space in science, in workplace and in everyday life. It also includes the ability to review and analyse space, which is essential to educated citizens for decision-making.

According to Booth and Thomas (2000), spatial thinking includes cognitive skills related to map reading and making, processes involving representation, scale,

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transformation, production and recall of symbolic information, recognition and understanding of spatial projections, coordinate systems, geometric configurations, formulation of verbal instructions as well as navigation and orientation based on observation and instruments handling. In education, though, other forms of thinking such as verbal, metaphorical, hypothetical, and mathematical, have supplanted spatial thinking.

Spatial thinking is defined as a constructive synthesis of three components: (a) concepts of space, (b) tools of representation, and (c) processes of reasoning (NRC 2006). The geospatial domain presents an excellent opportunity towards achieving a meaningful connection between theoretical, higher-level concepts and tools of representation and their application in everyday life such as locating one's home or following directions to an unknown place. For example, to identify areas vulnerable to flooding due to sea level rise, learners should grasp spatial concepts such as location, distance, proximity, and elevation, use representation tools such as maps and terrain models, and be able to perform reasoning processes, such as combining maps to evaluating multiple criteria (e.g., location of settlements) and making inferences about environmental consequences. These components are also helpful in understanding many other georeferenced phenomena, such as the spatiotemporal change of countries and their boundaries due to historical events.

However, research proves that the three components of spatial thinking are not treated equivalently in education; low-level spatial concepts are given priority relatively to higher-level ones and spatial representations, whereas higher-order cognitive skills are rarely prompted (Injeong and Witham 2009). Furthermore, geospatial knowledge is usually static and independent from other knowledge, impeding critical thinking and understanding of complicated interactions among entities, events, and phenomena in space.

The NRC Report marked the need for a major turn in education towards the enhancement of spatial thinking: "fostering spatial literacy can be achieved only by systemic educational reform" (NRC 2006). In Europe, however, there is not a declared official priority in this area yet.

In this context, the GEOTHNK Project is a European effort for a scientifically grounded, technologically sustainable framework for the development of learning pathways for enhancing spatial thinking across education sectors and learning environments. The Project takes a methodological approach that accounts for several conceptual, pedagogical, and developmental premises such as (a) spatial thinking notions and dimensions, (b) the formation of spatial perception during one's lifetime, and (c) knowledge structure for facilitating intuitive thinking.

The paper is organised as follows: Sect. 2 reveals different aspects of spatial thinking and how they apply to education and Sect. 3 presents several educational initiatives worldwide that focus on spatial thinking and knowledge. Section 4 exposes the GEOTHNK approach to spatial thinking teaching and learning, while Sect. 5 discusses insights gained by the project thus far, and finally Sect. 6 indicates that way forward.

2 Spatial Thinking; Basic Notions and Aspects

Before we begin by exploring notions relative to spatial thinking, a discussion on scale is necessary. Montello (1993) divides space into four classes, depending on the projective size of space relative to the human body and, judging from the cognitive processes needed for the understanding of spatial dimensions. This classification divides three-dimensional space into:

- Figural space; perceived in all its properties, without requiring locomotion by humans
- Vista space; includes the human body, is relatively as large or larger than that and comprises a room or a town square
- Environmental space; larger than the human body, comprising semantic information, is variable and hardly perceptible without moving into it, comprises of buildings, neighbourhoods, cities and, finally,
- Geographical space; much larger of the human body and cannot be understood directly even by human movement. Conversely, it can be perceived through representations, such as maps or schematic models.

Therefore, which type of space GEOTHNK deals with? To answer this, it should be pointed out that the term "geospatial" refers to environmental and geographical scales according to the previous classification and it is used in literature for representation and analysis of geographic phenomena (Golledge et al. 2008). Geographers in the traditional curricula deal with geospatial phenomena and refer to environmental and geographical space; GEOTHNK focuses mostly on these two but incorporates knowledge related to figural and vista space as well.

Furthermore, spatial abilities include the following (Golledge 1992):

- thinking geometrically;
- imaging complex spatial relations at various scales, from urban systems to interior room designs or table top layouts;
- recognizing spatial patterns in distributions of functions, places and interactions at a variety of scales;
- interpreting macro-spatial relations such as star patterns;
- giving and comprehending directional and distance estimates as required by navigation, or the path integration and short-cutting procedures used in way finding;
- understanding network structures used in planning, design and engineering; and,
- identifying key characteristics of location and association of phenomena in space.

Finally, the distinction between knowledge of space and knowledge about spaces made by Eliot (2000) is significant; he suggests that the former is phenomenal, while the latter is intellectual.

3 Spatial Thinking Initiatives in Education

As the importance and amplitude of spatial thinking in various scientific and everyday tasks has been acknowledged, several efforts are currently made towards its effective development through education, some of which are outlined in what follows.

3.1 TeachSpatial

TeachSpatial[1] (2011) is an environment for browsing several hundreds of teaching and learning resources annotated with spatial concept terms. To date the initiative: (a) lists 129 spatial concept terms grouped in 10 categories derived from the National Science Education Teaching Standards (NRC 1996), (b) gives links to reference publications related to spatial cognition, spatial teaching and learning, and spatial literacy, and (c) provides stakeholders with collaborative tools for sharing views and experience.

3.2 Geographic Information Science and Technology Body of Knowledge (GIS&TBoK)

The Geographic Information Science and Technology Body of Knowledge (AAG 2006) by the American University Consortium for Geographic Information Science (UCGIS) attempts to draw an outline of the concepts and skills pertaining to GIS, GIScience, remote sensing, satellite navigation systems, and cartography. The intention was to serve as resource for curriculum design and curricula mapping and comparison, for educational assessment and accreditation, and professional certification. GIS&TBoK is hierarchically structured, composed of 10 Knowledge Areas, further divided into 73 Units and 329 Topics. Each topic includes a list of 5–10 educational objectives corresponding to varying levels of knowledge and skills.

Currently, GIS&TBoK is being revised in the context of the BoKOnto project,[2] which will transform the initial body of knowledge into an ontology for the field of GIScience and Technology.

Following a very similar context, GI-N2K[3] constitutes the European answer to GIS&TBoK envisioning to establish its European counterpart. Twenty-five

[1]Undertaken by the Center for Spatial Studies, University of California, Santa Barbara, while supported by the U.S. National Science Foundation.

[2]http://gistbok.org/#.

[3]http://www.gi-n2k.eu/.

countries participate in the project with 31 partners from the academic and non-academics sectors, the GI industry and GI associations of professionals and experts.

3.3 Schools Online Thesaurus—ScOT

Schools Online Thesaurus website—ScOT (2014) provides a controlled vocabulary used in schools in Australia and New Zealand; it includes terms (concepts and topics) of various thematic areas, as described by the countries' formal curricula.

Terms (concepts) contained in this thesaurus, are structured hierarchically. For some concepts, there exists a structure of multiple inheritance; they are subconcepts of more than one concept, which actually means that they belong to more than one topic of the curriculum. An example is coordinates, which belongs to two knowledge areas, Science and Mathematics shown in Fig. 1.

The thesaurus contains over 10,000 concepts, of which only a small part has spatial dimension. It is worth noting that the majority of these "spatial" concepts are part of the vocabulary of two out of ten Knowledge areas (Mathematics and Science), which provides evidence of the close relation between spatial thinking and STEM disciplines. To a lesser extent, spatial concepts can be found in other Knowledge areas such as Arts, Society, and Technologies.

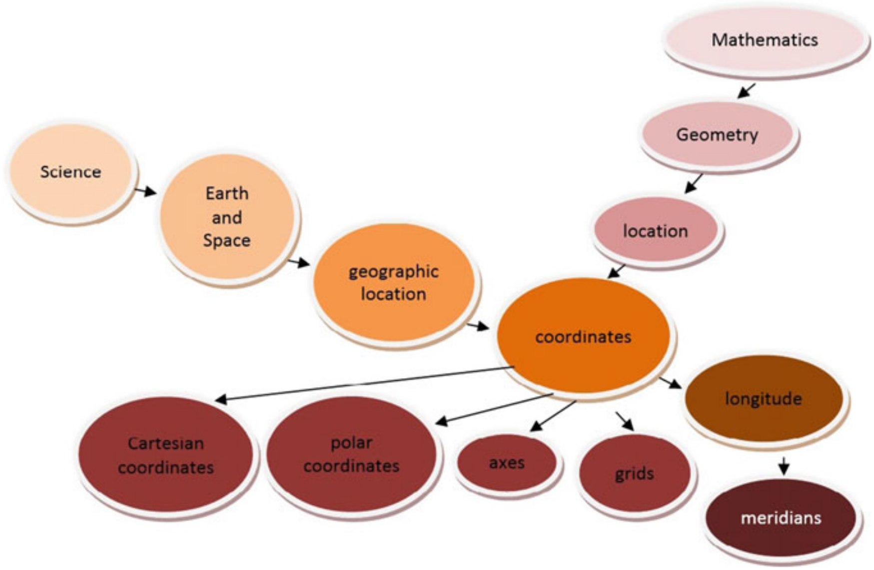

Fig. 1 The complete schematic representation of coordinates in ScOT

3.4 ITS Education Asia

The website ITS Education Asia (2013) developed by a group of private schools and enterprises, aims primarily at students in the fields of economics, literature and language, science and psychology. This website is a collaborative effort between a number of private schools in Asia to help pupils of secondary education, early university students, and school teachers in understanding and teaching the aforementioned courses.

Dictionaries are developed for various knowledge areas, among which the Geography Dictionary and Glossary (Harrington 2014) which contains over 1500 terms all cross-referenced and linked.[4] Advantage of the Geography dictionary is that a number of definitions contain links to online resources in an attempt to facilitate understanding of the underlined concepts.

A close inspection of the Geography dictionary reveals that it lacks a great deal of "geospatial concepts" directly defined and therefore not included in the glossary as distinct entries. They, nonetheless, are indirectly included in existing definitions; from the example of longitude, a number of spatial concepts can be identified. Browsing the Mathematics dictionary (Halliday 2014), several "spatial" concepts are defined therein (e.g. distance), another proof connecting spatial thinking to STEM disciplines.

4 Geospatial Thinking Building Blocks in GEOTHNK

The European project GEOTHNK[5] aims at: (a) enhancing spatial thinking through an innovative ICT-based approach and an open, collaborative educational environment and (b) offering a methodological approach that allows the interdisciplinary organization and semantic linkage of knowledge.

The GEOTHNK approach goes beyond the provision and organization of resources. An innovative learning and teaching environment has been developed for the semantic linkage of geospatial concepts, representation tools, and reasoning processes in between and across other domains that may also provide relevant and meaningful contexts (e.g., Environment, Earth Sciences, Social Sciences, etc.). As mentioned, "spatial thinking is a constructive amalgam of three elements: concepts of space, tools of representation, and processes of reasoning" (NRC 2006) and GEOTHNK follows this premise.

GEOTHNK Community of users cover diverse target groups; teachers, university students, science center educators, and adult learners which address different

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[4]An example is the definition of longitude (http://www.itseducation.asia/geography/l.htm#Longitude), where underlined words indicate lemmas in the dictionary and the user is prompted to look up another reference as well by following a url.

[5]GEOTHNK Website, http://www.geothnk.eu/.

levels of education; schools (primary and secondary), higher Education, and adult education in two distinct educational environments; formal (schools and universities) and informal (science centers/museums). Moreover, since GEOTHNK constitutes a European project, its content is generated in six European languages: English, Bulgarian, Dutch, German, Greek, and Romanian.

To accomplish the project's objectives, the pedagogical methodology adopted in GEOTHNK follows the Inquiry Based Learning Model (IBLM) as formulated over the years by various researchers and perspectives (Collins 1986; DeBoer 1991; Rakow 1986), and has been officially promoted to pedagogy for improving science learning in many countries (Hounsell and McCune 2002; NRC 2000; Rocard et al. 2007). Five essential features characterise IBLM when applied in classroom; learners: (1) engage themselves in scientifically oriented questions, (2) give priority to evidence in responding to questions, (3) formulate explanations from evidence, (4) connect explanations to scientific knowledge and (5) communicate and justify explanations.

The IBLM is implemented by the GEOTHNK authoring tool and community,[6] which gives educators and learners an open, collaborative environment for developing learning pathways based on the three components of spatial thinking; users are prompted to add to their scenarios concepts, representation tools, and reasoning tools. A Learning Pathway describes the organization and coordination of various individual learning resources into a coherent plan so that they become a meaningful learning activity for specific target audiences in a specific learning environment. The GEOTHNK Community allows users to revisit, revise and continually develop pathways, or even use pathways created by others for creating their own new versions, in a process reflecting social learning in the community.

4.1 Concepts

The set of GEOTHNK concepts is formulated based on a thorough analysis of existing vocabularies, which have been presented in Sect. 3. GEOTHNK includes 342 concepts, both spatial (e.g., coordinates, altitude, and distance) and non-spatial (e.g., natural resources and alternative energy), concepts referring to tangible objects (e.g., city and canal) and concepts referring to abstract notions (e.g., form and connection). Spatial concepts are considered important not only for understanding relative disciplines such as Mathematics and Geography, but they are either directly or indirectly related to other disciplines as well such as History and Social Sciences. Each concept is described by three elements: (a) a term, (b) a definition, and (c) links to useful educational on-line resources to facilitate

[6]GEOTHNK Authoring Tool and Community, http://portal.opendiscoveryspace.eu/community/geothink-community-400866.

Fig. 2 The concept "planning" in the GEOTHNK authoring tool

understanding of concepts (770 in total collected by the consortium); Fig. 2 shows a characteristic example.

The set of GEOTHNK concepts was developed according to the following principles: (a) interdisciplinarity, (b) transversality and, (c) semantic linkage of concepts.

4.1.1 Interdisciplinarity

Interdisciplinarity, among the major innovative elements of GEOTHNK, is accomplished through the inclusion of three kinds of concepts:

- General concepts not particularly focused on any specific discipline, such as class, accuracy, analysis, and analogy but rather cross-cut different disciplines,
- Specific concepts relevant to particular disciplines such as Geography, Earth Sciences, Environment, and Mathematics. For example, the concept continent is mainly relevant to Geography, deforestation to Environment and interpolation to Mathematics.

- Interdisciplinary concepts relevant to several scientific fields that function as a bridge for linking these and for developing multifarious scenarios. For example, the concept city may be used for several pathways dealing with a variety of subjects, such as urban planning, population distribution, urban evolution through history and urban sprawl. Each one of these pathways deals with the concept city from a different perspective, associates it with different other concepts, and triggers different aspects of spatial thinking.

The motivation for selecting such a diverse set of concepts is the integration of knowledge from different disciplines. GEOTHNK does not aim at imposing a single, specific view of concepts that users should adhere to, but to provide a wide, flexible range of views on these. In that way, users may develop different pathways for the same concept or topic reflecting diverse views or interests.

4.1.2 Transversality

Geospatial thinking varies according to various factors (age, background knowledge, etc.) and therefore cannot be treated uniformly for all target groups. The transversal character of GEOTHNK concepts, i.e., their adaptation to the needs of all target groups is reflected in the three elements that describe the concepts: (a) terms, (b) definitions, and (c) links to useful resources. Terms and definitions are derived from WordNet (2014), which provides alternative terms for each concept and comprehensible definitions with example sentences that meet the needs of GEOTHNK's target groups.

However, the transversal character of GEOTHNK concepts is mainly reflected in the links to useful resources that describe each concept. For each concept, a range of resources with varying degrees of difficulty is offered for fitting the needs and background knowledge of the user groups, as shown in Fig. 2. In general, a teacher needs more simplified explanation of concepts; a university student needs a more elaborate description, while an adult learner usually needs a more general one.

4.1.3 Semantic Linkage of GEOTHNK Concepts

Equal importance as the development of the GEOTHNK set of concepts is given to the establishment of interrelations among them. Concepts are organised in a three-level hierarchy that reflects clusters of basic notions and subject areas such as geometric primitives, spatial relations, space-time primitives, geography etc.

The concepts have been further analysed based on WordNet's large lexical database for discovering relations among them. GEOTHNK concepts are not linked only through strict taxonomical relationships such as hypernymy/hyponymy but also through other relations such as meronymy/partonomy and association. In this

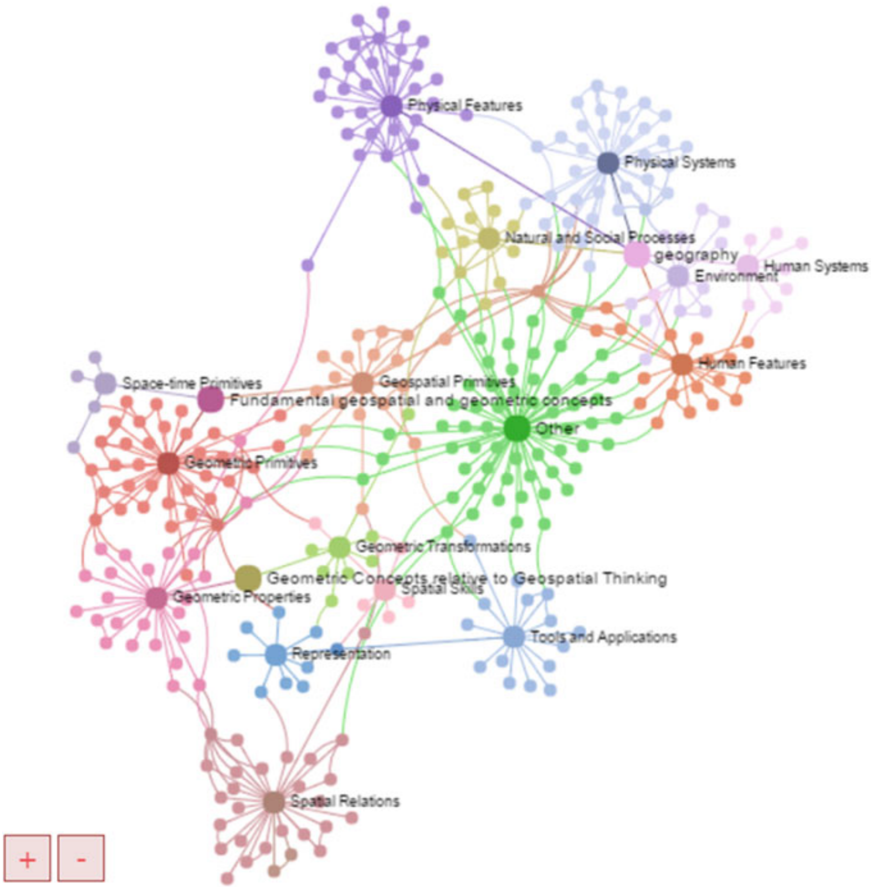

Fig. 3 GEOTHNK semantic network

way, GEOTHNK does not enforce a specific view regarding concepts and their relations but allows flexibility during the development of pathways. To ensure semantic linkage, GEOTHNK concepts form a semantic network (Fig. 3), of a total 802 taxonomic relations, developed initially in English and further translated into the languages of the Consortium. Users are able to browse it to find out the structure of geospatial knowledge. Furthermore, once a pathway is created, the platform enables its overview in graphical form, that is, it highlights the concepts involved in the pathway, and the relations between them. In Fig. 4, the excerpt of the semantic network that corresponds to a particular learning pathway represents the conceptual structure of the pathway, which reflects the creator's conceptions of the subject matter.

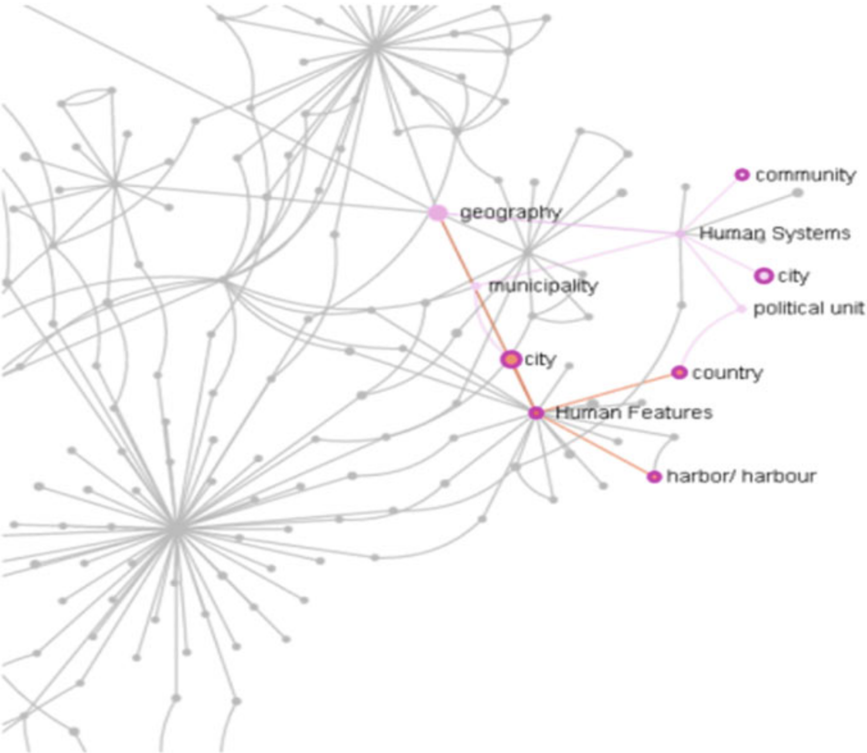

Fig. 4 The semantic network of an individual pathway (First world war: the conflict of ideologies)

4.1.4 Instances

"Putting on the map" learning pathways is an important functionality—and innovation—of the GEOTHNK educational platform which aims at: (a) connecting the conceptual/semantic to the geospatial/cartographic information as to a better understanding of geospatial concepts and geographic space, and (b) supporting an additional search mechanism, i.e., the map-based search of learning pathways. This is achieved through concepts' instances and the extraction of their geographic coordinates from gazetteers. In particular, certain concepts referring to real entities, natural (e.g., rivers, mountains, etc.) and man-made (e.g., cities, towns, etc.) are populated with instances extracted from GeoNames geographical database.[7] Instances play a dual role; (a) they serve as examples to help clarify the meaning of concepts (e.g. many pathways developed for explaining the notion of flood or the concept of sea level rise use the Netherlands as an instance of the concept country)

[7]http://www.geonames.org/.

Fig. 5 Putting GEOTHNK learning pathways on the map

and (b) their positions on a map (by their coordinates) support map-based search of pathways as shown in Fig. 5.

4.2 *Representation Tools*

Representations, either internal or external, serve as an effective reasoning tool and trigger complex reasoning processes and abilities (NRC 2006). The ability to create and use spatial representations is a necessary process towards spatial thinking. Representations, which include maps, models, diagrams, and graphs help in making the most abstract concepts understandable (Mathewson 1999). According to Newcombe and Huttenlocher (2000) symbolic representations of spatial location, either in language description or in the various kinds of optical displays serve the transmission of information obtained. On the other hand, science and technology are developed through exchange of information and data and a large part of these are presented as diagrams, illustrations, maps, schematics, which summarize information and contribute to their understanding by the wider public (Mathewson 1999). Representations also “help us remember, understand, reason, and communicate about properties of and relations between objects represented in space, whether or not those objects themselves are inherently spatial” (NRC 2006).

Additionally, Uttal (2000) found out that the use of maps and thinking about them can help children understand abstract concepts of space and gain systematic thinking about spatial relations with which they have not come into direct contact. In addition, the “exposure” to maps can help children think the numerous spatial relationships that may exist among locations.

Representation tools vary in terms of the following: (a) media (tangible, digital, auditory, etc.), (b) form (static, dynamic, interactive), and (c) level of detail (from abstract graphs to detailed aerial photographs or satellite images). Representations may depict geospatial entities and phenomena at different scales such as oceans, landforms, water bodies, cities, forests, industrial areas, buildings, etc. They may also depict entities and phenomena beyond environmental and geographic scales (Montello 1993), both at the micro scale e.g., DNA maps and macro scale, e.g., maps of the universe. Space and spatial representations are also used as a metaphor for creating the so-called spatializations.

To support the development of multifarious pathways, GEOTHNK provides links to various categories of representation tools (links to 55 online representation tools added by the consortium):

- Maps, Map Viewers, and Map Making; includes online maps and web mapping applications for map viewing (e.g., Google Maps, Bing maps, OpenStreetMap, etc.) and map making (e.g., MapMaker Interactive).
- Country Maps; includes maps from GEOTHNK partner countries to support users from different countries in pathway development.
- Atlases; includes mainly educational resources for world maps accompanied with other useful information such as geopolitical, social, religious, statistical etc.
- Historical maps; provided from digital Libraries may be used for the development of pathways that deal with the evolution of geospatial entities through time.
- Virtual globes; includes web-based 3D applications that display geographic data on spherical representations of the Earth.
- Satellite and Aerial Imagery; includes aerial photographs and satellite images provided mainly for educational purposes. Figure 6 shows the NASA Earth Observatory featuring the Image of the Day as an example of a repository of satellite imagery that GEOTHNK provides link to.
- Data Visualizations[8]; tools and resources for viewing, exploring, and creating data visualizations, such as graphs, charts, mind maps, tree maps heat maps etc., not necessarily representing geospatial data but any kind of data.
- Models; includes 2D and 3D geometrical models, which are commonly used for supporting STEM education.

[8]Examples include spicynodes (http://www.spicynodes.org/) and biggeplate (http://www.biggerplate.com/).

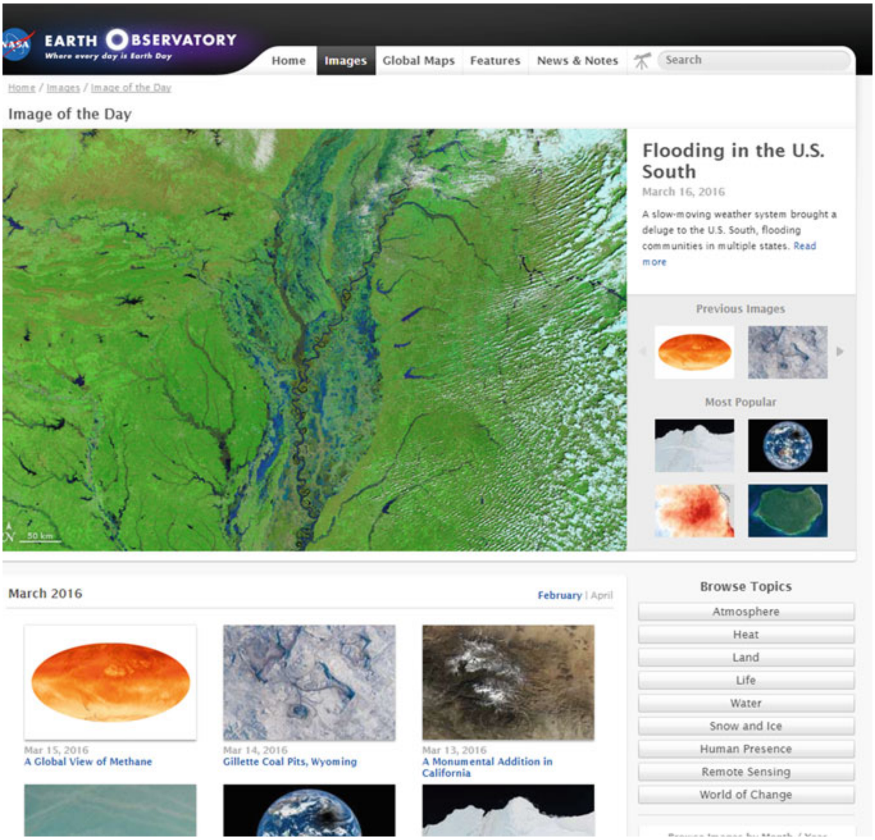

Fig. 6 The NASA earth observatory, image of the day repository, http://earthobservatory.nasa.gov/IOTD/

4.3 *Reasoning Tools*

Thinking is a cognitive process, while reasoning is considered an important cognitive ability (Presseisen 2001). Marzano and Pollock (2001) identified six general reasoning skills: (1) identifying similarities and differences, (2) problem solving and fault detection, (3) argumentation, (4) decision making, (5) hypothesis testing and scientific research, and (6) the use of logic and reasoning. Furthermore, studies by Holyoak and Morrison (2005) and Presseisen (2001) recognized that reasoning process covers cognitive processes, such as analysis, hypothesis, problem solving, and generalization.

Reasoning processes, therefore, are cognitive processes that allow the combination of spatial knowledge and representations to achieve problem solving and decision making through analysis, classification, hypothesis, generalization, and evaluation. The idea is that defining spatial thinking as an operating procedure facilitates the development of spatial literacy.

A reasoning tool may be any kind of tool (educational game, learning activity, interactive application, etc.) that may facilitate the understanding of a concept or pathway and prompt reasoning processes. The reasoning tools on the GEOTHNK educational platform are classified into two types:

1. Reasoning tools for understanding a specific concept. For example, for teaching the concepts distortion and projection, Google Mercator Puzzle[9] represents such a choice.
2. Reasoning tools for understanding or implementing a learning pathway. For example, for implementing a pathway for urban planning, an educational game such as Plan It Green[10] may be used.

Reasoning tools are not predefined, since they are pathway-specific. For this reason, the platform allows users to add new reasoning tools relevant to their needs and objectives.

5 Feedback and Insights Gained from the GEOTHNK Community

Users contribute to the repository by either: (a) creating new educational objects or pathways, (b) reusing pathways developed by other users, (c) tagging educational resources, and (d) creating new reasoning tools.

To date, there are 700 registered members in the GEOTHNK Community. These have added or reused 427 on-line resources (144 educational objects and 283 pathways), have created 68 reasoning tools, and have introduced over 4000 tags on resources.

It is important to point out that the content is implemented in six different languages. Regarding learning pathways, several have been developed in more than one language, since their contributors have showed an interest in helping the community and addressing a bigger audience with their contribution, fact that raises the number of pathways to 415.

The partnership has been monitoring the quality of the uploaded content throughout the project's life cycle, which led to the identification of 40 exemplary pathways. These represent the best examples of content created on the platform in terms of the overall approach (use of all three components of spatial thinking, meaningful allocation of resources, and adoption of the Inquiry Based Learning Model). They have been especially indicated on the platform as exemplary scenarios so that users can assess them easily and have a clear image on how to

[9]http://gmaps-samples.googlecode.com/svn/trunk/poly/puzzledrag.html.
[10]http://www.planitgreenlive.com/en/build-your-own-city.

develop coherent learning pathways that follow the GEOTHNK approach to its fullest. Indicative examples of such pathways consist: (a) perceptual image of an urban environment,[11] (b) Milky Way—the back-bone of night,[12] (c) the injectivity, surjectivity, bijectivity properties of functions—graphical recognition,[13] and (d) Volcanoes and Plate tectonics.[14]

Concerning the relation of added resources to education levels, the great majority of resources addresses formal educational contexts; 119 for primary, 294 for secondary, and 77 for higher education. However, regarding target audiences, 42 resources have been added for science centers educators for any educational context, and 73 resources for adult learners. These numbers indicate that GEOTHNK has succeeded in meeting the various target groups' needs as formulated in the beginning of the project.

Another interesting finding is the connection of GEOTHNK resources to curriculum subjects as these have been defined by the community members. The vocabulary provided to the Community for connecting resources to the curriculum comes from Open Discovery Space (ODS),[15] a multilingual open learning platform for sharing eLearning resources, in the context of which a vocabulary of subjects for several European curricula has been formulated. Table 1 gives solid evidence of the strong relation between spatial thinking and STEM disciplines; as expected, Science comes first, and following downward the hierarchy of the ODS vocabulary, Geography and Earth Science Mathematics appear in the list as well as Environmental Education, Physics, and Astronomy, while ICT is also present in the list of subjects. Table 1 gives also some insights on the relation of spatial thinking to Humanities, with the presence of English teaching and History subjects in the list of most chosen disciplines.

A closer look in the subjects included in the general area of Geography and Earth Science, reveals 21 resources developed for Maps and plans, 19 in the context of GIS, 9 for Cartography and 6 for Spatial Transformations, to name a few relevant to the overall thematic area of Mapping and Cartography. While examination of the general area of Mathematics, exposes, 34 resources relevant to Geometry, 10 to Graphical Display of Data and 7 to Transformation, which can also be considered related to Mapping and Cartography.

Another inspection on the Community analytics provides interesting facts about content of the resources added by the users. Regarding GEOTHNK Concepts included in user-generated learning pathways, Table 2 shows the twenty most used

[11]http://portal.opendiscoveryspace.eu/edu-object/perceptual-image-urban-environment-830235 created by a Greek postgraduate student.

[12]http://portal.opendiscoveryspace.eu/edu-object/milky-way-backbone-night-834098 developed by a Bulgarian university professor for pre-service Astronomy teachers.

[13]http://portal.opendiscoveryspace.eu/edu-object/injectivity-surjectivity-bijectivity-properties-functions-graphical-recognition-830247 contributed by a secondary education Romanian teacher.

[14]http://portal.opendiscoveryspace.eu/edu-object/platentektoniek-en-vulkanen-834837 uploaded by a Dutch science center educator.

[15]http://opendiscoveryspace.eu.

Table 1 GEOTHNK resources and curriculum subjects

Curriculum subjects	Resources
Science	221
Geography and Earth Science	197
Mathematics	52
Environmental Education	41
Physics	13
Astronomy	9
ICT	32
English teaching	27
History	25

ones, with the predominance of the concept map being undisputable giving evidence on how the use of maps in education can be a powerful tool for enhancing spatial thinking abilities of learners. High on the list are the concepts Representation, scale, and mapping finding that also indicates the strong relation of spatial thinking teaching and learning and Cartography-related notions.

Spatial thinking interdisciplinary character is given also evidence upon variety of pathways developed including the same concept. For instance, 38 scenarios include the concept scale, as indicated in Table 2, which relate to a diversity of curriculum subjects; Cartography, Astronomy, Physics, Mathematics, Geography, Earth science, geology, Mapping etc.

During the GEOTHNK Project, both the overall approach and the GEOTHNK Authoring Environment have been validated. The validation instruments and feedback tools especially developed for the needs of the project have proven to be effective as they both worked perfectly with different target groups participating.

Teachers and teachers' trainers admitted that school students found it feasible to follow the GEOTHNK activities and that they enjoyed using reasoning tools that were suggested by GEOTHNK. Moreover, they declared that their students' spatial thinking skills have been improved and that the educational framework (Inquiry Based Model) was the most appropriate pedagogical approach for communicating geosciences. Finally, they were familiarized with tools that were new to them after admitting that they did not use such tools in class before.

On the other hand, university students stated that being taught via GEOTHNK could help them do better in their studies apart from mentioning that they found the experience interesting. Also, they answered that GEOTHNK platform was important for their improvement and that the use of reasoning and representation tools suggested by the platform is fundamental and at the same time beneficial for the preeminent teaching of geospatial issues. In the very same perspective, they agreed that GEOTHNK educational pathways eased the teaching of geosciences. Overall, they replied that geosciences issues became more attractive for them after the use of GEOTHNK.

Meanwhile, science centre educators noticed that visitors of science centres and museums found their involvement with GEOTHNK enjoyable and it was feasible

Table 2 Twenty most used GEOTHNK concepts in user-generated learning pathways

Concept	Occurrences
Map	*109*
Location	90
Geography	85
City	75
Representation	*70*
Spatial relations	59
Area	54
Distance	52
Methods and abilities	51
Island	48
Fundamental geospatial and geometric concepts	44
Geographic information systems	42
Geometric concepts relative to geospatial thinking	42
City	39
Scale	*38*
Spatial relation	38
Time	37
Physical systems	36
Mapping	*35*
Tools and applications	35

for them to follow GEOTHNK activities. They also stated that adult learners enjoyed the use of representation and reasoning tools and that in this case they contributed to the development of problem-solving skills of the adult learners. Most importantly, they declared that geosciences' issues became more attractive for adult learners after the use of GEOTHNK. They finally admitted that through the development of spatial thinking their problem-solving skills are also empowered.

6 Conclusions

To support spatial thinking in formal learning environments, it should be incorporated into the general education system including educational practices, curricula, teaching support materials, and assessments. In Europe, no such priority is yet formulated, which presents a challenge for projects such as GEOTHNK to turn into policies and trigger educational policy reform in the long term.

Our experience from the GEOTHNK Community has shown that there is more to spatial thinking than meets the eye. GEOTHNK groups of users have a wide, multidisciplinary conception of spatial thinking that cross-cuts different subjects and levels of education More specifically, regarding teachers in the community, these vary in terms of the discipline they practice; there can be found English, Math, even

Art teachers that constitute a multifarious audience that blends with Geography teachers and give strong evidence that spatial thinking cross-cuts the curriculum and should be dealt with accordingly.

GEOTHNK has proven very successful in reaching its initial objectives. It has raised awareness among educators of different education levels in Europe towards spatial thinking and how it can be taught inside and outside the classroom. Future steps include among others, tracing spatial thinking across the curriculum, which is a challenging task since it cross-cuts curriculum subjects. Furthermore, we envision directly addressing the learners; to date GEOTHNK focuses on educators and how these can be encouraged in including spatial thinking notions into their teaching, while it would very valuable to assess how the GEOTHNK approach can actually enhance learners' spatial thinking skills. Finally, discussion from the previous section has indicated that spatial concepts relate somehow to the international trend and discussion about crosscutting concepts in education, thus a step further would be to showcase how crosscutting concepts such as scale, pattern, and system may be explicated using real-case examples from the spatial or geospatial domain connected to spatial thinking skills.

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