Evaluation of the use of spatial thinking components (concepts, representation tools and reasoning tools) in educational pathways

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Abstract

GEOTHNK is an online repository and authoring environment for the collection, creation, and sharing of educational resources that cultivate spatial thinking skills through different disciplines and educational contexts. It is based on the definition of spatial thinking as a constructive synthesis of three components: (a) concepts of space, (b) tools of representation, and (c) processes of reasoning [16]. The GEOTHNK platform provides for the incorporation of these three components in the process of developing educational pathways. The paper presents the analytics of the GEOTHNK repository and evaluates the use of spatial thinking components in pathways based on the three-dimensional taxonomy of spatial thinking developed by [10].

Keywords: spatial thinking, educational platform, concepts, representation tools, reasoning tools.

1 Introduction

GEOTHNK is an online educational platform for the collection, creation, and sharing of educational resources for: (a) enhancing spatial thinking through disciplines and educational contexts and (b) providing for the interdisciplinary organization and semantic linkage of related knowledge.

The study *Learning to Think Spatially* [16] proposed a definition of spatial thinking as the constructive combination of three main components: a) spatial concepts, b) representation tools and c) reasoning processes.

Spatial concepts are building blocks for spatial thinking. They render spatial thinking a distinctive way of thinking using 3d-space as the ground for understanding and solving problems (ibid.). Attempts to identify and classify spatial concepts in geography include: [3], [5], [6] and [10].

Representations are also crucial for enhancing spatial thinking. They "help us remember, understand, reason, and communicate about the properties of and relations between objects represented in space, whether or not those objects themselves are inherently spatial" [16]. Representations, which include maps, models, diagrams, and graphs, help in making the most abstract concepts understandable [14]. Symbolic representations of spatial location, either in language description or in different kinds of optical displays, serve the transmission of information obtained from a person to others [17]. Additionally, the use of maps and thinking about them can help children to understand abstract concepts of space and to gain systematic thinking about spatial relations with which they have not come into direct contact. Furthermore, the "exposure" to maps can help children to think numerous spatial relationships that may exist among locations [24].

Thinking is a cognitive process, while reasoning is considered an important cognitive ability [20]. Six general reasoning skills have been identified [13]; identifying similarities and differences, problem solving and fault detection, argumentation, decision making, hypothesis testing and scientific research, and the use of logic and reasoning. Furthermore, studies by [9] and [20] recognized that reasoning processes cover cognitive processes, such as analysis, hypothesis, problem solving, and generalization.

GEOTHNK adopted the above-mentioned framework, and encouraged users to develop educational pathways (scenarios) according to specific requirements (Section 2). User-generated content on the platform analysis and assessment provides with useful insights on how users have reacted towards the proposed methodology.

Hence, the objective of the paper is twofold: (a) to briefly present the analytics of the repository (Section 3) and (b) to evaluate the usage of the proposed methodology for developing pathways that enhance spatial thinking based on the three-dimensional taxonomy introduced by [10] (Section 4). Finally, conclusions on the overall approach are described in Section 5.

2 Guidelines for designing pathways

A pathway on the platform describes the organization and coordination of various individual learning resources into a coherent plan so that they become a meaningful learning activity for a specific user group both in formal and informal environments.

2.1 Core components of educational scenarios

Research has shown that the three components of spatial thinking are not treated equivalently in education; low-level spatial concepts are given priority relatively to higher-level spatial concepts and spatial representations, whereas higher-order cognitive skills are rarely prompted [10]. Furthermore, geospatial knowledge is usually static and independent from other knowledge, impeding critical thinking and understanding of complicated interactions among entities, events, and phenomena.

Thus, there is a clear need for enhancing and integrating spatial thinking components and engaging users in more critical, inquiry-based teaching methods. In this context, GEOTHNK provides the technical and semantic infrastructure for developing pathways that incorporate these three distinctive components.

2.1.1 Concepts

The authoring environment allows users to choose concepts from a semantic network of 342 concepts classified into different types (e.g. (geo)spatial concepts, concepts referring to spatial relations, concepts referring to physical features and systems, etc).

The concepts' list was formulated by thorough analysis of existing educational vocabularies. More specifically, the following have been examined:

- TeachSpatial's [23] concept lexicon includes a set of 129 spatial concepts derived from [15].
- ScOT [21] is a controlled vocabulary of terms used in Australian and New Zealand schools. It includes ten major subject areas under which all other concepts are classified.
- The Canadian National Standards for Geography [1] define and organize geographic knowledge and skills to be developed by students.
- Open Discovery Space [18] provides a controlled vocabulary to achieve consistent description of educational resources and to facilitate their retrieval.
- The Geography [8] and Mathematics Dictionary & Glossary [7] developed under [11].

The semantic network (Figure 1) - translated in six languages - consists of the concepts and their between taxonomic relations extracted from [25]. Moreover, links to online resources have been collected to explicate the concepts.

For each concept, the following elements are specified (Figure 2): (a) concept term, (b) concept definition, and (c) links to useful resources. To suit different education levels, more than one definition has been used to explicate a concept; the same holds for the number of resources attached to it.

Figure 1: Excerpt of the semantic network.

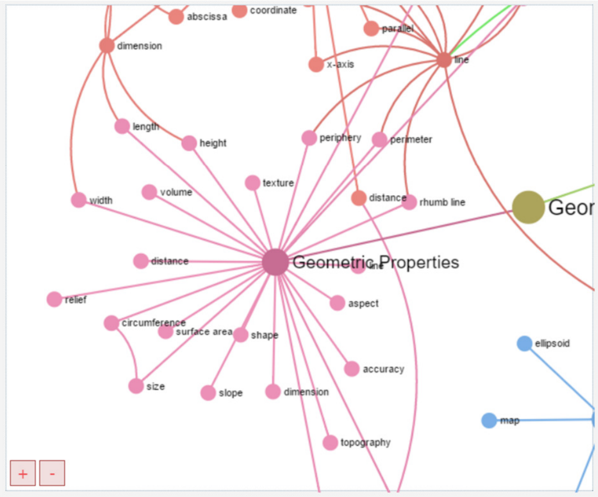
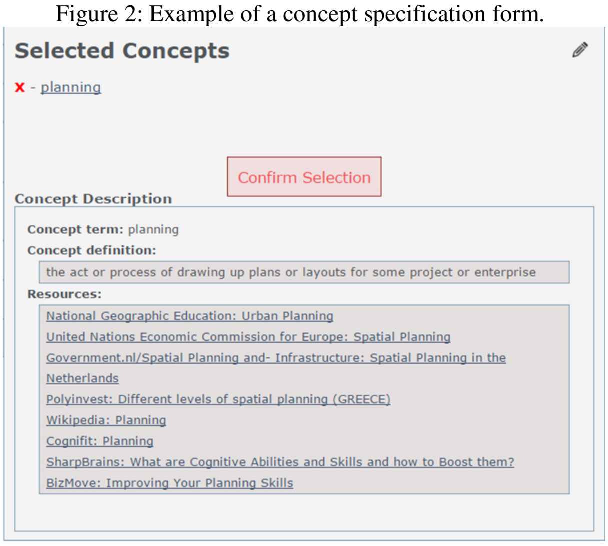


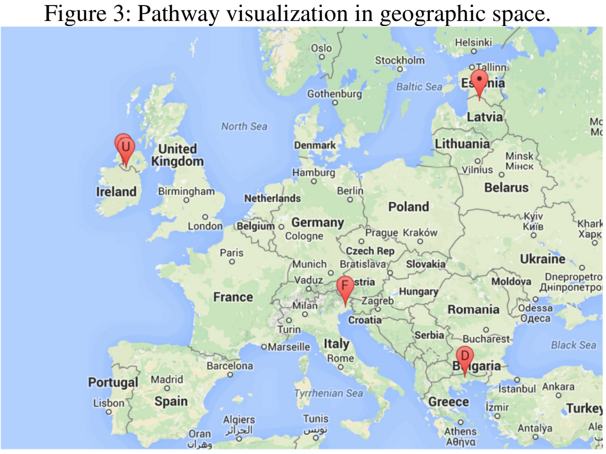
Figure 2: Example of a concept specification form.



2.1.2 Instances

Users may also add instances to their scenarios since many spatial concepts can be exemplified in space (e.g. cities: New York, London, Marseille etc.). Instances are dynamically drawn from GeoNames geographical database. Enrichment of pathways with instances supports educational scenarios visualization in real geographic space and map-based search.

Figure 3: Pathway visualization in geographic space.

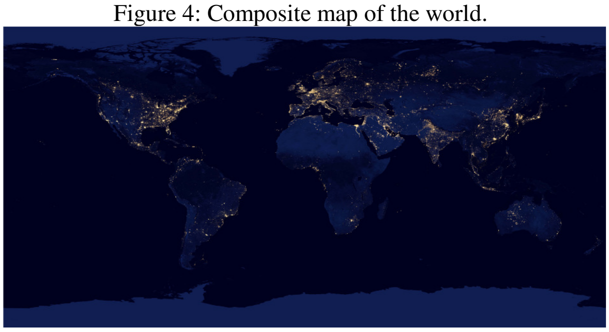


2.1.3 Representation tools

GEOTHNK provides links to 55 online representation tools classified under eight categories such as Maps, Map Viewers, and Map Making, Historical maps, Satellite and Areal Imagery, Data Visualizations etc.

For instance, a user developing a scenario “Where are cities located on Earth?” may select the representation tool NASA Wavelength Digital Library from the category “satellite and areal imagery”, and attach the following image (Figure 4) to the scenario.

Figure 4: Composite map of the world.



Source: NASA Earth Observatory.

2.1.4 Reasoning tools

A reasoning tool may be any kind of tool (educational game, learning activity, interactive application, etc.) that facilitates the understanding of a concept or scenario and prompts reasoning processes. In contrast to pre-defined concepts and representation tools, reasoning tools, since scenario-oriented, are added by users. For instance, a user may use Google Earth as a reasoning tool to calculate distances among different locations.

3 Analysis of the GEOTHNK educational platform user-generated content

Although GEOTHNK repository has been enriched with different types of elements by the project consortium (Table 1), it mainly relies on a crowdsourcing approach for the development of educational resources. Users contribute to the repository by:

- creating new educational objects or scenarios,
- reusing scenarios developed by others,
- tagging educational resources, and
- creating new reasoning tools.

Table 1: Elements provided by the project consortium.

Element	Value
Geospatial concepts with definitions translated in partner languages using computational lexicons	342
Taxonomic relations between concepts	802
Links to online resources for documenting concepts addressing different age groups and educational levels	770
Links to online representation tools	55
Instances of geospatial concepts drawn from GeoNames	2.158.751
Exemplary scenarios as good examples for users	77

Tables 2 and 3 show some analytics for the crowdsourcing aspect of the GEOTHNK platform. Table 2 shows the number of contributors to the platform, while Table 3 shows their contribution to the platform’s content.

Table 2: Contributors to the platform.

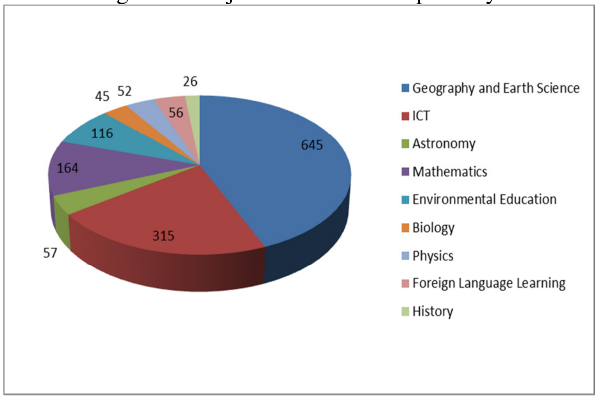
Role	Contributors
Teachers and Teachers’ Trainers	284
University Students	298
Experts	74
Science Centre Educators	32
Parents	28
Total	716

Table 3: Indicators of the platform’s crowdsourcing.

Indicator	Value
Educational resources developed (educational pathways/ educational objects)	466 (300/166)
Reasoning tools added	77
Use of geospatial concepts in pathways	282
Use of concepts’ instances in pathways	1475
Use of representation tools in pathways	327
Use of reasoning tools in pathways	387
Number of tags	5560

Another important aspect is the interdisciplinarity of the developed pathways, which was one of the major initial aims of the project. Figure 5 shows how resources relate to several subjects. As expected, Geography and Earth Science prevail, followed by Environmental Education, Mathematics, Astronomy, Physics, ICT, but also the less anticipated History and Foreign Language learning.

Figure 5: Subjects treated within pathways.



4 Assessing the use of spatial thinking components

Since GEOTHNK relies on users' contribution, there was concern regarding their reaction towards the proposed framework for creating pathways. To assess the use of spatial thinking components in pathways developed by the platform's users, we draw on the three-dimensional taxonomy of spatial thinking developed by [10]. This taxonomy defines spatial levels structured along three axes and has been applied to evaluate geography textbook questions. The first axis constitutes the classification of the concepts of space. Thirty-one concepts are identified as essential to spatial thinking further categorised into three subcategories; primitives, simple-spatial, complex spatial plus an additional one for non-spatial concepts. The second axis identifies use and non-use of representation tools since no framework for classifying representations in terms of complexity exists. Finally, the third axis establishes classification of reasoning processes based on the three levels of thinking proposed by [2]: the input, processing, and output levels of thinking. The framework can be visualized as a 4 x 3 x 2 cube to comprise the subcategories of the taxonomy (for concepts, reasoning processes, and for use or non-use of representation tools respectively). This structure defines 24 cells, each representing a unique combination of the spatial thinking components, with Cell 24 being associated with the highest possible spatial thinking level.

Based on this structure, the use of spatial thinking components in pathways is assessed by identifying which subcategories of the spatial thinking components users of the platform favour the most, giving insights about their familiarization with spatial thinking, their ability to adopt the proposed framework for pathway development, and their competence in synthesizing and combining spatial thinking components.

Table 4 shows the 20 most used concepts in scenarios and the number of times each concept has been used. According to the above-mentioned taxonomy, the mostly used concepts may be considered primitive or simple like distance and location (Table 5). Complex spatial concepts such as scale, network and map projection also appear in scenarios, but less often than simpler concepts.

Table 4: Use of geoconcepts (20 most used).

Number of times used	Concept
122	map
103	location
88	geography
81	Representation
78	city
62	Spatial Relations
58	island
57	area
54	distance
51	Methods and Abilities
46	geographic information systems
46	Fundamental geospatial and geometric concepts
43	problem solving
43	Geometric Concepts relative to Geospatial Thinking
40	scale
39	city
39	analysis
38	Spatial Relation
37	planning
37	time

Table 5: Use of concepts according to the taxonomy of spatial thinking [10].

Number of times used	Concept
Complex-Spatial	
16	distribution
13	pattern
12	cluster
2	diffusion
3	hierarchy
20	network
7	layer
1	relief
40	scale
35	(map) projection
Simple-Spatial	
88	distance
15	direction
2	connection
4	link
7	motion/ movement
33	boundary
7	region
33	shape
6	arrangement
27	proximity/ adjacency
Primitives	
103	location
9	size/ magnitude

Table 6 shows that the majority of representation tools used comes from the category maps with Google maps prevailing over the others.

Another interesting aspect of the taxonomy of spatial thinking is the classification of reasoning processes. This allowed classifying reasoning tools users have added on the platform. Table 7 shows the mostly used reasoning tools based on the level of thinking, i.e., the reasoning processes they trigger. GIS software seems to be highly popular among several scenarios (ArcGIS, EduGIS, QGIS), as well as other applications such as Google Earth and distance calculator.

Table 6: Use of representation tools (10 most used).

Number of times used	Representation tool
146	Google maps
48	Google Earth
45	National Geographic Atlas Maps
24	GeoGebra
8	OpenStreetMap
6	worldatlas
6	Satellite and Information Service
4	National Geographic Maps
4	Google Maps Gallery
4	ARGIS maps
4	UMapper

Table 7: Use of reasoning tools (10 most used) and the level of thinking they belong to.

Number of times used	Reasoning tool	Level of thinking
53	Distance calculator	input
49	Google Earth	input, processing, output
47	ArcGIS (Trial Edition)	input, processing, output
34	Flood Maps	input
27	Google maps	input, processing, output
19	QGIS	input, processing, output
13	Stellarium	input
12	orientare spatiala	processing
11	EduGIS	input, processing, output
11	Educational stimulation software PHET	processing
10	PERMAP 11.8a	processing

5 Conclusions

GEOTHNK platform is not just a repository of educational resources. It supports their development based on a rich semantic infrastructure that incorporates the three core components of spatial thinking and supports the interdisciplinary organization and semantic linkage of knowledge.

While mostly used concepts may be considered primitive or simple, common-sense concepts are also highly used (Table 4). The prominence of concepts such as map, city, river, etc. in referring to and representing geographic reality, is somewhat expected based on evidence from experiments [4], [12], [19], and [22] on human categorization of geospatial categories.

Prevailing of the concept map is also verified within the second core building block of spatial thinking; the majority of representation tools used comes from the category of maps. Complex concepts appear in various pathways covering different age groups (from 6 - 9 up to 25+ years) and subjects (geography, mathematics, sociology, etc.), but to a lesser extent. This may be justified by the fact that the majority of users are not experts in spatial thinking. More specifically, concerning teachers and teacher’s trainers, these vary in terms of the discipline they practice, coming from a whole range of disciplines from Science to Humanities.

Finally, reasoning tools added by users cover all three levels of thinking. Analysis of the reasoning tools in pathways reveals that users favour processing thinking level reasoning tools (23), followed by input (18), while output (15) come third.

The analysis of the platform user-generated content shows, that the approach to spatial thinking has been exploited and adopted by users, since the three components of spatial thinking have been used hundreds of times in educational scenarios.

Connection of spatial thinking to formal curricula and assessment of learners’ spatial thinking per se and as a vehicle for learning in different disciplines constitute future research steps.

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