Development of Methodological Tools for Assessment and Enhancement Geospatial Literacy

Christos Charcharos

School of Rural and Surveying Engineering
National Technical University of Athens
H. Polytechniou Str. 9, 15780, Zografos Campus
Athens, Greece
chchar@central.ntua.gr

Abstract

Recent studies have demonstrated the importance of spatial thinking in sciences and in everyday life. The dissertation consistes of four distinctive but consecutive phases and its main purpose is the development of a methodological tool for the holistic assessment and enhancement of spatial abilities. This need is dictated by the fact that the current international approaches are limited to the assessment of individual small-scale spatial thinking factors, using paper-and-pencil questionnaires, while those of large-scale are usually neglected. In order to achieve that, in the first phase of the dissertation, spatial thinking will be delineated by identifying all its discrete factors through the implementation of Multidimensional Scaling (MDS). Afterwards, the methodological tool will be designed, implemented and evaluated. In addition, it will either be supported by a digital platform (e.g. GEOTHNK) or be a serious game that addresses to everyone (from young people to adults). In the third stage, the often-supported correlation between spatial thinking and problem-solving abilities will be investigated, using appropriate statistical methods. The last phase of the dissertation concerns the enhancement of spatial thinking at formal learning settings through the development of learning activities and scenarios that exploits Information and Communication Tools (ICT). Thus, students will be able to familiarize themselves with the building blocks of spatial thinking (spatial concepts, representation tools and reasoning processes).

Keywords: Spatial thinking, small-scale, large-scale, assessment, enhancement.

1 Introduction

Spatial thinking is the cognitive ability to visualize and interpret location, position, distance, direction, relationships, movement, and change over space, in different situations and at different scales (Sinton et al., 2013). It 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 suitable areas for constructing a winery based on various criteria (altitude and distance from towns and rivers), someone should grasp spatial concepts (location, distance, proximity, area of influence and elevation), use representation tools (maps and terrain models), and be able to perform reasoning processes (combining maps and making inferences about the potential areas).

Spatial and geospatial thinking are used as identical concepts, but there is an important difference that distinguishes them. In order to realize that distinction, someone should fully understand the models of geographic space, which can be categorized based on their projective size in relation to human body and the mobility that is required to comprehend their dimensions. Montello (1993) considers that the geographic space consists of four major classes: figural, vista, environmental and geographical. The first two spaces are projectively smaller than the human body or equal to it respectively and can be apprehended without appreciable mobility, while the environmental and geographical space are projectively larger or much larger than the human body and can be perceived via mobility or maps respectively. Golledge (2008), using the previous classification of geographic space, notes that the term "spatial" refers to the figural and vista space, while the term “geospatial” refers to the environmental and geographical space.

The report of National Research Council (NRC, 2006) "Learning to Think Spatially: GIS as a Support System in the K-12 Curriculum" argues that spatial thinking is essential in science and: “without explicit attention to [spatial literacy], we cannot meet our responsibility for equipping the next generation of students for life and work in the 21st century”. This report marked the need for a turn in education towards the enhancement of spatial thinking and spatial literacy.

The results from NRC’s report stress the rewarding effects of developing geospatial skills in increasing the participation in STEM disciplines (Science, Technology, Engineering, Mathematics), lacking of which acts as a barrier for students leading them to dropout (Utal & Cohen, 2012). Even more, spatial thinking is a vital talent for achieving STEM innovation, however due to being neglected by educational systems it has been missed (NSF, 2010).

Spatial skills are not innate but can be taught and cultivated with meaningful results. Their empowerment can be achieved through formal learning settings (Hegarty, 2014; Uttal et al., 2012 & 2013) and according to the NRC report: “fostering spatial literacy can be achieved only by systemic educational reform”. For example, children's spatial abilities can be enhanced by puzzle games or the use of spatial language and gestures by teachers (Newcombe, 2010). Sorby (2009) improved the performance of undergraduate students of polytechnic schools through a spatial visualization course.

This dissertation will try to give more insights regarding: a) the “families” of spatial thinking abilities by defining the small- and large-scale spatial thinking factors, b) methods for holistic assessment of spatial thinking, c) the often-supported correlation between spatial thinking and problem-solving abilities and d) the enhancement of spatial thinking abilities through the use of ICT tools and resources.

2 Research Questions

According to Booth & Thomas (2000), spatial thinking includes cognitive skills related to map reading and making, processes involving representation, scale, 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. This complexity hinders the delineation of spatial thinking because there isn’t an explicit categorization of its factors. Many researchers have dealt with this issue and various factors have emerged such as spatial perception, spatial visualization and mental rotation (Linn & Peterson, 1985), visualization, spatial relationships, flexibility of closure, closure speed and perceptual ability (Carroll, 1993), navigation, dynamic spatial ability, environmental ability etc. In addition, spatial thinking factors have been defined in a variety of ways (e.g. similar descriptions with different terms, identical terms with different meanings). Furthermore, the number of factors varies from author to author and ranges from two to ten (D’Oliveira, 2004). It is remarkable that the majority of them refers to small-scale factors, while those of large-scale have not been studied extensively.

The second contribution of the dissertation concerns the development of a methodological tool for the holistic assessment of spatial thinking. So far, questionnaires are used to assess a single spatial thinking factor, particularly those of small-scale. For example, Card Rotation test identifies two-dimensional orientation and mental rotation of objects, Hidden Image test evaluates flexibility of closure, Paper FormBoard assesses two-dimensional spatial visualization (Ekstrom, 1976). In addition, some questionnaires have been developed that simultaneously evaluate several small-scale factors, such as the Spatial Thinking Ability Test (Lee & Bednarz, 2012) and the Spatial Ability Test (Khaing, 2012). Therefore, there aren’t any means for holistic evaluation of both small- and large-scale spatial thinking factors. Moreover, most of the aforementioned questionnaires were developed without the contribution of a geospatial scientist. Thus, spatial abilities are determined in the narrow context of psychology and not within the broad spectrum of spatial thinking (Hegarty et al., 2002).

The investigation of the relationship between spatial thinking and problem-solving skills constitutes the third pillar of the dissertation. Problem-solving skills have been associated with other cognitive skills such as critical and reflective thinking skills (Demirel et al., 2015), metacognitive and innovation skills (Brumer et al., 2014). Recent studies have also examined the correlation between these two cognitive abilities. However, in these studies only a specific spatial thinking factor is associated with a specific type of problem. For example, the type of visual representation with the ability to solve verbal problems (Boonen et al., 2014) or the ability to locate objects with the ability to reason about distances (Mohring, 2015).

The fourth axis of the dissertation concerns the development of educational resources in order to cultivate spatial thinking through formal learning settings. In the international literature, various methods can be spotted, including the use of virtual environments (Hauptman, 2011), educational scenarios (Kavouras et al., 2014) or Web-GIS (Jo et al., 2016). In all these methods, the curriculum of secondary and tertiary education was studied and the resources were developed targeting specific courses. Although there are many educational resources at an international level, those that are available in Greece are few and limited to the development of educational scenarios without exploiting Information and Communication Technology (ICT) tools.

3 Methodology

The dissertation consists of four successive phases, which are analyzed below:

- In the first phase, an extensive literature review has been conducted in order to identify the representative factors / "families" of spatial thinking.
- The second phase involves the design and implementation of the methodological tool in which learning analytics tools will be integrated.
- The third phase concerns the evaluation of the methodological tool and the investigation of the relationship between spatial thinking and problem-solving skills.
- The subject of the fourth phase is the enhancement of spatial thinking through the development of educational resources using a properly structured toolkit.

More specific, in the first phase the international literature has been studied in order to record all small- and large-scale spatial thinking factors. So far, 33 factors have been identified, 20 of which are characterized as small-scale factors. Approximately 100 participants will take part in an experimental process, which will cluster these factors into categories. Using existing questionnaires that have been checked for validity and reliability, a score will be calculated for each factor. Through appropriate statistical analyses (Pearson correlation coefficient or Spearman's rank correlation coefficient), the correlation matrix of these factors will be produced, which will also be used as the entry data for conducting multidimensional scaling (MDS), resulting in the identification of the "families" of spatial thinking.

The next phase includes the design and implementation of the methodological tool, which will be an extension of the GEOTHNK platform developed in the framework of a European project to promote spatial thinking in formal learning settings (Kavouras et al., 2014). Firstly, the functional requirements of the system, the goals to be achieved and the end users, consisting of young people and young adults (ages 13 to 25), will be defined. At the implementation stage, except for the methodological tool, an online questionnaire will also be developed, meeting the necessary standards of validity and reliability. The methodological tool will provide the ability to interact with the user in order to evaluate spatial thinking. Thus, learning analytics tools are likely to be used, which will collect, analyze and measure data from the learners, for purposes of understanding and optimizing learning and the environments in which it occurs. Several learning analytics tools have been developed, such as SNAPP, C4S, AWE, PASS (Atif et al., 2013), which will be evaluated in order to identify the one that best suits the needs of the methodological tool.

In the third phase, a preliminary evaluation of the methodological tool with a relative small number of participants will be carried out in order to identify any errors and omissions. Once these errors are corrected, the methodological tool will be used to assess spatial thinking of secondary and tertiary students. Additionally, problem-solving skills of the same students will be evaluated, using the "Programme for International Student Assessment" (PISA) questionnaire (OECD, 2015) or the Adult Literacy and Lifeskills Survey (OECD, 2005), addressed to people between 16 to 65 years old. Appropriate statistical methods and analyses (as mentioned previously) will be used to explore the possible relationship between spatial thinking and problem-solving skills. In addition, through a regression analysis, the relative contribution of spatial thinking "families" to the development of problem-solving skills will be examined.

Finally, the fourth phase concerns the development of new educational resources that will enhance student's spatial thinking. The curriculum of secondary and tertiary education will be studied in order to identify the appropriate courses, in the context of which the resources will be developed. In order to create interactive educational resources, ICT tools will be exploited, thus familiarizing the students with concepts of space, representation tools and reasoning processes. For example, one idea is to develop a serious game regarding spatial thinking, using existing game engines, such as Unity 3D. Its purpose is twofold: a) to present an alternative to existing methods of assessment and be more attractive to children, as well as b) to serve as means of enhancement and assessment of spatial thinking simultaneously.

4 Expected Results

The expected results of this dissertation constitute its contribution as well as its innovative features, which are the following:

- the delineation of spatial thinking by identifying all its discrete small- and large-scale factors,
- the design, implementation and evaluation of a methodological tool, supported by a digital platform for the holistic assessment of spatial thinking,
- the correlation, if any, between spatial thinking and problem-solving skills, and
- the development of new learning activities to enhance spatial thinking through formal education.

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