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The effects of geography lessons with geospatial technologies on the development of high school students' relational thinking

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ABSTRACT

Geospatial technologies offer access to geospatial information via digital representations, such as digital maps, and tools for interaction with those representations. The question is whether geography lessons with geospatial technologies really contribute to the development of students' geospatial thinking, in particular geospatial relational thinking, as is suggested in the literature about geospatial technologies in secondary education. This paper reports about the outcomes of a quasi-experimental research project, in which a geography lesson series with geospatial technologies was compared with a conventional geography lesson series that had the same content. Although the lesson series covered only three lessons, the data showed that the lesson series with geospatial technologies contributed significantly more to the development of students' geospatial relational thinking than the conventional lesson series. The effect size was 'medium large'.

1. Introduction

Challenges in the world around us, such as climate change challenges, food challenges, poverty challenges, energy challenges, migration challenges, city planning challenges, and natural hazard challenges, are growing in complexity. They exist at scales ranging from local to global, cut across human and natural systems, involve many interdependent variables that are changing over time, and have a strong spatial component. These challenges are important for our future, but are difficult to understand, predict, and solve. One of the main goals of secondary geography education is to provide students with the ability to translate the challenges that they observe or read about, into a more coherent understanding. Also, they should learn to reason about solutions for these challenges, and to formulate judgements about these solutions, so that they can make informed decisions in their future everyday and professional lives. A growing number of educators worldwide have become convinced that the ability to think spatially is key to the development of these competences, and that education with geospatial technologies may contribute to the development of spatial thinking (e.g. Kerski, 2008; Lee & Bednarz, 2009; National Research Council, 2006). However, little is known about the effectiveness of instruction with geospatial technologies. This paper investigates the learning outcomes of a lesson series with geospatial technologies on one of the components of spatial thinking: spatial relational thinking.

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2. Spatial thinking and relational thinking

Spatial thinking is a kind of thinking that has been receiving more and more attention from educators in the past ten years. It refers to the knowledge, skills, and habits of mind related to the use of: concepts of space; tools of spatial representation; and processes of spatial reasoning (National Research Council, 2006). According to the authors of the influential book "Learning to think spatially", spatial thinking is universal kind of thinking that is useful in a wide variety of academic disciplines and everyday problem-solving situations (National Research Council, 2006). Huynh and Sharpe (2013, p. 3) argue that spatial thinking is "core to the theoretical and practical underpinnings of geography". Spatial thinking within the geography domain is somewhat different from spatial thinking in other domains. Geographers typically use a *geo*spatial reference frame. They study problems that are connected to locations on Earth, rather than problems in abstract thinking spaces. In other words: for geographers, the place on Earth matters.

Spatial thinking consists of several distinct but interrelated abilities. It is somewhat broader than *spatial ability*, although the two are related to each other (Lee & Bednarz, 2009). Cognitive psychologists (e.g. McGee, 1979) and geographers (e.g. Huynh & Sharpe, 2013; Lee & Bednarz, 2009) generally agree that two key components are 'spatial visualization' and 'spatial orientation'. *Spatial visualization* is the ability to mentally manipulate, rotate, twist, or invert individual objects (McGee, 1979), while *spatial orientation* is the ability to determine the relative position of objects, to change the point of view, and to maintain a sense of direction when moving through an environment. However, there is some disagreement about whether a third component, 'spatial relations', is also part of spatial ability (Gilmartin & Patton, 1984; Golledge & Stimson, 1997; Lohman, 1979; Montello, Lovelace, Golledge, & Self, 1999). Many geographers argue that the ability to reason about spatial distributions and patterns, spatial interactions, and spatial relations is an important part of spatial thinking (Albert & Golledge, 1999; Bednarz, 2004; Gilmartin & Patton, 1984; Golledge & Stimson, 1997; Huynh & Sharpe, 2013; Lee & Bednarz, 2009; Self & Golledge, 1994). The spatial relations component is the most often addressed component in geography courses (Bednarz, 2004), and Huynh and Sharpe (2013) argue that it's the geospatial reference frame and the focus on spatial relations what make geospatial thinking different from the general kind of spatial thinking.

Although many geographers argue that the spatial relations component is the most important component of geospatial thinking, it is also the least clearly defined component (Lee & Bednarz, 2009). According to Golledge and Stimson (1997, p. 158), the spatial relations component includes the ability "to recognize spatial distributions and spatial patterns, to connect locations, to associate and correlate spatially distributed phenomena, to comprehend and use spatial hierarchies, to regionalize, to orientate to real-world frames of reference, to imagine maps from verbal descriptions, to sketch maps, to compare maps, and to overlay and dissolve maps". Although this description of the spatial relations component has formed the basis for several geospatial thinking tests (among others: Huynh & Sharpe, 2013; Lee & Bednarz, 2009), it has some shortcomings.

First, many of the subcomponents in Golledge and Stimson's definition of the spatial relations component are not directly linked with spatial relations. For example, recognizing spatial patterns can be a prerequisite for recognizing spatial associations, as it requires one to compare two spatial patterns to see if there is any match. However, recognizing spatial patterns can also be a goal *in itself*.

Second, the terms contain different verbs, such as: 'recognizing', 'connecting', 'comprehending'. Most refer to the construction of new knowledge. This is a somewhat limited view on spatial thinking, as it hardly addresses spatial reasoning skills. For example, students should not only be able to recognize spatial distributions and spatial patterns, but should also be able to explain them, and to reason how they might change in the future due to autonomous processes or as a result of human interventions in the system. This kind of reasoning requires them to structure and apply their knowledge about spatial associations or causal relations. These spatial reasoning processes are an important part of spatial thinking, as they are needed to understand, for example: how the Arab Spring is related to the heat wave in Russia in 2010; why some glaciers in South Norway are advancing, while they are retreating in the rest of the world; and why the construction of the Erie Canal resulted in an economic boom in New York, while the construction of the Beaver Canal failed to do the same for Philadelphia.

For the reasons outlined above, it might be better to change the name of the component from 'spatial relations' to 'spatial analysis and spatial reasoning', and to distinguish a subcomponent called 'geospatial relational thinking'. It is clear now that this subcomponent goes much further than recognizing spatial associations alone, as it also includes geospatial relational reasoning processes. The subcomponent connects to *systems thinking*, which is a holistic approach that focuses on how the constituent parts of a system are related to each other, how such systems respond to changes, and how systems work within the context of larger systems. It aims to provide insight into how things influence one another within a whole system over time, based on the belief that the components of a system can best be understood in the context of relations with each other and with other systems, rather than in isolation. Systems thinking often focuses on cyclical cause and effect. Attention to feedback mechanisms, with their reinforcing effects (positive feedbacks loops) or balancing effects (negative feedback loops), is an essential component of systems thinking.

Systems thinking is well anchored in the earth sciences tradition, which is one of the four traditions in geography distinguished by Pattison (1964). An *earth systems thinking* approach views the world as a system that consists of four central subsystems (Mayer, 1995): the geosphere, the hydrosphere, the atmosphere, and the biosphere (including humans). Orion's (2002) didactic model for science education based on the earth systems approach emphasizes the study of geochemical and biogeochemical cycles in the different subsystems (e.g. the rock cycle, the water cycle, the food chain, the carbon cycle, and the energy cycles), and the interrelations between those subsystems through the transfer of matter and energy from one subsystem to another. In order to be able to reason about relations in such systems, students should develop a dynamic, cyclic, and systematic representation of these systems, thereby taking feedback mechanisms, stocks, and time lags into account (Kali, Orion, & Elon, 2003).

Although earth systems thinking and geospatial relational thinking both aim to structure the complexity of systems, there are also several differences. The first difference is that earth systems thinking solely focuses on physical and chemical processes, while geospatial relational thinking focuses on the natural system, the human system, and the relations between these two systems. Van der Schee (2000) distinguishes two types of relations: vertical relations; and horizontal relations. *Vertical relations* are relations *within* regions, such as the relations between different physical geographic properties in a region (e.g. soil, climate, hydrology, ecology) and relations between different human geographic properties (e.g. demography, sociology, economies, politics) in a region, and human–nature relations. As regions are situated in networks, and as flows may occur between regions, a change in a property of one region may result in a change in a property of another region. This is called a *horizontal relation*. Because of these horizontal relations, the interlinked natural system and human system