

Spatial thinking in secondary geography: A summary of research findings and recommendations for future research

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Abstract: *Since publication of the report Learning to Think Spatially (National Research Council, 2006), many geography educators and education researchers have examined ways to incorporate spatial thinking into geography classrooms at various levels (K–16). The dramatic increase in the number of journal article searches based on the keyword spatial thinking and geography education during the last decade reflects this trend. It is time for the geography education community to reflect on what research has accomplished in understanding effective ways to support spatial thinking by implementing geographic curricula, instruction, and assessment in secondary education. In this paper, I review the literature on spatial thinking education, particularly in the context of geography. First, I present definitions of spatial thinking and a framework of research on spatial thinking in secondary geography education. Next, I describe the studies that I have included for review and summarize the findings. Last, I conclude the paper with several recommendations for future research.*

Keywords: *spatial thinking; secondary geography; research on spatial thinking.*

Pensamento espacial na Geografia secundária: um resumo dos resultados de pesquisas e recomendações para futuras pesquisas

Resumo: *Desde a publicação do relatório “Aprendendo a Pensar Espacialmente” (Conselho Nacional de Pesquisa, 2006) muitos educadores geográficos e pesquisadores da área de Educação têm procurado maneiras de incorporar o pensamento espacial às suas aulas de Geografia, em diferentes níveis escolares (da educação infantil ao ensino médio). O dramático aumento no número de buscas por artigos científicos baseados nas palavras-chave “pensamento espacial e educação geográfica” durante a última década reflete essa tendência. É tempo de a comunidade da Educação Geográfica refletir sobre o que a pesquisa científica tem alcançado acerca do entendimento efetivo de caminhos para dar suporte ao pensamento espacial através da implementação de currículos de Geografia, estratégias de ensino e processos de avaliação na educação secundária. Neste artigo eu faço a revisão da literatura acerca do pensamento espacial na educação, particularmente no contexto da Geografia. Primeiramente, eu apresento definições do pensamento espacial e um painel da pesquisa do pensamento espacial na educação geográfica secundária. Em seguida, eu descrevo os estudos que eu incluí para revisão e resumo os resultados. Por fim, concluo o artigo com várias indicações para futuras pesquisas.*

Palavras-Chave: *pensamento espacial; Geografia secundária; pesquisa sobre o pensamento espacial.*

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Spatial Thinking in Geography

Researchers have defined spatial thinking in many ways, but the definition suggested in *Learning to Think Spatially* (NRC, 2006) is popular among geography educators. It defines spatial thinking as problem-solving and decision-making by flexibly using spatial concepts, tools of representation, and processes of reasoning. Concepts of space, the first component, are the building blocks of spatial thinking. Spatial concepts help learners obtain, understand, and communicate knowledge about space effectively and efficiently. Representations such as maps, models, diagrams, and graphs, the second component, serve as tools to facilitate spatial thinking by stimulating complex reasoning, and organizing and externalizing abstract information into more understandable and therefore more easily communicable forms. Reasoning processes, the third component of spatial thinking, enable knowledge about space and representations to be combined for decision-making and problem-solving through analysis, hypothesis making, generalization, and evaluation. Following the definition, Sinton et al. (2013) made a case for how geographical thinking has a clear connection to spatial thinking in that it “requires a geographical lens, an approach to inquiry that is grounded in spatial thinking” (p. 13). The authors illustrate how the concepts, representations, and processes that geographers use, especially the two key perspectives in geography—spatial and ecological perspectives—draw significantly from the realm of spatial thinking. The term “geospatial thinking” that many geographers and geography educators are using is grounded in such an understanding of the relationship between spatial thinking and geography. Baker et al. (2015) defined geospatial thinking as “a specialized form of spatial thinking that is bound by Earth, landscape, and environmental scales” (p. 3). Similarly, Ishikawa (2013) defined it as “spatial thinking in the field of geospatial science to emphasize both its spatial nature and its geographic contents” (p. 637).

A Framework for Review

Figure 1 presents a theoretical framework of research on spatial thinking education in geography (Jo, 2011), which also serves as a framework for this review. The framework consists of two closely related parts. The first part focuses on students’ learning experiences related to spatial thinking in geography classrooms. The outcome of student learning is viewed as the product of complex interactions among curriculum (what is taught), instruction (how it is taught), and assessment (how information about learning is obtained). Contextualizing this into student learning of spatial

thinking, achieving the goal of promoting students' spatial thinking skills requires explicit attention in the curriculum, in the teacher's instructional practices, and in assessments.

The second part of the framework is about teacher education, which influences classroom instructional practices. In the context of teaching spatial thinking with geography, a teacher's content knowledge can be conceptualized as knowledge about the subject matter of geography and knowledge about uses of spatial thinking both within and outside the discipline of geography. Pedagogical content knowledge refers to "the subject matter knowledge for teaching" (Shulman, 1986, p. 9) which is a "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). Thus, we can define pedagogical content knowledge for teaching spatial thinking as the teacher's ability to represent geographic concepts and ideas in a way that promotes students' spatial thinking skills. The framework also emphasizes enhancing teachers' awareness of, inclinations toward, and reflections on what they teach and how they teach it—teacher dispositions. We may therefore define teacher dispositions toward teaching spatial thinking as a teacher's awareness of spatial thinking as an important thinking skill, belief that spatial thinking can and should be taught, and inclination to explicitly incorporate spatial thinking into the classroom. In this review, I will summarize some of the currently available research findings, focusing on the first part of the framework, the curriculum, instruction, and assessment to incorporate spatial thinking into geography education at the secondary level.

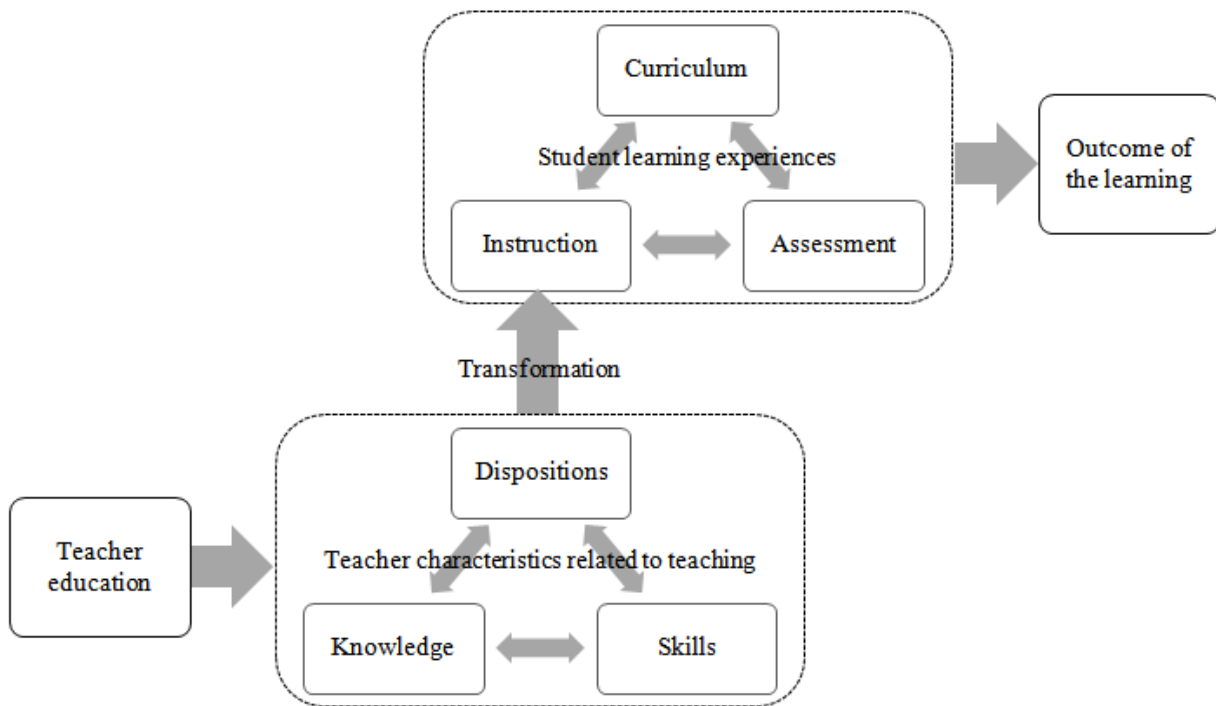


Figure 1: A framework for research on spatial thinking education in geography.

Studies Reviewed

My February 2018 search in educational research databases for “secondary geography education” yielded 2,416 peer-reviewed English journal articles published during the period 1998–2007. Adding “spatial thinking” to the keyword, however, reduced the number to just a few. However, this should not be surprising because the concept of spatial thinking received little attention in education until the NRC report was published in 2006. The same search for the period 2008–2017 yielded over twice as many (5,639) articles on secondary geography education and 44 articles explicitly focusing on spatial thinking. Among these 44 articles, 18 seemed relevant to this review, addressing the issues of developing curriculum, improving instruction, and assessing student learning of spatial thinking in geography at the secondary level. I excluded the other articles mainly because they (a) focus on teacher education, (b) are not in an education context (e.g., geographic or spatial distribution of variables), or (c) are commentary pieces rather than research studies. After reading the full papers, I included 13 articles that represent contemporary trends and key research findings in the context of spatial thinking education in secondary geography (Table 1). Categorization of the articles (i.e., curriculum, instruction, and assessment) is subjective and based, for the purpose of the review, on the author’s (or authors’) judgment about the focus,

findings, and implications of each article. The Reference section provides more information about these articles.

Authors (Year of publication)	Focus of research		
	Curriculum	Instruction	Assessment
Bodzin et al. (2014)	o	o	o
Bodzin and Cirucci (2009)	o	o	o
Cheung et al. (2011)		o	
Favier and van der Schee (2014)	o	o	o
Hammond et al. (2014)		o	
Jo and Bednarz (2009)	o		
Jo and Bednarz (2011)	o		
Kerski et al. (2013)	o	o	
Metoyer and Bednarz (2017)		o	o
Nielsen et al. (2011)	o	o	
Riihela and Maki (2015)		o	
Trautmann et al. (2013)	o	o	
Xiang and Liu (2017)	o	o	o

Table 1: Research studies reviewed in this paper.

Many geography education researchers focused on the role of geospatial technologies such as Geographic Information Systems (GIS) and remote sensing to support spatial thinking in the classroom. Kerski et al. (2013) analyzed the status of GIS in schools in 33 countries and found that most secondary educators ignored GIS, let alone spatial thinking. Jo and Bednarz's (2009, 2011) studies also showed that U.S. high school geography curriculum materials and classroom assessment tools, such as textbooks and textbook questions, are inadequate to support learning to think spatially. Studies introduced in this section represent a comprehensive effort to design new or reforming old curricula to better incorporate spatial thinking into classrooms using

geospatial technologies. The results of classroom implementations and learning assessment provide insight into future research on developing curricula to support spatial thinking in schools.

Findings from the Studies Reviewed

Developing and implementing spatial thinking curriculum with an assessment of student learning

Based on an existing environmental change curriculum, Bodzin and Cirucci (2009) developed a curriculum unit on environmental issues relating to land-use change to promote spatial thinking skills using easy-to-use geospatial tools. The researchers formed a design partnership with the classroom teacher, who was proficient in technology use. The unit was implemented in four eighth-grade earth and space science classes over 14 days of class periods in which students used various geospatial tools such as Google Earth and remotely sensed images to investigate ground cover and land-use change in their own local area. Assessment of student learning used eight items aligned with the unit's learning outcomes, including remotely sensed images for identifying and describing land-use and environmental changes over time. Some items required analyzing data sets and interpreting graphs. Based on the assessment results, the authors suggested that the unit facilitated several types of spatial thinking such as identifying and interpreting features in remotely sensed images, understanding and flexibly using the concepts of distance and direction, identifying distribution patterns of major land-use types in urban areas, and evaluating the impact of urbanization on the earth's surface.

A later study by Bodzin et al. (2014) is one of the most comprehensive empirical studies involving the development, implementation, and assessment of a geospatial curriculum. The researchers developed an 8-week geospatial technologies-integrated energy resources unit that 13 middle school teachers implemented in classrooms totaling more than 1,000 students. The curriculum activities were explicitly designed to promote geospatial thinking and reasoning that involved geospatial visualization, orientation, and geospatial relations to investigate energy resource issues. Some activities guided students in evaluating the strengths and weaknesses of different solutions to authentic energy resource problems. Pre- and post-tests used multiple choice items aligned with specific geospatial thinking and reasoning skills: (a) using geospatial analysis to make inferences about space, geospatial patterns, and geospatial relationships; (b) using geospatial data analysis to explore geospatial relationships such as distance, direction, and topologic relationships;

(c) using inductive and deductive reasoning to analyze, synthesize, compare, and interpret information; and (d) using logic and reasoning to identify strengths and weaknesses of alternative solutions and conclusions. The students' overall post-test mean scores yielded a statistically significant increase, and the result of multiple regression analysis suggests a close relationship between the students' content knowledge gain and geospatial thinking and reasoning skills. Another significant difference observed between the student pre- and post-test score means was the differences between the 13 participating teachers. The factors that can account for the mean differences, though, were not clear, so identifying them remains an important objective for the future research.

Favier and van der Schee (2014) also developed a series of geography lessons with geospatial technologies and examined its effectiveness through an assessment of student geospatial thinking. Unlike the other studies described, this study compared experimental and control groups to assess the curriculum's effectiveness. The curriculum focused on geospatial relational thinking, defined as "a deep kind of thinking which has some links with systems thinking" and "an important part of geospatial thinking, which is a valuable way of thinking to analyze and reason about the big challenges in the world around us" (p. 227). The lessons, developed for both groups, concerned water-related spatial planning issues in two regions in the Netherlands. While they covered the exact same topics and issues, those for the experimental group emphasized systematic thinking about geospatial relations and used EduGIS, a minimal GIS application, and Watermanager, which are readily available for teachers via the Internet. The authors developed a new assessment for pre- and post-tests of student geospatial relational thinking regarding ability to (a) identify non-spatial or geospatial relationships in representations, (b) organize geospatial relationship, and (c) evaluate measures and create solutions. The results showed that the experimental group outperformed the control group in the post-test, which the authors attributed to the experimental group students paying more explicit attention to systematic geospatial thinking.

Xiang and Liu (2017) also compared a geospatial technology-infused curriculum with a traditional one in terms of their effectiveness in developing student spatial thinking. Both groups learned about coastal geography. The geospatial curriculum included a series of lessons with three components—spatial thinking skills, content knowledge, spatial visualization—and was implemented over two semesters for 80 students in secondary geography classes in Singapore. Students received an essay question to assess their ability to identify spatial changes over time and transfer this skill to a novel context. The authors found that understanding and being able to

apply certain concepts (e.g., shape and size) are key to one's ability to interpret spatio-temporal changes. Uses of geospatial technologies such as Google Earth turned out to be helpful for developing such skills. The authors also highlighted some factors influencing the effects of using geospatial technologies on learning, including students' prior knowledge and skills in spatial thinking, explicit instruction in spatial concepts, and the design of geospatial curriculum aligned with students' cognitive development.

Some key findings from research on curriculum development to support spatial thinking, described above, are evident. First, the curriculum should explicitly address specific spatial thinking skills to be taught, and the assessment of student learning outcomes should be aligned with those specific spatial thinking skills targeted. Second, the context is important. Spatial thinking is domain-specific. Therefore, spatial thinking must be taught in relation to specific knowledge, skills, and practices in geography with an appropriately designed curriculum. Third, spatial concepts should be explicitly taught before or during the implementation of a spatially-rich geography curriculum. Conceptual knowledge and related spatial thinking skills can be assessed using tasks or assessment items that require analytic and relational systems thinking.

Developing and implementing spatial thinking curriculum without an assessment of student learning

Some studies developing and implementing spatial thinking curricula and curriculum materials lacked assessment of student learning. Instead, they focused more on their student or teacher participants' perceived benefits of the new curriculum or awareness of the innovative features and the key goals of the curriculum. Nielson et al. (2011) were unique in developing a stand-alone spatial thinking course, rather than just a curriculum unit or curriculum supplemental materials, and offering it as an official elective course in a local laboratory school. The purpose was to incorporate geospatial technologies to engage students in spatial thinking. Students learned explicitly about the concept and foundation of spatial thinking before delving into geospatial technology tools and skills such as ArcGIS mapping, field data collection using GPS, and the foundations of remote sensing. Students also participated in a project to complete a general atlas of the community. The researchers used students' course blogs and reflective papers to gauge the success of the course. Overall, students demonstrated their awareness of the nature and

importance of spatial thinking as well as the potential of geospatial technologies for problem-solving and decision-making.

Science educators also developed curriculum materials that used geospatial tools such as interactive maps. For example, Trautmann et al. (2013) developed curriculum materials for middle and high school biology classes to help students learn about biodiversity through geospatial exploration. Specific learning objectives for the students included analyzing a region's biodiversity using geographic representations, in this case GeoPDFs, an interactive map-based PDF, and analyzing spatial data. Students explored bird-sighting data and made connections between species distribution and geographic and environmental factors such as topography and the location of roads, cities, rivers, and coastlines. Although the curriculum included no process to assess its impact on student content knowledge or spatial thinking skills, teacher comments and reflections about the overall learning experience were highly positive.

Importantly, participating teachers played a significant role in many studies in developing, testing, and implementing the spatial thinking curriculum and curriculum materials in their classrooms, which may account for their positive evaluation results and support. Ensuring strong teacher engagement is key to success in curriculum design and reform to support spatial thinking. However, a significant weakness was these studies' failure to provide empirical evidence of their effectiveness on student learning. Continuation and extension of the research to connect the potential of the curricula to positive student learning outcomes is imperative.

Identifying instructional strategies and tools effective to support spatial thinking

Many studies on spatial thinking education in secondary geography compared the effectiveness of different instructional strategies and tools on facilitating student spatial thinking skills to identify specific strategies and tools for teaching that are more effective to support spatial thinking while minimizing intrusive changes to the existing curriculum or content structure. For example, Metoyoer and Bednarz's (2017) study compared the impact on spatial skills and spatial-relations content knowledge of teaching central place theory with GIS and without GIS. For two days, students received instruction on central place theory that focused explicitly on the practice of spatial thinking with or without using GIS. The pre- and post-test results suggest that instructions using GIS are more effective than conventional instructional strategies for teaching spatially dependent content.

In another example, Hammond et al. (2014) incorporated a hands-on activity to help students learn the concepts of latitude and longitude. In this activity, the teacher deliberately guided students to break down and apply the concepts piece by piece. The article did not report student learning assessment, but the detailed description of the preparation and implementation of the activity, including handouts for students as well as opportunities for extension and adaptation into other social studies classrooms, provide insights into the characteristics of instructional strategies that can support student learning of spatial concepts.

Some studies focused on the development of learning platforms and tools with the ultimate purpose of providing a teacher- and student-friendly learning environment that can more effectively support spatial thinking. For example, Riihela and Maki (2015) developed *PaikkaOppi*, an online GIS tool to promote GIS studies and spatial thinking in upper secondary schools in Finland. According to the authors, the primary goal was “to combine the spatial data of various topics in geography into an online mapping interface and create convincing and meaningful pedagogical models to support its use” (p. 18). A total of 14 pilot courses were taught in three Finnish schools during a three-year time period. The effectiveness of the tool for improving student spatial thinking skills was not clear because the article focused more on the benefits and technical challenges of using the learning environment in comparison with other tools such as Google Earth or desktop GIS. Nevertheless, the teachers involved in the pilot studies suggested that the online GIS application should benefit upper secondary school cross-disciplinary educational goals.

Cheung et al. (2011) developed an interactive geospatial learning platform enabling students to practice spatial thinking skills of visualization, what-if analysis, overlay analysis, and spatial pattern analysis. Taking a “bottom-up” approach, the authors engaged teachers in the geospatial data platform’s initial design and implementation process and pedagogy for their classrooms. The focus was explicitly on student knowledge acquisition in geography rather than on computer instruction. Detailed descriptions of the student activities and teacher reactions inform characteristics of teacher- and students-friendly resources for incorporating GIS and remote sensing for spatial thinking into ordinary secondary classrooms.

Studies reviewed in this category focused mostly on classroom teaching and learning activities and processes. From this perspective, researchers and participating teachers designed, compared, and evaluated instructional strategies and tools. The studies also commonly provided a detailed description and information about the resources to benefit other teachers who might adopt them

in their classrooms. These studies emphasized the importance of teachers' scaffolding and guidance in student learning and suggested that an authentic problem-solving activity utilizing reform-based teaching methods would make scaffolding more effective. However, how to help teachers develop such scaffolding skills was not clear. Discussion of effective professional development for teachers to flexibly adapt and use the strategies and tools will be beneficial.

Recommendations for Future Research

For a decade, attention to and interest in spatial thinking have increased in geography education. This paper aimed to review research findings regarding curricula, instruction, and assessment that can support spatial thinking in secondary geography education. Much of the effort to incorporate spatial thinking into secondary classrooms has been in accordance with finding ways to use geospatial technologies for teaching and learning. Research has shown that the status of spatial thinking and geospatial technologies in schools is low as of yet but that the potential is promising.

This literature review suggests several recommendations for supporting spatial thinking education in secondary geography classrooms. First, more research is necessary to understand the nature of geospatial thinking, a special type of spatial thinking that involves geographic space and inquiry. Research has shown that spatial thinking can be facilitated with appropriately designed curricula and curriculum materials. However, a meaningful educational effect is apparent only when specific types of spatial thinking skills are explicitly aligned and taught with disciplinary-specific knowledge, skills, or practices.

Second, a coordinated effort is necessary to develop valid and reliable tasks or question items for assessing various types of geospatial thinking skills. The potential of new curricula and curriculum materials should be evaluated through an assessment of student learning outcomes.

Third, research on instructional strategies and tools to support spatial thinking should inform teachers or teacher educators of various ways to implement and adapt those strategies and tools. In many studies, assessment of the effectiveness of an instructional strategy or tool occurred after a one-time intervention in which the researcher gave the instruction. Providing detailed information and flexibility will help more teachers implement the strategies and tools in their own classrooms. Action research by teachers to assess effectiveness in a variety of contexts may provide an opportunity to accumulate more convincing evidence.

Lastly, and critically, geography education researchers should take teacher education into consideration when conducting research involving curricula, instruction and assessment to support spatial thinking. The role that teachers play in successfully implementing innovative ideas in education such as spatial thinking, cannot be overemphasized.

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