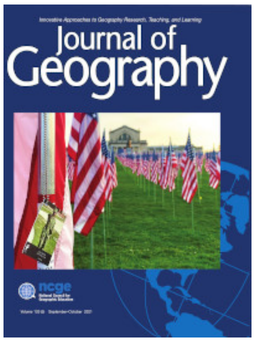

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The Factors and Mechanisms That Influence Geospatial Thinking: A Structural Equation Modeling Approach

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ABSTRACT
Geospatial thinking is crucial for understanding the spatial order of the world. The factors influencing geospatial thinking deserve attention in geography education. Utilizing correlation analysis, we found that general intelligence, geographic knowledge, and geographic learning interest had a significant influence on geospatial thinking. This article attempts to understand how these factors affect geospatial thinking by using structural equation modeling. The results indicate that they impacted geospatial thinking directly. In addition, general intelligence and geographic learning interest had an indirect impact on geospatial thinking.

KEYWORDS
geospatial thinking; influencing factors; mechanism; structural equation modeling; mediating effect

Introduction

As humans, our survival and development is inseparable from the understanding, analysis and transformation of geographic space. While interacting with the environment around us, we usually need to process spatial information such as "shape, location, path, relation among entities, and relation between entities and frames of reference" (Newcombe and Shipley 2015, p. 180). Spatial thinking is a useful and essential quality for survival, which is closely related to our daily life, study, work and even to scientific discovery (Wai, Lubinski, and Benbow 2009; Lubinski 2010; Newcombe 2010).

People vary in their level of spatial thinking, but we can all learn to cultivate these skills (Liben 2006; Terlecki 2004; Wright et al. 2008). In the book *Learning to Think Spatially*, the Committee on Support for Thinking Spatially pointed out that spatial thinking can be taught and developed, and that it should be an important part of the education curriculum (National Research Council (NRC), 2006). Roger M. Downs, one of the book's authors, claimed that if educators do not explicitly develop students' spatial thinking abilities, the next generation will not be equipped with the skills necessary for living and working in the 21st century.

In scholastic education, the geography curriculum is an important vehicle for developing students' spatial thinking abilities (Bednarz and Bednarz 2004; Jo and Bednarz 2014). Geography pushes students to consider the occurrence and development of objects in their spatial dimension, and to describe and analyze various phenomena using spatial frameworks. The spatial perspective is a unique way through which the geography discipline views the world, where the geographic thinking mode is shaped in the process of solving geographical problems (Hettner 1927; National Research Council (NRC), 1997; Shoorcheh 2019). Geographic thinking includes but ultimately transcends spatial thinking. This is because geographic thinking requires an understanding of the relationship between spatial concepts in order to express the meaning of complex space through maps, graphics and images, as well as to explain spatial patterns and associations (Golledge 2002; Metoyer and Bednarz 2017). In fact, the geography curriculum standards of many countries place importance on spatial thinking. For instance, US educational leaders regard spatial cognition as the first of six basic elements of the geography curriculum and consider spatial literacy to be a core aspect of geography education (Geography Education Standards Project 1994). Educational leaders in Germany consider geospatial ability to be an integral part of the geography discipline (German Geographical Society 2014). According to educational leaders in Finland, the spatial viewpoint is a key component of geographic thinking that should be taught to students (Finnish National Board of Education 2016). Chinese educational leaders consider the development of geospatial concepts, geospatial relationships and spatial processes to be of great importance (Ministry of Education of the People's Republic of China 2017). The concepts such as spatial cognition, spatial literacy, geospatial ability and spatial viewpoint were integral to geospatial thinking. In most geography classrooms, however, teaching geospatial thinking depends on the teachers' individual understanding of the subject.

There have been many efforts aimed at cultivating geospatial thinking. GIS, Google Earth, virtual globe, Iberpix™, Wikiloc™ and other geospatial technologies, are favored by geography educators as effective tools for visualizing spatial

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relations (e.g., García de la Vega 2019; Madsen and Rump 2012; National Research Council (NRC), 2006; Osborne et al. 2020; Schultz, Kerski, and Patterson 2008; Xiang and Liu 2017). In addition, the use of embodied actions, the GEOTHNK approach, the visualise-predict-check and geospatial elements are also effective ways to improve geospatial thinking (e.g., DeSutter and Stieff 2017; Kavouras et al. 2016; Patahuddin, Rokhmah, and Ramful 2020; Yuan 2009).

In spite of these advances, many geography teachers remain unsure about how to improve students' geospatial thinking. The theory of geospatial thinking development alone does not provide practical guidance for educators on how to develop geospatial thinking abilities among students. This paper addresses this gap by exploring what factors affect geospatial thinking and how they work, in order to provide practical guidance for teachers. Specifically, we test the influence of several factors and uncover the mechanisms at play in the development of geospatial thinking. We ask: How do the factors influencing geospatial thinking affect senior high school students' geospatial thinking abilities?

Literature review

The concept of geospatial thinking

In geography education literature, the concepts of geospatial thinking and spatial thinking are not clearly distinguished (Huynh and Sharpe 2013). In recent decades, some of the terms associated with spatial thinking used by geography educators have become almost the same as those associated with geospatial thinking (e.g., Lee and Bednarz 2012; Tomaszewski et al. 2015; Liu et al. 2019). Spatial thinking was defined as the knowledge, skills and habits that relate to spatial concepts, spatial representation tools and reasoning processes (National Research Council (NRC), 2006). The research object of spatial thinking consists of any space from the micro-scale to the planetary scale, which relates not only in Earth Science, but also to mathematics, history, and other fields (Golledge, Marsh, and Battersby 2008). Spatial thinking can be sub-divided into specialized spatial thinking in different fields. However, spatial thinking in the geographic context (geospatial thinking) is different from other fields (Favier and van der Schee 2014). Thus, it is necessary to highlight the *geo* attribute of geospatial thinking for clarifying its definition.

First, geospatial thinking operated on the scale of earth, landscape, and environment (Baker et al. 2015). It is different from spatial thinking, which is concerned with general space. Rather, geospatial thinking is used to analyze geospace in the real world that occurs on the earth's surface and its vicinity (Golledge, Marsh, and Battersby 2008; Longley et al. 2005). Geospatial thinking seeks to solve problems by using context-specific geographic information and geospatial reference frames rather than abstract concepts (Huynh and Sharpe 2013; Favier and van der Schee 2014).

Second, geospatial thinking requires geographic knowledge (or skills). The knowledge involves: (i) understanding and interpretation of geospatial concepts, such as geographic location, distribution, distance, direction, spatial relationship, motion, transmission, boundary, etc. (Battersby, Golledge, and Marsh 2006; Gersmehl and Gersmehl 2007); (ii) understanding and application of geospatial representation tools, including traditional maps, statistical charts, digital globe, satellite images, etc. (Carbonell-Carrera and Hess-Medler 2019); (iii) geospatial reasoning, that is, inferring the geospatial pattern and relationship based on the data or information of the earth surface (Bodzin et al. 2014).

Consequently, geospatial thinking is a way of processing information where human beings think about geo-space as being earth's surface or earth's representation displayed on a map or computer. It is manifested in the use of geospatial concepts and geospatial representation tools for geospatial reasoning.

Measurement of geospatial thinking

Spatial tests were initially conducted in the field of psychology (Kail, Carter, and Pellegrino 1979), which mainly measured spatial visualization and spatial orientation. However, the "space" in psychological tests is a small-scale space that does not correspond to the geographic scale. Therefore, geographers began to explore the measurement tools for spatial thinking that were suitable for a geographical context.

Early tools could only be used to measure specific aspects of geospatial thinking. For example, Golledge (1992) used map-based experiments to investigate how people understand geospatial concepts. Kali, Orion, and Mazor (1997) measured geologic spatial ability by asking college students to draw cross-sections of geological structures and imagine single face block diagrams. Albert and Golledge (1999) took a set of thematic layers to test how GIS users stacked the maps.

Some advances have been made regarding tools for measuring several aspects of geospatial thinking. Lee and Bednarz (2009) designed the Spatial Skills Test (SST) to measure the change in students' spatial skills after completing the GIS course. With the development of the concept of spatial thinking, Lee and Bednarz (2012) developed additional tools for measuring geographic content knowledge and spatial skills. They revised the SST and developed the Spatial Thinking Ability Test (STAT). The test presents topics related to geography and earth science in the form of maps. It examines students' understanding and application of geospatial concepts, as well as their ability to solve geospatial problems by acquiring map information. According to the developers, the test is suitable for measuring spatial thinking in the context of geography and earth science (Bednarz and Lee 2019). Existing studies have used the STAT to measure geospatial thinking (Verma 2014; Wan et al. 2017). The test includes eight aspects:

> "Comprehending orientation and direction; comparing map information to graphic information; choosing the best location based on several spatial factors; imagining a slope profile based on a topographic map; correlating spatially distributed phenomena; mentally visualizing 3-D images based on 2-D information; overlaying and dissolving maps; and comprehending geographic features represented as point, line, or polygon" (Lee and Bednarz 2012, p. 18).

Ishikawa (2013) also designed a Geospatial Thinking Test, which measured one's abilities related to geospatial concepts and reasoning. The test topics included spatial distribution, reference frame, map projection, map scale and earth motion. The author also conducted an empirical comparative study between his test and the STAT. His conclusion was that the two tests measured the abilities or skills related to different components of geospatial thinking.

In the same year, Huynh and Sharpe (2013) developed a geospatial test to measure geospatial thinking expertise. This test, like the SST, focused on understanding spatial relationships in a geographical context. Its measurement items involve six dimensions: analysis, understanding, application, representation, scale and spatial relationship. The geospatial ability measurement scale compiled by Xu and Yuan (2013) has also been deemed effective for measuring geospatial thinking. It included three dimensions, namely perception, thinking and imagination about geospace.

In spite of these advances, developers were not sure how well their tools could capture geospatial thinking, because the structure and complex components of geospatial thinking are not yet fully understood. Therefore, no measurement tool has been unanimously recognized by the academic community. Among the existing tools, the STAT is the most widely used, and has been applied in 22 studies from eight countries or regions (Bednarz and Lee 2019).

Factors influencing geospatial thinking

Bednarz and Lee (2019) summarized 22 studies relating to the factors influencing spatial thinking. In this literature review we focus on spatial thinking in the geographical context, to summarize the factors that have been found to influence geospatial thinking. Regarding demographic factors, several geography educators studied the influence of gender on geospatial thinking and came to different conclusions. Some empirical studies demonstrated that men's geospatial thinking was significantly better than women's (Shin, Milson, and Smith 2016; Tomaszewski et al. 2015). However, Wan et al. (2017) found no significant difference between male and female students. Considering the complex elements of spatial thinking, Ward, Newcombe, and Overton (1986) found that gender differences existed in some types of spatial thinking. In addition, there is evidence that age (or school grade), ethnicity, socioeconomic status, choice of study (major), and urban proximity affect geospatial thinking (Shin, Milson, and Smith 2016; Tomaszewski et al. 2015; Verma 2014, 2015).

Participation in geography courses and students' characteristics were also found to affect geospatial thinking. Verma (2015) found that the number of geography courses taken affected students' geospatial thinking. Among all geography courses, GIS courses have received the most attention (Huynh 2009; Lee and Bednarz 2009; Shin, Milson, and Smith 2016). The characteristics that affect geospatial thinking in the process of geography learning are geographic learning interest, map literacy, general intelligence and geographic knowledge (Collins 2018; Wakabayashi 2015; Wan et al. 2017). In addition, scholars have found a weak correlation between travel experience and geospatial thinking (Collins 2018; Shin, Milson, and Smith 2016).

The mechanisms through which geospatial thinking is developed

Although there have been many studies on the factors influencing geospatial thinking, less attention has been given to the mechanisms through which geospatial thinking is developed, with the exception of a study conducted by Wan et al. (2017). The authors discovered four main factors that influenced geospatial thinking using correlation analysis and the t-test. They also conducted a binary regression equation model with geospatial thinking as the dependent variable and general intelligence and geographic knowledge as independent variables. This study was an in-depth analysis of the mechanism through which geospatial thinking is developed. However, the study sample was small and it is not clear whether the conclusions can be generalized to middle school students as a whole. Furthermore, the specific mechanisms through which the factors influence geospatial thinking were not clearly outlined, especially the relationship between the factors.

To date, the mechanisms through which geospatial thinking is developed are not clearly understood, and it is therefore not clear how to develop geospatial thinking. We seek to address this limitation by conducting a study testing the four factors affecting geospatial thinking that was proposed by Wan et al. (2017). In doing so, we provide new empirical evidence and help develop the theory of geospatial thinking. We used the structural equation modeling approach to explore the complex relationship between the various influencing factors in order to clarify the mechanisms at play.

A conceptual framework for the mechanisms that influence geospatial thinking

We carefully considered the four factors identified by Wan et al. (2017). The first factor, general intelligence, is the ability of the human brain to understand the complexity of the world, which emphasizes not only logical thinking, reasoning, problem-solving and memory, but also the ability to adapt to the environment and acquire knowledge (Snyderman and Rothman 1987). It enables people to process spatial information. As such, we hypothesize that general intelligence affects geospatial thinking (H1). However, it should be noted that intelligence is an elusive concept that is difficult to detect with a single test (Stemberg 1986). Moreover, when people believe the test they are taking can measure intelligence, their internalized stereotypes would affect their scores (Steele 1997). Therefore, in this study, the measurement of general intelligence is mainly concerned with the difference in students' performance on the given test, rather than their overall intelligence.

Second, geography courses help students develop a spatial perspective and accumulate knowledge through discussing geospatial problems. We hypothesize that a higher level of geographic knowledge is associated with higher geospatial thinking among students (H2). Third, geographic learning interest refers to one's sensitivity and curiosity about geography issues. Higher interest in learning geography leads to more willingness to explore the spatial relationship between geographic matter. Thus, we hypothesize that geographic learning interest influences students' geospatial thinking (H3). Fourth, people with experience in using maps tend to master graphic reading skills to a greater extent than those with less experience. The reading of maps and graphics is an important way for people to obtain geospatial information, where they establish a spatial connection among information while solving geographical problems. So, we hypothesize that previous experience using maps affects geospatial thinking (H4). Additionally, Zhang, Yang, and Lu (2018) specified that higher interest in the topic of geography and a higher level of general intelligence results in better academic achievement in the geography discipline for students. As such, we hypothesize that general intelligence and geographic learning interest affect one's level of geographic knowledge (H5; H6). Figure 1 presents the conceptual framework describing how the various factors influence geospatial thinking.

Methods

Participants

Our sample included students from the Sixth High School of the Changchun Automotive Industries Development Area located in Jilin, China. In terms of students' academic performance, this school is considered a model school in the Jilin province. The students of this school, like those from other schools in China, were admitted through the municipal entrance examination, where students who scored in the top 30% among all students in the city were admitted.

The school is located in the urban-rural area of the city. Most of its students come from working class families and a few come from peasant families. Most of the students' families earn middle-class incomes. About 2% of the students come from upper class families and 4% to 5% from lower class families. In addition, most of the students are of Han origin, and about 7% of the students have other backgrounds (Manchu, Hui, Korean, Mongolian, etc.). This school is an ordinary high school in China.

The school has three grades (equivalent to grades 10 to 12 in the United States). Each grade has five liberal arts classes and ten science classes. Dividing students into liberal arts class and science class is customary for Chinese senior high school students. In the first two years, all students were required to learn the basic knowledge relating to the Chinese language, a foreign language, mathematics, sports and art courses, as well as liberal arts courses (politics, history, geography) and science courses (physics, chemistry, biology). In the third year, while continuing to take Chinese language courses, a foreign language, mathematics and sports, liberal arts students would take additional liberal arts courses, while science students would take additional science courses.

All the students took geography lessons in the form of lectures. They had studied geography for two years in junior high school, and had some knowledge of national geography and world geography. Students' geography learning content in the six semesters of senior high school are shown in Table 1. Science students learn the basic knowledge required by geography curriculum standards. Liberal arts students need to gain deeper knowledge to prepare for further study in geography related majors.

To make the sample as representative as possible, we included different groups in our study (i.e., students with different types of courses and different levels of exposure to the geography curriculum). In December 2016 of the first semester, we randomly selected a liberal arts class and a science class from each grade. The number of sample students from different classes is shown in Table 2. The total number of students in the classes is 246, with 92 males and 154 females. Students were between 14 and 18 years old, with five students aged 14, 90 students aged 15, 86 students aged 16, 50 students aged 17 and 15 students aged 18.

Materials

The spatial thinking ability test

To measure students' geospatial thinking, we used the Spatial Thinking Ability Test (STAT) designed by Lee and Bednarz (2012). The test has 16 multiple-choice questions covering eight components that were listed in the literature review. The reliability of the STAT was acceptable (Cronbach's $\alpha = 0.682 > 0.6$).

The international standard intelligence test

We took the International Standard Intelligence Test (ISIT) developed by Anders Dittlev Jensen, a member of the Danish Mensa Club, to measure students' general intelligence. The test was presented in nonverbal graphic form, to minimize the effect of cultural variables. 39 questions were used to test students' learning ability, memory, innovative thinking and problem-solving capacity, reflecting one's general intelligence. The test was printed in color and the questions were arranged from easy to difficult. Participants were required to complete the questionnaire within 40 minutes. The reliability of the ISIT was acceptable (Cronbach's $\alpha = 0.753 > 0.6$).

The geographic learning interest test

Drawing on the physics learning interest test developed by Hu, Yang, and Gao (2010), we compiled 31 items using a five-item Likert-type scale to test students' interest in geography learning based on the characteristics of the geography discipline. To verify whether the items could effectively reflect the concept of geographic learning interest, we invited seven geography education experts from universities and middle schools to evaluate the validity of the test. Finally, the content validity of the test was 0.856 and the authority coefficient of experts was 0.872, which shows that our test had strong validity. To verify whether the validity evaluation of different experts was consistent, we calculated the Kendall

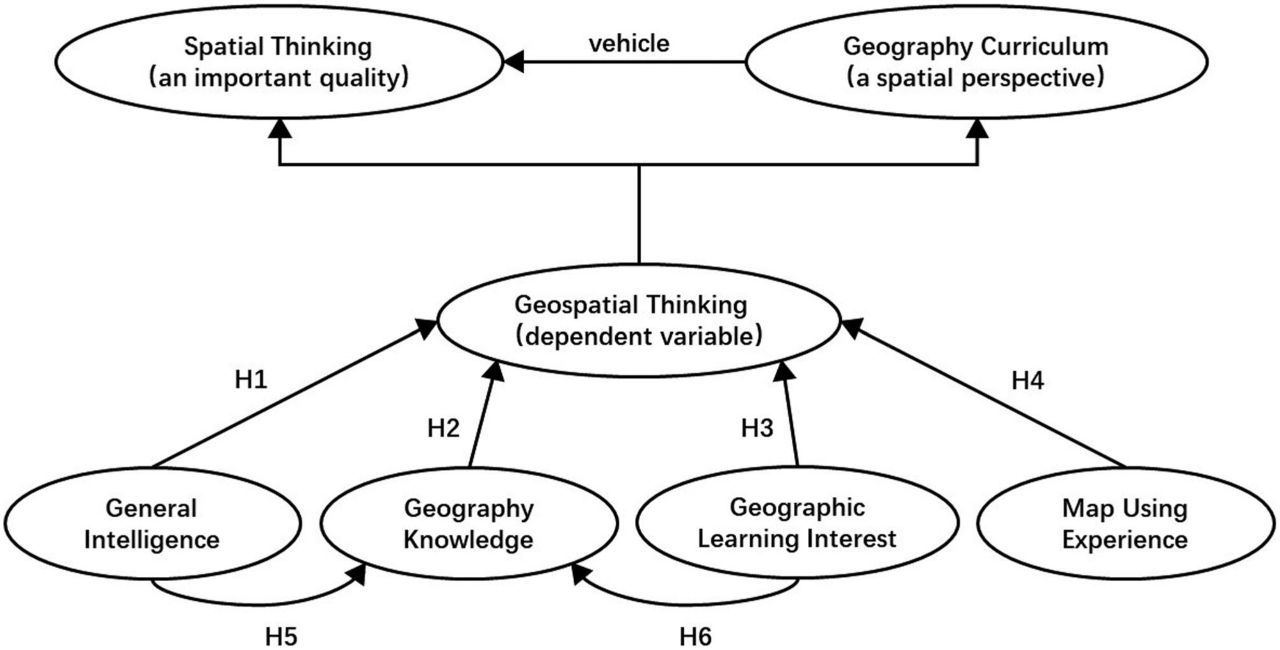

Figure 1. Conceptual framework of the influences on geospatial thinking.

Table 1. Learning requirements of different students in geography course.

Grade	Semester	Learning content	Weekly lessons: Liberal arts students	Weekly lessons: Science students
Senior one	1	Physical Geography	2	2
	2	Human Geography	3	1
Senior two	1	Regional Development	3	1
	2	Tourism Geography	3	/
Senior three	1	Environmental Protection	3	/
	2	Comprehensive Review for College Entrance Examination	3	/

Table 2. The number of sample students in different classes.

	Senior one	Senior two	Senior three	Total
Science students	53	32	32	117
Liberal arts students	56	52	21	129
Total	109	84	53	246

Concordance Coefficient of the seven experts' scores, which was 0.236 ($p < 0.05$). This indicates that the experts' scoring results were consistent and that the validity evaluation was credible.

The test consisted of four dimensions: thinking enthusiasm[1], learning input[2], learning willingness[3] and extension[4]. The sample items of the four dimensions are as follows: (1) *I often think actively about questions asked in geography classroom*; (2) *After my geography homework or examination papers are corrected, I often look carefully*; (3) *I like attending geography class*; and (4) *I like going through what the teacher hasn't said in the geography textbook after class*. Students rated the items from 1 (strongly disagree) to 5 (strongly agree), with higher scores indicating higher interest in geography learning. The reliability of the test was good (Cronbach's $\alpha = 0.936 > 0.6$).

The map using habit test

Students' experience with maps was measured through the Map Using Habit Test developed by Wan et al. (2017). The test was also used in their research about factors affecting the geospatial thinking. We invited seven geography education experts to evaluate the validity of the test. The content validity of the test was 0.695 and the expert authority coefficient was 0.833, showing that our test had acceptable validity. In addition, the Kendall Concordance Coefficient of the seven experts' scores was 0.320 ($p < 0.05$), indicating that the experts' validity evaluation was credible.

The test contained 43 questions, including three dimensions of map using possibility[5], map using tendentiousness[6], and map information sensitivity[7]. The three test dimensions include questions such as: (1) *How many paper maps do you own?* (2) *Do you often read maps (including electronic maps and paper maps) while traveling?* (3) *When you read a news article such as "A large amount of ash from the Icelandic volcanic eruption affected Europe," do you immediately think about the location of Iceland?* The reliability of the test was good (Cronbach's $\alpha = 0.875 > 0.6$).

Geographic knowledge

To assess geographic knowledge, we took the students' geography exam scores from the school. The school usually tests students' geographic knowledge level at regular intervals, in the form of monthly examinations, midterm examinations and final examinations. We took all the exam results of the students in our sample from the time they were admitted to this school. We calculated the arithmetic average of their

Table 3. Results of the correlation analysis for the factors influencing geospatial thinking.

	Geospatial thinking		
Factors of influence	Correlation coefficient	*P* value	Significant difference
General intelligence	0.390***	0.000	high significance
Geographic learning interest	0.185**	0.004	high significance
Map using experience	0.058	0.365	insignificance
Geographic knowledge	0.397***	0.000	high significance

**Correlation is significant at the 0.01 level (double tail).
***Correlation is significant at the 0.001 level (double tail).

exam results to represent students' level of geographic expertise.

Procedure

This research was carried out by the authors in cooperation with the school, in order to meet the school's need to better understand students' geospatial thinking level and the possible influencing factors. First, we explained the research design and submitted relevant survey materials to the school directors. They held an administrative meeting to discuss the research ethics and survey requirements. Then we were allowed to investigate several classrooms in two geography lessons.

On December 5, 2016, the researchers entered the classroom to recruit volunteers to participate in the research. The geography teacher of the class explained to students that the researchers were assisting the school in conducting research on geography education. Then, the researchers explained that the purpose of the research was to diagnose participants' geospatial thinking and possible influencing factors. The teachers made it clear that students could choose to participate or not to participate. The students who participated in the research would get a folder as a souvenir. Students were also told that their participation would not affect their academic performance and interpersonal relationships. Moreover, they were told that participants' answers would be kept confidential.

All students from the sample classes participated in the survey voluntarily. The survey was conducted twice during the geography lesson. The first survey was from December 7 to December 9. Participants filled out the ISIT within the required 40 minutes. The second survey was carried out from December 12 to December 14. Participants answered questionnaires about geospatial thinking, geographic learning interest and map using experience, following the instructions of the researchers. The second survey lasted 40 minutes and the students reported that they had completed all the questions. During both surveys, the geography teacher was also present in the classroom. A total of 246 students completed the questionnaire and the completion rate was 100%.

According to the students' answers, we assigned scores for each test in an anonymous way. There were three cases with incomplete answers that could interfere with the subsequent analysis, so we excluded them from the sample. The final number of participants in our study was 243, consisting of 90 male students and 153 female students.

Statistical analysis

First, the Harman Single Factor Test was used to confirm the reliability of the data. Using data from self-reported questionnaires is at risk of common method bias. Common method bias refers to the artificial covariation between predictor variables and criterion variables caused by the same data source or raters, the same measurement environment, or the measurement items themselves (Podsakoff et al. 2003). This kind of artificial covariance is a systematic error, which can potentially yield misleading research results and conclusions. Although we designed some reverse items in the questionnaire to control for this risk, we still needed to verify whether there was common method bias.

Second, the Pearson Correlation Analysis was conducted using SPSS 22.0 to estimate the correlation between the influencing factors and geospatial thinking. We identified factors that may have nothing to do with geospatial thinking later.

Third, we constructed a structural equation model using AMOS 21.0. The structural equation modeling approach can help us test our hypothesis and explore the complex relationship between the four factors. According to the result of path analysis in the structural equation model, we obtained the specific paths and effect size for the influencing factors. This allowed us to assess how and to what extent do the factors affect senior high school students' geospatial thinking.

Results

The common method biases test

We conducted the Harman Single Factor Test. There were 41 factors with eigenvalues greater than one in the case of no rotation. The mutation interpretation rate of the first factor was 12.22%, which was less than 40% of the judgment criteria. Consequently, we concluded that the problem of common method bias was not a great problem, and that we could use the sample data for further analysis.

Correlation analysis of the factors influencing geospatial thinking

We performed the Pearson Correlation Analysis to find the linear correlation between geospatial thinking and its factors of influence. The results are shown in Table 3. There is a significant moderate correlation between geospatial thinking and geographic knowledge ($r = 0.397$, $p < 0.05$) and general intelligence ($r = 0.390$, $p < 0.05$). There is a significant weak correlation between geospatial thinking and geographic learning interest ($r = 0.185$, $p < 0.05$).

However, there is no significant correlation between geospatial thinking and map using experience ($r = 0.058$, $p > 0.05$). We used the Gpower software to calculated the test efficiency of this correlation analysis and obtained a power value of 0.147.

Table 4. Model fit test for the mechanism of influence for geospatial thinking.[1]

Model fit[2]	Ideal scope	Initial model	Modified model	Conclusion
CMIN/DF	<3	2.427	2.181	qualified
CFI	>0.90	0.888	0.905	qualified
GFI	>0.90	0.906	0.913	qualified
IFI	>0.90	0.890	0.907	qualified
RMSEA	<0.08	0.075	0.070	qualified

[1]The maximum likelihood estimation method was used to test the fitness of the model.
[2]Following the guidelines by Schumacker and Lomax (2007), we selected the Chi-square to degrees of freedom ratios (CMIN/DF), the comparative fit index (CFI), the goodness of fit index (GFI), the incremental fit index (IFI) and the root mean square error of approximation (RMSEA) to evaluate the model fitting.

Constructing the mechanisms of influence model for geospatial thinking

We took geospatial thinking as the dependent variable and the factors that showed significance in correlation analysis as the independent variables. Then, we constructed a model of the influencing mechanisms for geospatial thinking using the structural equation model. The results show that the causality test between the independent variables and dependent variable is statistically significant. In addition, Table 4 shows that the initial model fit the data well, but there was still some deviation to the standard. To make the model as realistic as possible, the AMOS provides us with the Modification Index (MI). MI implies that the errors of "thinking enthusiasm" and "extension", which are measurement indexes of geographic learning interest, had a covariant relationship. From the experience of school teaching, actively paying attention to and exploring geographical topics is a characterization of students' eagerness to expand geographic knowledge and broaden their horizons. There is indeed a reliable connection between "thinking enthusiasm" and "extension". Hence, it was acceptable to add a correlation path between the errors of the two factors. We reevaluated the model fitting, showing that all the indexes meet the standard (Table 4). The modified model can adequately explain the mechanisms influencing geospatial thinking (shown in Figure 2).

Analysis of the relationship between the factors influencing geospatial thinking

According to the model results (see Table 5), general intelligence, geographic knowledge and geographic learning interest have a positive influence on geospatial thinking directly. Their standardized influence coefficients are 0.420, 0.415, and 0.166 respectively. Meanwhile, the influence coefficients for general intelligence and geographic learning interest on geographic knowledge are 0.151 and 0.340, implying that general intelligence and geographic learning interest may affect geospatial thinking through geographic knowledge. In that case, geographic knowledge plays an intermediary role in this influencing mechanism. We made AMOS repeat random sampling 2000 times in the sample data. We generated an approximate sampling distribution and estimated a 95% confidence interval for testing the mediating effect of geographic knowledge. If the confidence interval did not include 0 then, the mediating effect was statistically significant (Kisbu-Sakarya, MacKinnon, and Miočević 2014). The results show that the confidence intervals of the mediating effects between the two factors (general intelligence and geographic learning interest) and geospatial thinking are [0.364, 0.592] and [0.161, 0.458], respectively. This indicates that mediating effect is significant. Their indirect effects were 0.063 and 0.141, accounting for 13.04% and 45.93% of their total effects respectively (see Table 6).

Discussion

In this study, we used a structural equation modeling approach to find the factors influencing geospatial thinking and to explore the relationship between the factors. The results tell us the influence path and size of the influence on geospatial thinking.

Geographic knowledge, general intelligence and geographic learning interest have positive effects on geospatial thinking. This is consistent with previous studies (Collins 2018; Wakabayashi 2015; Wan et al. 2017). Regarding the mechanisms of influence for geospatial thinking, we found that general intelligence had the greatest influence on geospatial thinking, with a total effect of 0.483. It can be said that, when controlling for geographic knowledge and interest in learning geography, if the general intelligence is improved by one unit, students' geospatial thinking level would improve by 0.483 units on average. Intelligence is a relatively stable attribute formed over a long period of time. For geography courses, it could be more meaningful to explore the influence of geographic knowledge and geographic learning interest on geospatial thinking, as these two factors are more malleable. The impact of geographic knowledge on geospatial thinking is 0.415, and the influence of geographic learning interest on geospatial thinking is 0.307. The result tells us that these two factors have an important influence on the level of geospatial thinking, which is of interest to geography teachers. It is worth mentioning that Wan et al. (2017) also concluded that the influence of general intelligence, of geographic knowledge and of geographic learning interest on geospatial thinking decreased in turn.

The accumulation of geographic knowledge is an important intermediary through which general intelligence and geographic learning interest can affect geospatial thinking. Although their indirect effect size is small (only 0.063 and 0.141, respectively), our results indicate that geographic knowledge is responsible for the observed influence of these two factors on geospatial thinking. 13.04% of the influence of general intelligence on geospatial thinking is caused by geographic knowledge. 45.93% of the influence of geographic learning interest on geospatial thinking is caused by geographic knowledge. This indicates that geographic knowledge plays an important role in the development of geospatial thinking. Our results also support the argument that mastering geographic concepts and geographic thinking contribute to the development of geospatial thinking (Golledge, Marsh, and Battersby 2008; Huynh 2009; Goodchild and Janelle 2010). Additionally, the influence of geographic learning interest on geographic knowledge

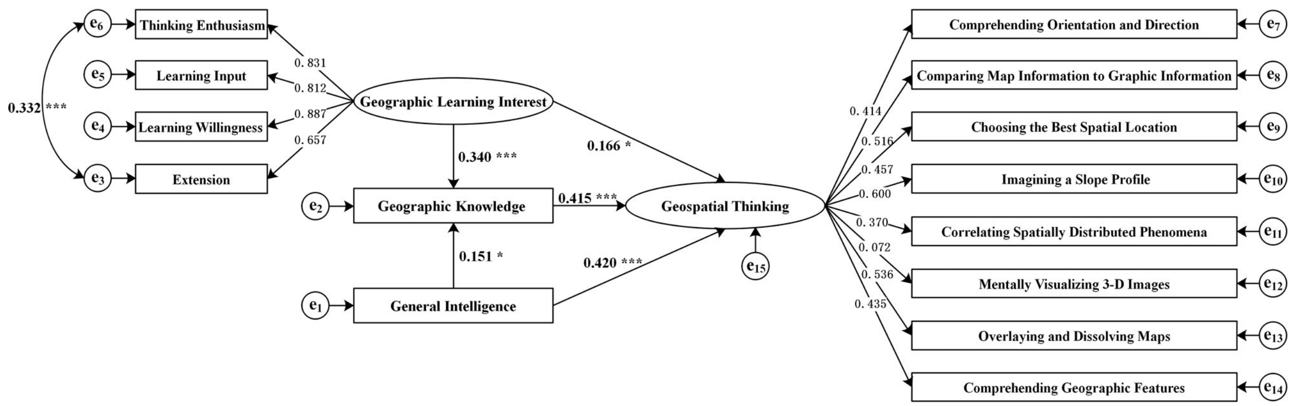

Figure 2. Mechanisms of influence for geospatial thinking (modified model).

Table 5. Standardized regression weights and significant difference.

Path	Standardized regression weights	Standard error	Critical ratio	Significant difference
Geographic learning interest to geographic knowledge	0.340***	0.250	4.916	high significance
General intelligence to geographic knowledge	0.151*	0.165	2.503	significance
Geographic learning interest to geospatial thinking	0.166*	0.006	2.118	significance
Geographic knowledge to geospatial thinking	0.415***	0.002	4.354	high significance
General intelligence to geospatial thinking	0.420***	0.006	4.536	high significance

*The regression weight for the path is significantly different from zero at the 0.05 level (two-tailed).
***The regression weight for the path is significantly different from zero at the 0.001 level (two-tailed).

Table 6. The effect of the factors on geospatial thinking.

Factors of influence	Direct Effects	Indirect Effects	Total Effects
General intelligence	0.420	0.063	0.483
Geographic knowledge	0.415	——	0.415
Geographic learning interest	0.166	0.141	0.307

(0.340) is stronger than the influence of general intelligence (0.151). It implies that students with lower intelligence levels are able to cultivate their geographic learning interest, which would increase their geographic knowledge level.

We need to be cautious about the effect of general intelligence on geospatial thinking. The intelligence test itself does not necessarily take into account the group characteristics of different cultural backgrounds (Li and Cai 2009). Influenced by situational factors, intelligence tests are often affected by biases related to social, cultural, economic, racial, and ethnic issues (Das, Naglieri, and Kirby 1994). In our research, although students of different nationalities had the same educational experience, they had different cultural backgrounds, which may affect their scores in the same intelligence test. This may cause the test results to not fully reflect the real intelligence level of some participants. Furthermore, we only used one method to measure general intelligence, which may not be applicable to students from different countries or regions, thus limiting the generalization of our research conclusions.

We did not find a significant correlation between map using experience and geospatial thinking. This is contrary to the previous research findings. Wan et al. (2017) found that map using experience was related to geospatial thinking ($r = 0.198$, $p < 0.05$). An intervention study by Collin (2018) showed that students' geospatial thinking was improved after using maps. Another study concluded that the interest in map use influenced geospatial thinking, especially in spatial pattern recognition, spatial correlation and landscape visualization (Wakabayashi 2015). Some scholars have also pointed out the importance of maps for people to process spatial information and conduct spatial thinking (Hilman 2020; Segara et al. 2018). Maps are the graphic representation of spatial understanding, and they are drawn to represent the world after careful selection of spatial data (Thrower 1996). It is difficult for people to directly observe the large-scale surface of the earth given their life experience. However, through various visualization angles (such as tilt or top view) and different scales of representation, maps help us understand the geographical world and enable us to understand spatial relations from an abstracted perspective (Wood 1992). It was also proved that the use of maps activated spatial thinking and had a positive effect on the completion of spatial tasks (Lobben, Lawrence, and Pickett 2014). Therefore, the use of maps help people acquire large-scale spatial concepts, promotes thinking about spatial relations and discover new information (Uttal 2000).

Based on the inference outlined above and on previous studies, map using experience should be relevant to geospatial thinking. However, our study failed to confirm this due to several possible reasons. First, in our study the power of the correlation analysis for map using experience was only 0.147, which indicates a probability of 14.7% that the "irrelevant" conclusion is correct. The low power makes it difficult to test the hypothesis. Second, the geography course in the sample school emphasized knowledge and ignored practice, which could explain why we found that map use did not have a significant effect on geospatial thinking. The geography teachers followed the curriculum standards in teaching students how to use maps to form a "space-region" view for understanding the geographic environment. However, teachers needed to teach on a way that ensured students would pass the examination, and emphasized memorization and theoretical understanding of geographic knowledge rather than practical ability. Consequently, in classroom activities, students were rarely exposed to open or task-based geospatial problems that need to be solved by consulting maps and processing spatial information. Students tended to recite geographic knowledge to cope with the exam and rarely thought about space around the map. They spent more time on LBS apps to think about space in daily life. Maybe geospatial thinking is more relevant to the map using experience based on geo-media than that based on paper maps. This also reminded us that, map using experience test should seek to assess how students use maps to think about space, and what habits they develop in the process of thinking. For example, some students only use one map for positioning, and others looking at multiple different maps to understand the location. These two kinds of students have different ideas about maps, which leads to different information richness obtained from maps, and eventually to forming different understandings of spatial information (Uttal 2000). These factors may lead to differences in geospatial thinking levels. Therefore, follow-up studies need to develop a more comprehensive test of map using experience, which can help us better assess the relationship between map using experience and geospatial thinking.

This study has three primary limitations. First, we conducted a cross-sectional study. Our research confirmed the correlation between factors, but we cannot make a clear statement about the causality of the factors. Second, we must be cautious when generalizing from our results. Although we considered the school selected for this study to be an ordinary (and therefore representative) high school in China, the research participants may have certain unique characteristics. We only used one method to measure the variables in the study, which does not necessarily apply to students from different cultural backgrounds around the world. We can only claim that we provided additional empirical evidence on the factors influencing geospatial thinking by using one specific case. Future studies should survey more students, especially students from different cultural backgrounds. Third, the factors influencing geospatial thinking are not limited to those discussed in this study. Future studies should analyze additional factors and explore their mechanisms of influence on geospatial thinking.

Conclustion and future research

This study explored the factors influencing geospatial thinking. We found that geographic knowledge, general intelligence and geographic learning interest significantly impacted geospatial thinking. In addition, geographic knowledge was a mediator in the relationship between general intelligence and geospatial thinking, and between geographic learning interest and geospatial thinking. However, the influence of map using experience on geospatial thinking was not demonstrated.

This study provides a theoretical basis and guidance for improving senior high school students' geospatial thinking abilities. It suggests that the cultivation of geographic knowledge and learning interest is helpful for improving geospatial thinking. However, these factors do not involve the essence of students' spatial thinking process. In the future, we need to further determine how geographic knowledge and learning interest affect geospatial thinking and what factors are involved (e.g. students' ability to identify spatial elements, to establish spatial connections and to make spatial decisions).

Notes

1. We measure students' enthusiasm and consciousness for attention and exploration towards geographical topics.
2. We measure students' concentration and engagement in geographic learning activities, such as attending class, doing homework, and reviewing lesson.
3. We measure whether students' willingness to learn geography is acceptance or resistance.
4. We measure students' thirst for expanding geographic knowledge and broadening their horizons.
5. We measured whether the students had the opportunity to read maps and their previous experience using maps.
6. We measured students' intention to use maps and their preference for map types.
7. We measured whether the students could understand the geographic information conveyed in the news by imagining psychological maps and drawing pattern maps, as well as their ability to extract geographic information from maps.

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