A Project entitled

Exploring the Effects of GIS Learning on Students' Spatial Skills

Submitted by

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Declaration

I, *ZHANG Zhi Han* declare that this research report represents my own work under the supervision of *Dr HUI Lai Hang Dennis*, and that it has not been submitted previously for examination to any tertiary institution.

Signed

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Abstract

Learning to think spatially is one of the eternal themes of geography education. These kinds of skills enable students to interpret geographic data in the subject and help them comprehend the complexities of spatial problems we face today. In the past thirty years, GIS (Geography Information System) has become a promising technology for educational uses in geography due to its unique advantages in visualization, overlaying maps, and analyzing spatial data. With rapid development in technology today, GIS skills are gradually stressed in geography and the workforce. Based upon these trends, the research emphasizes the significance of spatial skills as an amalgam of two elements: spatial thinking skills as soft skills and GIS skills as hard skills. This research incorporates GIS into a geography inquiry named "Where does wild ginseng grow in Jilin Province." A test on spatial skills is used to examine the effect of GIS learning on the spatial skills of university students. Twenty students in EdUHK completed pre- and post-tests before and after the two-hour workshop. Analysis of changes in the student's test scores revealed that the GIS workshop helped students with mastering GIS skills in a short period. In contrast, no significant improvements in spatial thinking skills were observed. The enhancement of GIS skills resulted from motivating inquiry questions, hands-on experiences, detailed explanations of functions, and a case-study-based site suitability analysis. However, the lesson design needs questions encouraging spatial thinking and reflection that contribute to critical thinking. And since the workshop lasted for a short period, no sufficient learning experiences exist to foster better spatial

thinking skills. The findings of this study emphasized the vital role of instructional design in making the most of GIS and provided practical suggestions for planning inquiry-based GIS lessons.

1. Introduction

In modern society, everyone is confronted with personal decisions that necessitate spatial thinking. These decisions, whether minimal or important, can have a prominent influence on nature and society when thousands of them are multiplied (Bednarz, Heffron & Huynh, 2013). Geography education plays a vital role in preparing students to think spatially and therefore make reasonable decisions in a wide range of fields. The status of spatial thinking was highlighted by Sarah Bednarz (2007), and she asserted that spatial thinking with support from geospatial technologies should be central to a creative geography curriculum. Based on the consensus on the significance of cultivating spatial skills or spatial thinking in geography education, numerous pieces of literature tried to define spatial skills, spatial thinking, spatial abilities, and related concepts. Nevertheless, no uniform understanding of these concepts can be found. Rather than concerning the detailed discrepancies between each definition in different studies, this research defined spatial skills as an amalgam of two elements: GIS skills as the hard skills and spatial thinking skills as the soft skills.

Geographic Information System (GIS) has been recognised as a promising instrument for developing students' spatial skills. The use of GIS has been claimed to be underlaid by spatial cognitive abilities (Albert & Golledge,1999; National Research Council, 2005) and responds to the need to keep geography education progressing in the considerable developments in technology. Following this, learning GIS introduces the students to the rising geography-dependent careers. GIS also provides an excellent opportunity for constructivist approaches to teaching and learning (Doering, 2003; Kinniburgh, 2010; Rickles, Ellul & Haklay, 2017). On the basis of these perceived advantages, a couple of countries have recognised it as an important geography skill students are expected to own (Kerski,2001; Liu, Bui, Chang &Hans,2010; Department of Education, 2013). In contrast to the broad scope of professional GIS skills, entry-level GIS skills are narrowed to the abilities to understand the formats of spatial data, manipulate basic tools, create maps, and interpret the framework of spatial analysis in this research.

Cultivating students' spatial thinking skills is vital not only because a considerable amount of geographic learning is underpinned by spatial thinking (Bednarz,2007) because there are also substantial needs for talents who manage to interpret and analyse geographic information in different sectors. The attributes of spatial thinking are debated. One of the most cited studies defined that spatial thinking is comprised of concepts of space, using tools of representation, and applying process of reasoning (National Research Council, 2005), which overlapped some characteristics of GIS skills as mentioned. An earlier study explained spatial thinking skills in more detail, dividing it into the cognitive abilities to conduct spatial visualisation, spatial orientation, and process spatial relations (Golledge &Stimson, 1997), which is adopted in this research. Following this, Lee & Bednarz (2009) further construct the relationships between GIS activities and spatial abilities, providing this study with the framework to understand how GIS can be effective in improving students' spatial thinking skills.

While numerous studies hold optimism towards the effect of GIS in the educational sphere, what needs to be reexamined is under what conditions this technology can foster teaching and learning. (Means & Penuel, 2005; Milson, DeChano, Bunch, Caito, & Qiu, 2005; Segall & Helfenbein, 2008). It should be reminded that the role of teachers and their lesson design plays a vital role in making students improve their spatial skills in GIS learning (Bednarz, 2004). As a result, this research aims to obtain evidence for two research questions: What and how does GIS learning affect students' spatial skills? And What are the characteristics of quality GIS teaching and learning? A quasi-experiment design is used to evaluate the validity of this tool as a pedagogical resource in the topic of finding out where ginseng grows in Jilin province. In this research, a GIS-involved inquiry-based teaching plan is designed and tested among 20 university students in a workshop. Students' performances in spatial skills are quantified as the score they get in the pre-test and post-test. By comparing the scores before and after the intervention, the effects of GIS learning are analysed, which can enrich the empirical studies on the implementation of GIS education quantitatively.

2. Literature Review

2.1 Educational Technologies and Constructivist Teaching Strategies

The geography curriculum in schools is constantly evolving to keep up with a fast-changing world - whether it changes in the relationship between people and places or new iterations of technology. Within this general trend, technology should be applied to classroom teaching: Technology can facilitate geography learning, especially spatial literacy, which is a key focus in geography.

Three types of technology that have been used to teach geography include GIS, VR/AR and Google Earth. Compared to the other two technologies, GIS has three unique functions to help students learn: firstly, the visualisation capabilities of GIS. On the one hand, GIS can visualise complex spatial data and help students understand spatial distribution features. On the other hand, GIS can flexibly display spatial distribution features at various scales compared to paper maps with fixed sizes and themes, helping students to accurately understand the spatial relationships between places in the real world. Secondly, GIS supports overlaying a variety of layers, which makes it particularly suitable for analysing various factors of a geographical phenomenon, for example, the impact of geographical factors such as slope, vegetation cover and precipitation on the probability of landslides; and the impact of agglomeration effects, transport and infrastructure on the location of industries. In the classroom, students first need to think about which layers to select (i.e. which factors are considered to have contributed to a geographical phenomenon) for analysis and then assess the impact of these factors using tools such as buffer zones and distance analysis. Thus, using GIS can facilitate students' active higher-order thinking and improve their understanding of maps than using paper maps in textbooks. Thirdly, the strength of GIS, compared to AR/VR or google earth, lies in the storage, processing and analysis of spatial data. Not only can students find data from databases through SQL and filtering, but they can also (with teacher guidance) use a range of spatial analysis tools: including buffering, overlay analysis, statistical analysis, etc., to draw conclusions supported by evidence. Such spatial analysis hones students' geographic inquiry skills: using GIS to analyse spatial patterns (one of the curriculum objectives for high school). With this function, GIS can perfectly help site selection problems in a sophisticated and refined manner.

However, the prerequisite of these advantages claimed is effective implementations of innovations, which is mostly supported by constructivist teaching strategies. Inquiry-based learning (IBL), problem-based learning (PBL), project-based learning, as well as some cooperative learning are all examples of constructivist classroom activities. Among the mentioned teaching strategies, geography education (in particular HK) highlights the role of inquiry-based learning in geography education. This call for inquiry-based learning is based on the recognition that learning geography is not about rigidly accepting ready-made knowledge. It's about "do geography"-students study in the process of proposing inquiries into questions about the world that surrounds us (the CDC-HKEAA Committee on Geography, 2017) and answering the questions or testing the hypothesis (Lambert & Balderstone, 2012).

This research adopts the framework of geography inquiry proposed by Roberts (2013), which consists of four stages of a learning cycle. As one of the promising technologies in geography education, GIS, in particular, the three main features: visualisation, overlaying layers, and data analysing, has its role in each stage of inquiry. At the first stage of inquiry, numerous studies have demonstrated the power of GIS to improve students' motivation to learn (Xie & Reider, 2014; Ercan, Bozkurt, Tastan & DAĞ, 2016; Schulze, 2021; Aladağt, 2010; West, 2003) : GIS-supported teaching enhances students' interest, curiosity, relevance to life, autonomy and excitement about the content of the learning topic. By encouraging students to generate new ideas and build students’ interest in the learning content, GIS-based teaching enhances students’ intrinsic motivation.

GIS can also contribute to using data more effectively. The scope of spatial data involved in a GIS system is much larger than that of traditional atlas, and some of these is real-time when most of maps on the textbook are about past stories. With such a wide range of data, students have more autonomy in investigating a geographical topic in a real-world context. In the process of collecting and selecting evidence from the dataset, students have more high-level thinking. GIS has powerful data search and statistical capabilities, helping students to organize spatial data they collected. This function not only refers to searching a place on the map, but can produce graphs and thus training students’ graph interpretation skills which is tested in data-based questions in public exams. The primary data can be input into a GIS system so that students can visualize the spatial pattern and conduct further analysis (Schlemper, Brinda, Kevin, Victoria & Sujata ,2019).

In the process of making sense of all data, students need to describe the spatial pattern observed, and GIS's ability to render complex data into visual interpretation – different colors, sizes of symbols- help students to achieve the task. Zoom in and out function of an electronic map enables students to see the pattern at different scales. Overlaying maps is a process of integrating a series of thematic maps to generate a new data layer as a product of existing layers. With this technique, students no longer need to turn to different pages for different maps. For instance, by overlapping the map of world volcanic distribution and the world plate boundaries, students can easily interpret the global distribution of tectonic hazards, compare two layers, and recognize the close relationships between volcanic and destructive boundaries. Optimal location analysis, another often used function of GIS, enables students to take all the factors into consideration, thus strengthening their understandings and make learning meaningful. Data analysis function is suitable for testing the hypothesis students proposed in the first stage. The quantitative results generated during the analysis provide compelling evidence to the arguments. As opposed to a generalized explanation that A rises or declines with B, more sophisticated GIS analysis generates detailed explanations in a real situation, which is often an inspiring new finding.

Finally, various GIS-based activities are suitable for reflecting on the learning. By comparing the output of their projects and the reality, e.g. an optimal site for a supermarket from GIS analysis compared to the location of existing supermarket, students can figure out the similarities and the gaps between a model and the real world situation and reflect whether data, the data processing method, or the research rationale lead to such difference.

2.2 Related Works

While numerous researchers stipulate that GIS should be integrated into geography education, a more pragmatic question is how to use it efficiently. Artvinli (2010) proposed the "The Pyramid of Educational Phases in GIS", which illustrated different levels of GIS uses. With increasing student autonomy, GIS teaching has evolved from a teacher-centred introduction to GIS at the bottom of the pyramid to a demonstration of geographic analysis with GIS. At a higher level, students themselves use GIS as a tool to analyse datasets and then create their own data sets. The pyramid provides a useful framework, although it requires modification, to organise the examples of GIS applications in education.

At the first stage of the GIS-involved lesson, it is necessary for the teacher to make a short introduction of it and the vast majority of empirical studies include this part (Sam & Alec, 2020; Rane, John & Murthy, 2020). Even though it is classified as a teacher-centred approach by Artvinli, some studies showed us a more engaging way – an ice-breaking game- to make students familiar with the operations. Timothy(1999) designed a project that guides students to designate a place for a new park. In the preparation stage of this course, students need to help a bird to find its compass and locate its destination, in which students get used to the interface and basic functions of

GIS software.

Secondly, teaching with GIS, namely demonstrating spatial data by the teacher as a tool to discuss geographic topics, is a broadly adopted method to provide supplementary materials for students learning. Compared to paper maps, the spatial data shown in class is expected to be time specific and more visually attractive.

At the third level of this pyramid, GIS is in the hands of students, who use already prepared spatial data to explore geographical inquiries. Numerous empirical studies and learning activities belong to this level, the spatial data which is mostly large-scale, official, professional, and unable to collect by students. In the textbook opportunities and risks 1.4 - a compulsory part of the HK geography curriculum, an online GIS tool is used to discover the distribution pattern of tectonic hazards. By comparing the distribution of three kinds of plate boundaries and the tectonic hazards, students identify the relationship between them. Similarly, the latest version of the Geography textbook of Shanghai designed a teaching activity on "Using Web-GIS platform to analyse changes in population density and population migration". In the first activity, students are asked to describe the characteristics of the population distribution in Shanghai and analyse the reasons for this. Secondly, students need to observe and explain regions with high in-migration. Finally, they need to conclude the factors affecting population migration based on the layers Web-GIS provides. Other studies expect to use GIS for decision-making and optimal location cases: students in India used an interactive Geomap to designate a perennial river for canal construction to solve drought problems (Rane, John & Murthy, 2020). Sixty model lessons integrated with web-GIS were developed in Slovakia (Csachová,2020), such as using web-GIS to find an ideal location of the capital of Europe. A pilot GIS program in Singapore (Liu, Bui, Chang & Hans, 2010) encompasses three tasks full scaffolding, some scaffolding, and no scaffolding. Students act as consultants to study the spatial pattern of migration and public services and suggest the optimal location to market products or to set up public utilities. A more ambitious American learning program about hurricanes (Sam & Alec, 2020) encompasses map interpretation – investigation of the relations between air pressure and the intensity of the hurricane, evaluation of the effectiveness of an advanced typhoon pressure model and creation of maps to present their findings.

At the highest level of education phases in GIS – research in GIS, students collect data on their own and do spatial analysis to create outputs. As a result, fieldwork is often involved. Citizenship education, especially studying local problems, is a popular field to adopt GIS education at this level due to the relatively simple data collection, e.g. Using a decibel meter to assess the noise pollution at a different site in a district. A summer workshop on GIS focused on applying GIS to explore spatial inquiries about social issues, encompassing youth unemployment, housing, crimes, and recreational facilities(Schlemper, Brinda, Kevin, Victoria & Sujata, 2019). Another category to mention is GIS usage in physical environmental learning projects, especially mapping water pollution, which involves more scientific techniques.

3. Methodology

3.1 Methodological approach

Aimed to understand what and how GIS learning affects students' spatial skills, this research adopts a one-group pretest-posttest design as the primary method. This method is commonly used to evaluate the effectiveness of an educational program. The researchers assess the skills or knowledge of participants before treatment as a pre-test. A pre-test is followed by the teaching of specific knowledge or skills, and after that, participants are assessed again as a post-test (Allen, 2017). In addition, in-depth information and evidence from participants were acquired through semi-structured interviews (Powney & Watts, 2018), which is commonly adopted in educational research.

3.2 Data collection methods

The study is set on the Eduhk campus, with a total of 20 undergraduate students participating in the two-hour face-to-face GIS workshop. The participants are recruited from different majors, including geography, environmental sciences, and other social sciences subjects.

For the design of the test, the first step was to delineate the assessment objectives (Plake &Jones, 2002). This study refers to the definition of spatial skills as the combination of GIS skills and spatial thinking skills, which are refined into spatial visualisation, spatial orientation and spatial relations. The pre-test and post-test questions were designed according to the study's definition of spatial skills with careful specification of each question in the test to improve its validity. The test consists of 20 multiple choices questions in total (Table 1) , with five questions targeted at the general understanding of GIS and spatial data, ten questions focused on the GIS skills covered in the workshop, as well as five questions testing spatial thinking skills based on the spatial abilities proposed by Gollege & Stimson (1997).

The workshop is planned in accordance with the four steps in geography inquiry-based learning. By displaying the ginseng seen in daily life to motivate participants, detailed step-by-step instructions in ArcMap are given to guide them in mapping the distribution of wild ginseng in Jilin province. The site suitability analysis that involves multiple criteria helps participants to make connections between all sorts of data. They are also required to reflect on the learning process and discuss the methods to improve the accuracy of results.

During this process, two types of data are collected for the purpose of this research, the scores of the pre-test and post-test. The test of spatial thinking is scored by the number of questions answered correctly. This research employs a paired sample t-test to analyse the average score for the pre-test and post-test. In addition, this study conducted semi-structured interviews with the subjects to gather information about their perceptions of using GIS learning to enhance their understanding of GIS, equip participants with GIS skills, and improve spatial literacy. Moreover, interviewees are invited to share their learning motivation for GIS during the course.

Table 1. Design of the Pre-test and the Post-test

Questions	Test items
1-5	General understanding of GIS and spatial data
	e.g. The components of GIS; Application scenarios of GIS; The differences between vector and raster data
6-15	GIS skills
	e.g. Digital Elevation model; Algebra expressions in raster calculator; Reclassification
	In addition, question 15 asked participants to reflect on the problems and uncertainty with spatial data, which was regarded as the criteria to be a critical spatial thinker (Bearman, Jones, André, Herculano & Michael, 2016)
16-20	Spatial Thinking Skills
16	Required the participants to visualize real-world topography based on the observation of a digital elevation model, which emphasizing the process to convert 2D information into 3D images. The design of this question refer to “Orienting to real-world frames of reference”.
17	Participants were asked to visually overlay layers of giant panda habitat from different periods; and to point out changes in spatial distribution of habitat by comparing the different layers. Not only the ability to overlay maps and recognize spatial distributions and patterns is tested, it also

	looks into participants' ability to draw inference based on the evidence obtained from the map.
18	Required participants to recognize the spatial relationships between different symbols and generalize the spatial pattern of a phenomenon from the same map, e.g. the distribution of earthquakes and the plate boundaries. It simulates the process of comparing several layers of spatial information about the same area of the screen in a GIS operation. The spatial cognitive processes, including "comparing, associating, and correlating spatially distributed phenomena" as well as "recognizing spatial distributions and spatial patterns" (Golledge & Stimson, 1997)
19	Participants were asked to select an optimal location for a nuclear power plant according to multiple criteria: the distance to residential area, the distance to the coastline, far away from the fault line and tectonic hazards, and built on a flat land. This question was designed to test Boolean logic in site suitability analysis, which is the basic rationale of raster calculator in GIS– the skills learnt in the workshop. It corresponds to the spatial ability to "overlay and dissolve maps".
20	This question asked participants to compare a map showing the present layout of SaiKung Town and a historical ariel photo and then figure out the reclaimed land. The basic rationale behind questions 20 is to firstly rotate the map but unconfused by the changing orientation, and secondly "orient to real-world situation", followed by compare two maps and connect the locations of different facilities.

4. Result

To determine the changes in students' spatial skills before and after the intervention, average scores of pre-test and post-test were analysed by applying a paired t-test (Table 2). The first set of data analysed was the average score in the pre-and post-test of 20 multiple-choice questions. Overall, it revealed that the average score of each question increased by 0.33 while the students who participated in the GIS workshop improved their test scores significantly as a result of the intervention ($p=0.000<0.01$). This result should not be surprising since these students were exposed to a workshop that covered almost all the test contents.

Paired t-test was also applied to test the significance of intervention on three subscales: a general understanding of GIS and spatial data, GIS skills, and spatial literacy. For the first subscale, although the result ($p= 0.038<0.05$) shows a significant correlation between the workshop and the initial understanding of GIS and the data it processes, the correlation is not as strong as the overall one. The comparable results of the second subscale presented a strong significance between the learning in the workshop and their GIS skills ($p=0.000<0.001$), which can be illustrated by the training to make GIS skills from scratch since most of the participants hadn't used ArcMap before the intervention. Thirdly, the relationships between students' spatial literacy test scores and the workshop were examined. The difference in the score improvement for this subscale was not large enough to be significant ($p=0.070$). The first possible reason is that participants can use their previous knowledge or map comprehension skills to answer the questions even if they have not attended the workshop. For example, 19 out of 20 participants were able to match the DEM with the terrain in the pre-test. This result can also be explained by the inefficiency of a one-off GIS workshop to cultivate an ability that needs long-term training.

Table 2. Paired t-test analysis of the pre-test and post-test scores

Variable/subscales	Pre-test		Post-test		P-value
(Rate of correct answers)	Mean	SD	Mean	SD	
Total score	0.553	0.274	0.883	0.152	0.000**
General understanding of GIS	0.740	0.178	0.940	0.027	0.038*
GIS skills	0.400	0.233	0.855	0.155	0.000**
Spatial literacy	0.670	0.289	0.850	0.206	0.070

The coefficient is significant at 0.01 level (two-tailed) and 0.05 level (one-tailed)

5. Discussion

This study demonstrated that, in a workshop setting, GIS learning helps students to learn more about the theoretical and technical aspects of GIS but doesn't have an encouraging influence on their abilities to identify distributions, visualise spatial information, or master other spatial abilities.

5.1 Effectiveness of the Workshop to improve students' GIS Knowledge and Skills

Significant differences between the pre-test and post-test were found based on the total 20 questions, the improvements of which are mainly contributed by the enhancement of students' understanding of GIS concepts and skills. The reasons for this improvement can be illustrated by the learning contents that are highly relevant to the test items and the inquiry-based lesson planning.

5.1.1 Creating a need to know

As expected, the learning motivation of participants was generally high, demonstrating the success of this workshop in creating a need to know, which is regarded as the foundation for conducting geography inquiry-based learning.

To begin with, the project title "Where does wild Ginseng grow in Jilin Province?" aroused the curiosity of students. Construction of motivating inquiry questions is not an easy job, from identifying the inquiry question to be answered to making the question motivating. A number of factors should be considered in determining the inquiry questions, such as if the question is geography-specific (Ali, Ahmet & Mehmet, 2013) and whether it can contribute to more understanding of the interdependence between human and natural environments(Günther Weiss, 2017). The geography questions are always relevant to the places, such as constructing a location analysis model. It is expected the knowledge and skills learnt in geography can be widely applied to solve questions beyond the classroom. In this context, the questions and the according learning materials should be meaningful in students' life. Another consideration is the authenticity of the question (Doering & Veletsianos, 2007; Shin, 2007; Bednarz, Heffron & Huynh, 2013), especially at the level of secondary and higher education. It is not only difficult to do in-depth research in a fictional context, but the real situation also empowers students with a sense of accomplishment to solve social problems and lets them feel the usefulness of the learning contents.

And when GIS is involved in learning, there are two more significant factors to be considered: how could GIS empower the inquiry and whether the data to be processed is available. With much effort invested in a GIS learning project, it is expected the inquiry can get the most out of the unique advantages of GIS: visualisation, spatial analysis, and map overlaying. Related learning activities involve representing the collected spatial data in GIS, evaluating the connectivity of transport planning, and drawing buffers to see the affected areas. It is equally important that the data is accessible and even readily adapted for educational use since the process of preconditioning data is time-consuming. This factor is, in effect, a strong limitation of the research topic even if there are increasing local open spatial data provided in recent years.

After the project topic is confirmed, more needs to be done to make the question motivating and adequately challenging. Some studies assert that motivation is more related to an unusual topic that is not common in the existing curriculum (Quain, 2014). This helps to illustrate why the ginseng topic is welcomed by students. Traditional constructivist researches emphasise the power of current importance and the civic responsibility of topics. Inquiries can be accordingly designed as decision-making questions, evaluating the existing or future planning, and case studies (Günther, 2017). A close relationship between the students and the topic also helps to increase motivation. A brief introduction to the topic helps to construct such relationships, e.g. When you travel to Changbai mountain, there are always many shops selling wild ginseng that are locally grown. Can we trust them? Does wild ginseng really grow in the country park? The last consideration to be mentioned is the optimal-challenge task. The abilities of students and their prior knowledge should be taken into account. Demanding learning objectives with advanced analysis can be counterproductive, which leads to frustrated feelings and low motivation.

Furthermore, students' motivation was enhanced by their meaningful investigation, which is perceived to be done in a more professional manner (West, 2003). Experiencing the powerful functions of ArcMap helps to motivate them since the strategy of "learning by doing" through hands-on activities has been manifested to encourage active learning and help students to develop their cognitive processes and conceptualise technological knowledge (Niiranen, 2021). It is interesting to mention that not all participants were impressed by the visualisation of spatial data on ArcMap as anticipated; some students mentioned that the interface, as well as the map, are not visually attractive.

This is the first time I have come across this software, and it is amazing how powerful the data processing system is and how it can be visualised. (a student who hadn't heard of GIS before)

I had never been exposed to Arcmap before, but I used it for the first time in the workshop and found it very interesting and useful, so I wanted to continue to explore it. In previous gis classes, I have only touched on the basic functions of this, for example, I could only draw a map, but I could not do data analysis, so the content I learnt was relatively simple. However, this ArcGIS workshop introduced a lot of data analysis functions, such as filtering out suitable slopes, so it was more interesting.

A further factor that is often overlooked is that participants are more active in learning due to the clear explanations about "Why do I need to know different types of data? Why do I need to use a raster calculator?". In this process, the capabilities of different tools are introduced, e.g. Only if the data set you use in all raster data could you apply a raster calculator to extract the areas that meet certain requirements. However, the need to know or the introduction of tools is not catered to in some GIS training courses despite the fact that step-by-step instructions are given.

I think I was more motivated to learn in your workshop than in my previous Geography class. I knew why I was doing it because there were specific explanations for each step, so I had a clearer understanding of the process of spatial analysis.

The GIS course I took before also had very detailed steps to teach you what to click on in this step and what data to enter in the next step. But it doesn't go into why it's done, what the function of the tool is, and what the significance of this step where we convert the coordinate system is for the next step, all of which I had no idea about.

Informing students of the necessity of learning not only boosts motivation but also is a crucial step in helping them to master spatial analysis. When students were asked what would be the most difficult part of spatial analysis if they were to do the such analysis themselves afterwards, rather than the detailed steps, they emphasised the importance of the design of workflow, that is, which kinds of analysis should be involved and in which sequence should I process the data. This finding is consistent with the results of other studies that argued that learning geospatial sciences tend to spend more time learning the software at the expense of neglecting the spatial reasoning that GIS works and presents (Golledge, Marsh & Battersby, 2008; Perugini & Bodzin, 2020).

To do a project, you first have to know what data you use and which kind of spatial analysis you need to conduct and then choose the corresponding tools to help you reach these goals. The most challenging part should be the framework of analysis, instead of operating ArcMap. I can find a lot of tutorials on Youtube or Bilibili to learn how to operate software, but it is difficult for me to draw an outline of the analysis.

5.1.2 Using Data

At the third level of the pyramid of educational phases in GIS (Artvinli, 2010), the GIS workshop in the research is a teacher-led confirmation inquiry, with all data and learning processes provided to the students. The data provided was used as examples to teach students the characteristics of spatial data. For example, students were asked to compare a raster map and a vector map that showed the suitable areas for ginseng and summarise the differences between raster and vector data rather than passively listen to their characteristics. After that, students were asked to classify five sets of raw data into vector and raster data, and most students successfully completed the task both in the class and in the post-test. It is equally important to provide extra data from different sources to introduce the common types of raster and vector data.

Not until that workshop can I distinguish the raster and vector maps. In the previous gis lessons, we were only provided with some abstract examples. Neither examples in real life were provided, nor did we know the common types *of raster and vector data.*

More understanding of spatial data types and the problems that GIS can solve. For example, I understand raster data and vector data better and can distinguish between them.

5.1.3 Making Sense of All Data

The site suitability analysis, which takes into account a number of variables, assists participants in drawing connections between various types of data. All sorts of strategies, ranging from describing and explaining patterns to analysing values, were applied in the third stage of geography inquiry-based learning. These activities helped to reinforce students' understanding of the GIS skills and their spatial literacy. For example, participants were asked to compare the DEM data with the topographic map of Jilin to find out the mountains in the southeast part of Jilin. The repetitive use of the raster calculator and reclassifying reinforced students' understanding of analysis tools. Students' feedback from the interviews manifests the statistical effectiveness of the training to improve their GIS skills.

I think my progress (in GIS skills) is quite remarkable and after a week I can still pretty much remember the steps. As I am an IT student, I actually use new software quite often. I think the most effective way to learn new software is to let the students work on a problem with the teacher's guidance, which is much more *effective than just talking about the functions.*

A qualitative leap forward. I hadn't used ArcGIS before, but now I know where the tools are now.

I think my GIS skills have improved a lot. For example, if I want to select a certain part of the raster data, I can use the raster calculator and the reclassification function.

The workshop also practised students' abilities to conduct quantitative research. By calculating the areas that are suitable for the growth of ginseng and identifying the counties in which those areas are located, students were able to rank the counties with the largest appropriate areas. The map, as well as the statistical tables students produced, provided them with the evidence to answer the enquiry question. In summary, it is found that short-term or one-off GIS workshop is a highly effective way to equip participants with a basic understanding and skills of GIS.

5.2 The undesirable effects of the workshop to improve spatial thinking skills

The statistical results and the students' feedback demonstrated that no significant enhancement of spatial thinking skills happened after they implemented this two-hour teaching experiment. The second part of the discussion aims to sort out the limitations of lesson design and provides constructive suggestions for further studies.

5.2.1 Overemphasising learning software at the expense of spatial thinking

It is the nature of a GIS course to use GIS software that has a complex interface and various functions and thus requires a certain level of IT skills. Unfortunately, these powerful spatial technologies can lead to a common lapse in lesson design. The theoretical understanding of spatial problems, the science underlying them (i.e., Geographic Information Science), and the value of spatial data can often be neglected in GIS modules in favour of developing the technical skills associated with using software (Bearman, Jones, André, Herculano & Michael, 2016). While students are expected to reason logically and spatially and be able to clearly explain the outcomes of the spatial analysis, the skill-based workshops that demand a few spatial cognitive processes are not able to help them think spatially. The participants elaborated on the situation,

> *When multiple layers are overlaid, students may know what a single step is doing, but they may not be able to say what spatial information the map brings to us.*

> *You get detailed instructions from the workshop. Each step is simple. I just click this, that, and do them. Although the logic was explained, the time was mostly spent on these clicks. Maybe only follow the steps, rarely learned what spatial thinking is.*

Without explicitly focusing on spatial-thinking techniques and integrating geographic inquiry, it should not be assumed that GIS will promote spatial thinking or content understanding (Sandra & Bednarz, 2016). More could be done to improve students' spatial thinking skills. Firstly, there could be more questions to guide students to describe and explain spatial distribution or compare maps. These questions could be asked in each step. For example, when students add the annual average temperature map and the DEM into the ArcGIS, they can be asked to compare the two maps and try to explain why northern Jilin with higher latitudes is warmer than southern Jilin. This is a high-order thinking question that can be broken down into four minor questions: a) Visualise the annual temperature map to identify the spatial variation of climate, b) Visualise the digital elevation model to identify the terrain of Jilin province, c) Compare the elevation of northern and southern Jilin, d) apply the geography knowledge to explain the spatial distribution of annual average temperature. In the process of asking geography questions, students practice spatial thinking skills, including associating and correlating spatially distributed phenomena, comparing maps, and visualising spatial information.

Secondly, although most GIS courses provide step-by-step instructions to help students cope with the new technology, avoid the feeling of frustration, standardise students' practice and therefore save time, it is controversial whether such detailed instructions are helpful to enhance their spatial thinking skills. According to the observation and the interviews, it was found that this kind of thoughtful scaffolding may not be necessary or beneficial for students.

I think the step-by-step guide could be reduced a bit, and there could be more sessions for us to think about how to proceed next.

For example, if there are some repetitive steps, such as inputting the values in the reclassification to reclassify slopes and the selected area, students only need an example to illustrate the logic of this tool and try the functions by themselves rather than detailed steps. Excessive instructions can also deprive students of opportunities to do spatial cognitive processes independently, leading to a heavy emphasis on learning software.

The third explanation for the failure is the absence of reflection as the final stage of geography inquiry due to the time limit. Students need leading questions to recap their learning experience: What have we learned? Have the major research questions been addressed? Furthermore, critical thinking skills (Committee on Geography, 2000) are developed in the course of analysing the quality of research results and how enquiry could be improved and developed (Robert, 2013). By asking about the accuracy of data sources, reflecting on the methodology, and evaluating whether the map generated can exactly represent the situation in the real world, students are encouraged to think deeply about the geospatial analysis. It is noteworthy that the 15th question in testing students' critical thinking is the only question whose average score decreased after the intervention, alarming the risk of exaggerating the technology without reflective thinking. As a result, the stage of reflection should be incorporated into the lesson design, but this needs more teaching periods.

5.2.2 Insufficient learning experiences

One of the limitations of the study is the short duration of the teaching experiment. The one-off workshop, as a pilot study, may not be able to reflect the potential benefits of GIS learning on spatial thinking skills. With reference to the time span of related studies, the effectiveness of GIS can be statistically observed after learning for several days or a semester (Sam & Alec, 2020; Lee & Robert, 2009; Liu et al., 2019; Sandra & Roberts, 2016; Bodzin & Cirucci, 2009), during which students have both lectures about the content knowledge and hands-on activities, such as collecting data and mapping. Since spatial thinking skills can hardly be cultivated through repetitive training (Sandra & Bednarz, 2016), it should not be surprising that the two-hour site suitability analysis made little difference to students' spatial thinking skills. This accounts for the statistical result and is supported by the participants.

> *I found this to be mediocre because I probably only used the software for about an hour and didn't experience a lot of analysis. Maybe it's not that helpful in developing spatial thinking.*

With increasing recognition of the encouraging effects of GIS learning, more secondary schools or universities are setting workshops or curriculums introducing this technology.

However, in the context of tight teaching schedules, which are common in high school education, the GIS educations are mostly fragmentary and are delivered in the form of workshops. The implication of the failure of this teaching experiment is that GIS learning cannot cultivate the spatial thinking skills that it is expected to achieve if students only have limited chances to try out the technology.

5.3 Limitations

With regard to the research methods, some limitations need to be acknowledged. First, the one-group pretest-posttest study design is sometimes regarded as a poor experimental design. With no control group, the internal validity of the test faces particular threats, such as instrument reactivity. Although the participants could not check their answers in the pre-test, the same test questions still heavily influenced how participants responded to the post-test. In addition, there could have more questions testing students' spatial thinking skills, which may help to better examine how students think spatially. Finally, a single workshop did not have the opportunity to do progressive cycles of verifying the effectiveness of the suggestions proposed.

6. Conclusion

The main goal of the current study was to determine whether GIS learning has a positive effect on students' spatial skills and what are the characteristics of optimal design of a GIS class. The statistical results have shown that a two-hour GIS workshop has a significant effect on GIS skills but makes no significant difference to students' spatial thinking skills. However, this study does not deny the value of GIS learning but asserts that certain instructional strategies are essential to teaching students spatial thinking skills (Bednarz, 2004). The geography inquiry cycle was applied to analyse the instructional design. To begin with, creating a need to know, there should be a geography-specific inquiry question that could be facilitated by GIS while the feasibility of inquiry should be considered. Next, every student should have the opportunity to use the software and do an investigation in a semi-professional manner. To motivate students and teach spatial analysis, the significance of each step needs to be clarified. Next, in a confirmation inquiry in which data are readily provided for students, students can learn how to classify data with an introduction to the types of spatial data. Thirdly, the type of GIS inquiries decides how to make sense of all data. Questions encouraging spatial thinking skills are equally important as GIS skills. The visualisation of spatial data as well as overlaying maps, helps the student to recognise spatial patter, associate spatially distributed phenomena and compare maps. Finally, the reflection is integral to the inquiry, which contributes to critical thinking skills and a deeper understanding of geospatial sciences.

This research also holds a critical attitude towards the traditional designs of GIS learning. The findings of the study suggest that step-by-step instructions are not necessarily beneficial for the development of spatial skills. Instead, independent learning and free exploration of GIS should be allowed. Admittedly, GIS teaching and learning is time-consuming, and multiple modules that span weeks or months are necessary to see improvement in students' spatial thinking skills.

The empirical findings in this study provide a deeper and more pragmatic insight into the lesson design of GIS lessons, in particular, how to incorporate GIS into inquiry-based learning in geography. Discussions elaborate on each step in formulating a meaningful GIS class, which may help preservice and present teachers to face the contemporary trends in geography education. There are still tremendous needs for the development of pedagogy and instructional materials in GIS learning that withstand long-term classroom tests. Such a study can help to further theory on spatial thinking processes while also providing the framework for more applicable approaches to teaching and learning.

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Appendix I

GIS Workshop Pre-test
In total 20 multiple choice questions

GIS 工作坊前测
总共有 20 道选择题

Part A. General understanding of GIS and spatial data
甲部. 对于 GIS 和空间数据的基本理解

1. What does GIS refer to?
   GIS 的全称是？
   A. Geoscience Interpolation System 地球科学插值系统
   B. Geoscience Inference Software 地球科学推测软件
   C. Geographic Information System 地理信息系统
   D. Geographic Interpolation System 地理插值系统

2. Which of the following is(are) (an) essential component(s) of a GIS?
   以下哪项是 GIS 的必要组成部分？
   A. Satellite 卫星
   B. Spatial data 空间数据
   C. Printer 打印机
   D. Internet 互联网

3. Which of the following processes is not involved in a GIS?
   以下哪项不能在 GIS 中进行？
   A. Map generation 生成地图
   B. Data visualization 数据可视化
   C. Spatial analysis 空间分析
   D. Probability Calculation 计算概率

4. Which of the following problems cannot be solved with GIS?
   以下哪一个问题不能用 GIS 解决?
   A. Figuring out the most vulnerable regions during a flood
      找出容易收到洪水威胁的地区
   B. Comparing the distribution of universities in different cities
      对比不同城市中的大学分布
   C. Selecting a favorable site for a new shopping mall
      为一个新的购物中心选址
   D. Testing the significance of variables
      测试变量的显著性

5. Which of the following statement is not true?
下列哪一个描述是错误的?
   A. The area of a polygon is a kind of attribute data
      多边形的面积是一种属性数据
   B. The lines showing underground network are examples of spatial data
      表示地铁网络的线是一种空间数据
   C. A matrix of cells consist of raster data
      像元的矩阵构成了栅格数据
   D. Remote sensing pictures are mostly vector data
      遥感数据大都是矢量数据

Part B. GIS skills
乙部. GIS 技能

6. Which of the following statement(s) about DEM data is(are) not true?
下列哪一个关于 DEM 数据的描述是错误的?
   A. DEM data refers to Digital Elevation Model
   DEM 指的是数字高程模型
   B. DEM data is a kind of vector data
   DEM 数据是一种矢量数据
   C. DEM data is frequently used in surface analysis
   DEM 数据经常被用于表面分析中
   D. The value of DEM data can be negative
   DEM 数据的数值可以是复数

7. Which of the following cannot be generated from DEM data?
以下哪一项数据不能由 DEM 数据生成?
   A. Length of polygons 多边形的周长
   B. Aspects 坡向
   C. Slope 坡度
   D. 3D terrain model 3D 地形模型

8. Which of the expressions in raster calculator can correctly extract the rasters whose values are between 111 and 888 in the layer “precipitation”?
以下哪一个地图代数表达式可以正确地提取出“降水”图层中降水量∈[111,888]的区域?
   A. 111≤“precipitation”≤888
   B. (“precipitation”≥111)|(“precipitation”≤888)
   C. (“precipitation”>=111)|(“precipitation”<=888)

D. （“precipitation”>=111）&（“precipitation”<=888）

9. There are four layers “proper_a”,”proper_b”, “ proper_c”, and “proper_d”, which are all consist of raster data. If you want to extract the intersections of these four layers, the expressions in raster calculator should be:

现在有四个图层 “proper_a”,”proper_b”,“proper_c”, 和 “proper_d”, 他们都是栅格数据。 如果需要提取这四个图层的交集部分，在栅格计算器中的表达式是:

A. “proper_a”+”proper_b”+“proper_c”+ “proper_d”

B. “proper_a”&”proper_b”&“proper_c”&“proper_d”

C. “proper_a”==”proper_b”==“proper_c”== “proper_d”

D. “proper_a”*”proper_b”*“proper_c”*“proper_d”

10. If you want to delete the data whose value=10 and reserve the data whose value=20 through reclassification, which of the tables shows the correct inputs?

如果你希望通过重分类删除一个栅格图层内值为 10 的数据，并保留值为 20 的数据，哪一个表的输入数值是正确的？

A.

Old value 旧值	New value 新值
10	0
20	1

B.

Old value 旧值	New value 新值
10	1
20	0

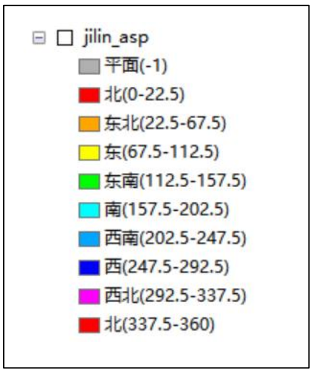
C.

Old value 旧值	New value 新值
10	NoData
20	1

D.

Old value 旧值	New value 新值
10	0
20	NoData

11. Which tables can extract the slopes that facing south and southwest through reclassification?
根据该图层的数值分类，以下哪一个表可以通过重分类提取出南坡和西南坡的数据？



A.

Old value 旧值	New value 新值
-1	NoData
0-157.5	NoData
157.5-247.5	1
247.5 - 360	NoData

B.

Old value 旧值	New value 新值
-1	NoData
157.5	NoData
157.5-247.5	157.5-247.5
202.5 - 360	NoData

C.

Old value 旧值	New value 新值
-1	0
0 - 157.5	0
247.5	1
202.5 - 360	0

D.

Old value 旧值	New value 新值
-1	1
0-157.5	1
157.5-247.5	0
202.5 - 360	1

12. Which tool can transfer raster data to vector data?
以下哪一个工具可以将栅格数据转化为矢量数据？

A. Raster to polygons 栅格到面

B. Reclassify 重分类
C. Raster calculator 栅格计算器
D. Identity 标识

13. The identity analysis can be applied to which set of data?
    标识功能可以用于哪一组数据的叠加分析中？
A. Polygon A and polygon B
   多边形 A 和多边形 B
B. Dem of Jilin Province and polygon A
   吉林省的 DEM 数据和多边形 A
C. Dem of Jilin Province and the land cover data(raster data) of Jilin Province
   吉林省的 DEM 数据和土地覆盖数据(土地覆盖数据为栅格数据）
D. Land cover data and polygon A
   土地覆盖数据和多边形 A

14. Which of the following statements is correct?
    以下哪个选项的表述是正确的？
A. You can find a tool in【Arctoolbox】to calculate the areas of polygons
   你可以在【Arctoolbox】中找到计算多边形面积的工具
B. Areas of polygons can be calculated in the attribute table of a layer
   你可以在图层的属性表中计算多边形的面积
C. Areas of polygons can be negative numbers
   多边形的面积可以是负数
D. You can only calculate the sum of values in the attribute table
   你只能在属性表中计算字段中值的总和

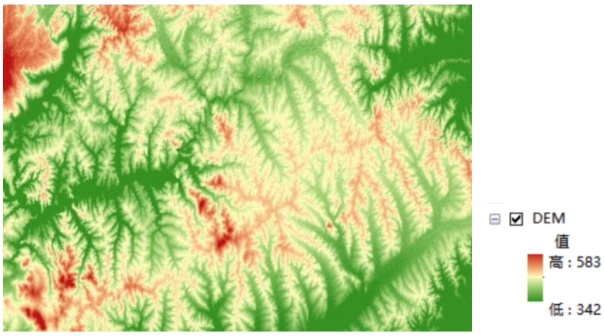
15. Which of the following statements is incorrect?
    下列哪个表述是不正确的？
A. The accuracy of spatial analysis is influenced by the resolution of raw data
   原始数据的分辨率会影响到空间分析的准确性
B. The site suitability analysis can be applied in various subjects, such as environment sciences, urban planning, and archeology.
   选址分析可以被广泛运用到各个学科中，例如环境科学、城市规划和考古学
C. The map generated by Arcmap can exactly shows the situation in real world
   用 Arcmap 生成的地图可以非常准确地反应现实世界的情况
D. Wrong sub-steps of spatial analysis lead to inaccurate results
   错误的空间分析步骤会导致最终分析结果的不准确

Part C. Spatial literacy

丙部. 空间思维能力

16. Which picture best matches the terrain dem shows?

哪张图最符合下图 DEM 展现的地形特征？



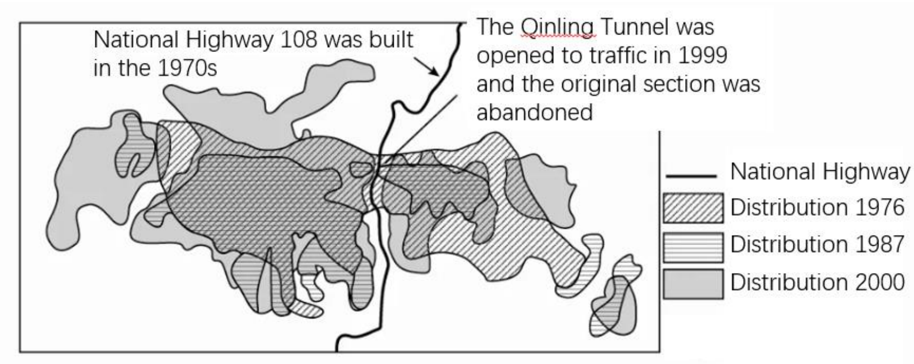
A.

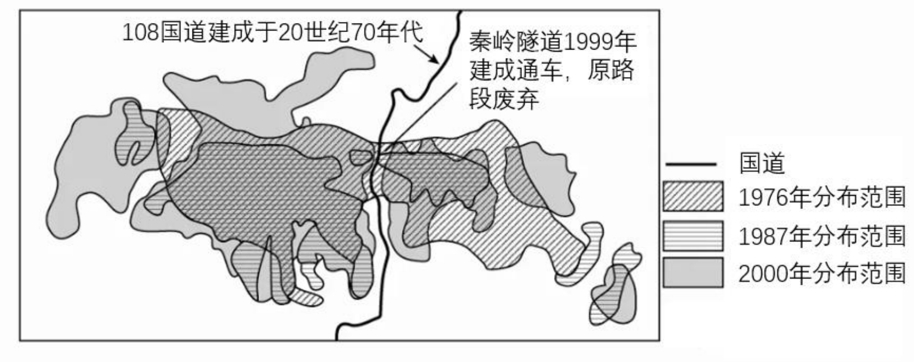
B.

C.

D.

17. The Qinling region a key area for the distribution of giant pandas in China. The area was once an important forest logging area, with a number of forestry enterprises carrying out logging operations in the area from the 1970s onwards, before natural forest logging was completely stopped after 1998. The map below illustrates the changes in the extent of giant panda habitat in the area in 1976, 1987 and 2000.
陕西南部的秦岭地区是我国大熊猫分布的重点区域。该地区曾经是重要的林木采伐区，20 世纪 70 年代开始，先后有多家森工企业在该区内进行采伐作业，1998 年后全面停止采伐天然林。下图示意 1976 年、1987 年和 2000 年该地区大熊猫栖息地范围的变化。





According to the materials given, which of the following description or inference is not correct?
根据题目所给材料，以下选项的描述或推断不正确的是？

A. The panda's habitat was significantly reduced in extent and fragmented into patches in 1987
到 1987 年大熊猫的栖息地面积退缩，碎片化严重

B. Large-scale deforestation has led to habitat shrinkage and construction of roads has led to habitat fragmentation
大规模采伐森林导致栖息地缩小，修建道路导致栖息地碎片化

C. The panda's habitat gradually expanded again around 2000, with a marked expansion to the south and west.

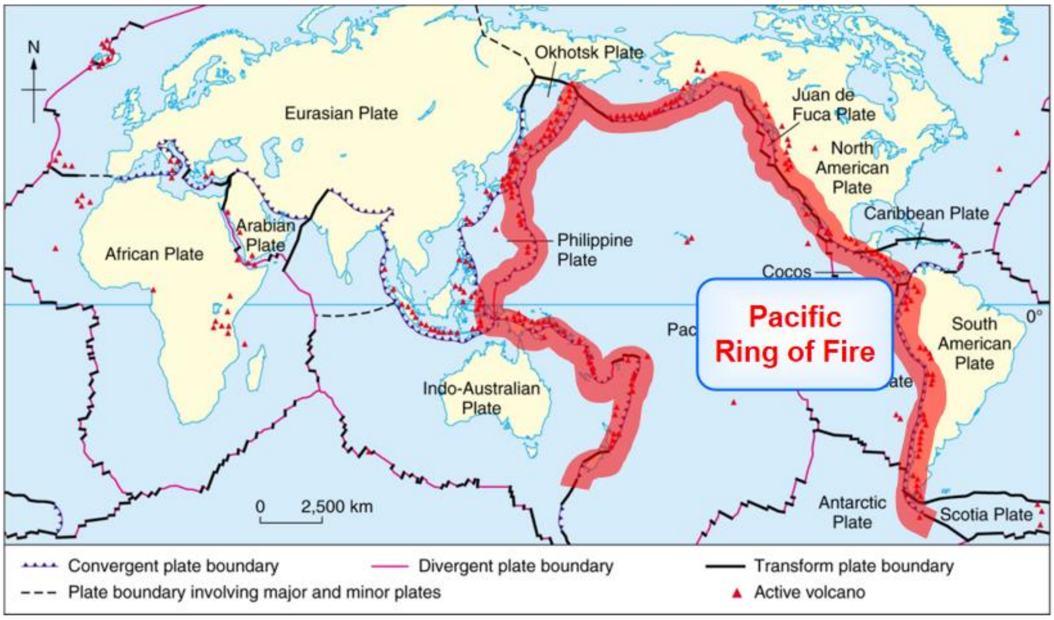
90年代至21世纪初(2000年)，栖息地面积有所增加，碎片化趋势减弱，分布范围有向南、向西扩展的趋势

D. The opening of the Qinling Tunnel facilitated the recovery and expansion of giant panda habitat.

秦岭隧道通车促进大熊猫栖息地的恢复与扩展

18. According to the world tectonic plates map, which of the following statement is not correct?

根据世界地质板块地图，以下选项中错误的是？



A. Pacific Ring of Fire mainly consists of convergent boundaries

环太平洋火山带主要由聚合型板块边界组成

B. All the earthquakes are found near the plate boundaries

所有的地震都发生于接近板块边界处

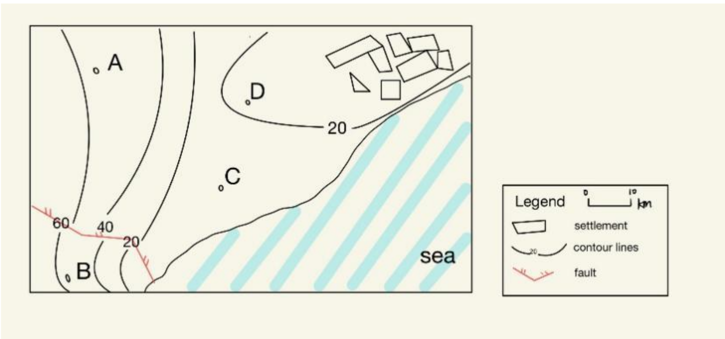
C. Most active volcanoes are found at divergent and convergent plate boundaries.
绝大多数的火山位于聚合型以及张裂型板块边界

D. Volcanoes can also be found above hot spots
在地质热点处也存在火山

19. In order to minimize the possible negative impacts of nuclear leakage and cool down the reactors, nuclear power should be constructed
- in the tectonically stable areas (far from fault lines, earthquake and volcano belt)
- near the sea
- built on the flat land
- avoiding residential areas.

为了减小核泄漏的可能危害以及冷却反应堆，核电站应该建于
- 地质稳定的地区（远离断层线，地震以及火山带）
- 近海
- 在平坦的土地上
- 避免住宅区

According to the requirements, which site is the most ideal site for a nuclear power plant?
根据以上要求，地图上的哪一个位置是建造核电站最为理想的位置？



A. A
B. B
C. C
D. D

20. Figure 1 shows the current coastline of Sai Kung Town. Figure 2 shows the layout of Sai Kung Town in 1967. Compare two maps, which building is built on reclaimed lands?
图 1 为西贡现今的海岸线。图 2 显示了 1967 年西贡的空间布局。对比两张地图，以下哪个建筑是建在填海的陆地上的？

A. Tang Shiu Kin Sports Ground
B. Sha Tsui Playground

C. Police station
D. Hong Kong academy

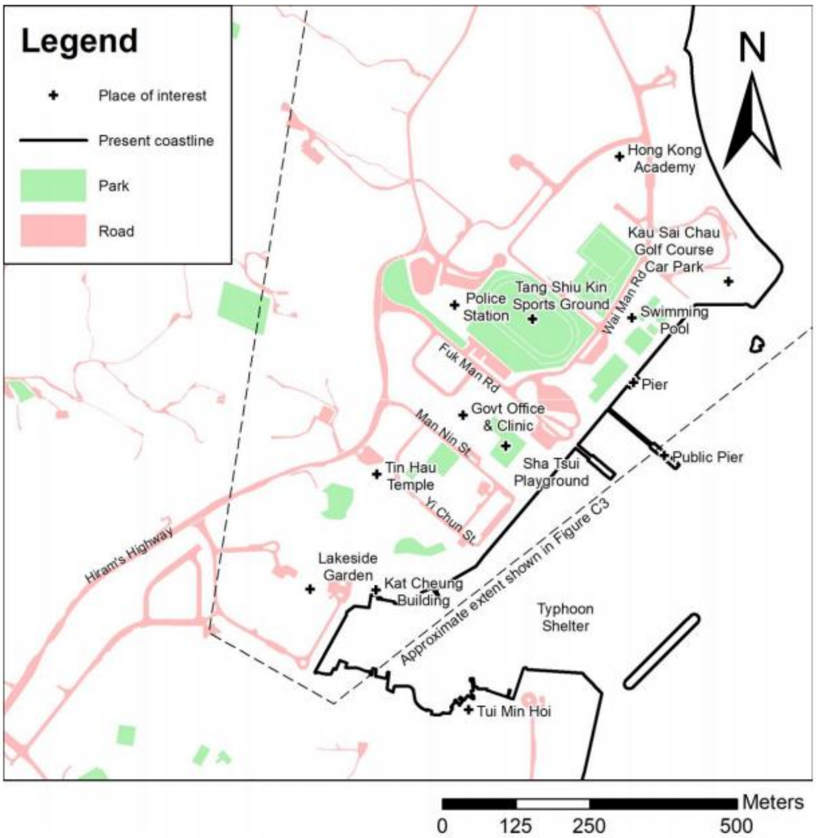


Figure C1: Current Coastline of Sai Kung Town.

图 1

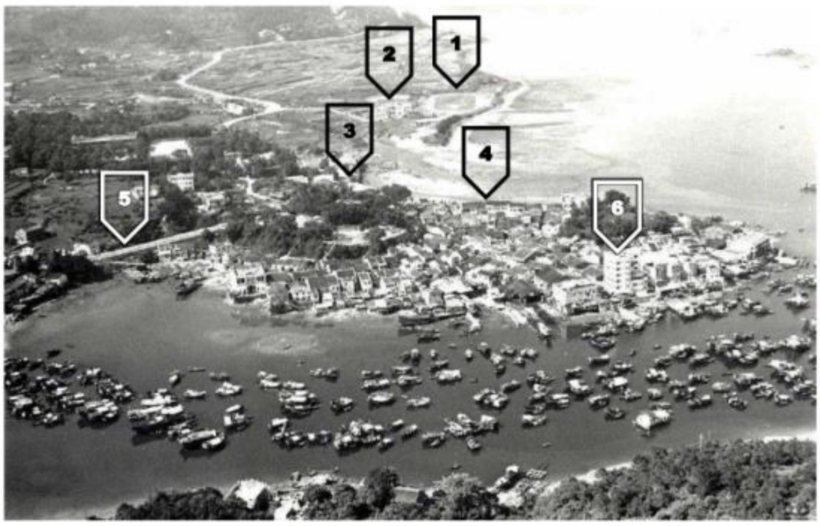


Figure C3: Sai Kung Town, 1967. 1: Sports ground; 2: Police station, 3: Tin Hau Temple 4. Yi Chun Street nowadays; 5: Hiram's Highway nowadays; 6: Kat Cheung Building.

图 2