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Enhancing Geographical Thinking Through Multimedia Spatial Visualization: A Study of Chinese High School Geography Learning

Shuchang Zhang

Institute of Foreign Languages, Southwest Jiaotong University, Chengdu, China
shuchangzhang916@gmail.com

Abstract. Under the trend of digitalization of education, multimedia spatial visualization has become a key driving force for geographical education innovation. Based on twelve core studies and two representative teaching cases, this article discusses how multimedia-based visualization can cultivate geographical thinking in Chinese high school classrooms. The research results show that tools such as GIS, animation and interactive models effectively reduce the cognitive load, enable students to participate in the construction of spatial characterization through visual interaction, and promote the transformation from vision and memory to vision and reasoning. Its core mechanism lies in the cognitive support provided by multimedia, which supports students to understand the spatial relationship and systematic connection between geographical phenomena through visualization, situational and inquiry-based learning. However, challenges still exist, including the limited digital capacity of teachers, regional differences in resources, and the lack of vertical empirical data. The study concludes that multimedia spatial visualization is not only a technological enhancement, but also a teaching bridge connecting cognitive development and geographical thinking cultivation, which provides valuable inspiration for high school geographical innovation and educational modernization.

Keywords: multimedia spatial learning, geographical thinking, high school geography, geography education reform, digital learning

1. Introduction

1.1. Current situation and research issues

In Chinese high schools, geography teaching is still mainly examination-oriented and content-oriented, emphasizing the coverage of textbooks, rather than cultivating geographical thinking and spatial reasoning ability [1]. Students often memorize facts without developing the ability to explain spatial patterns or causal processes. Xia pointed out that it is usually difficult for students to integrate time and space perspectives in comprehensive test questions, which reflects that they focus more on results than reasoning [2]. At the same time, the classroom use of multimedia is often at the

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display level—video, slideshow or static map—without making full use of its cognitive and interactive revelation.

Against this background, improving students' spatial understanding ability through multimedia spatial visualization has become an urgent teaching problem. Therefore, this study explores the following research issues: How to define and apply multimedia spatial visualization tools or strategies in existing geography education research? In the context of Chinese high school, how can these tools cultivate students' spatial understanding and geographical thinking? What teaching or technical challenges do teachers face when implementing this kind of teaching? Which visualization design elements and teaching strategies are the most effective in promoting geographical thinking?

1.2. Educational opportunities for multimedia space visualization

With the development of digital maps, three-dimensional models—animation and GIS technology, geography education is shifting from static teaching to dynamic visualisation. Multimedia spatial visualization helps students to concretize abstract geographical processes and cultivate a deeper understanding through the interaction of "seeing" and "thinking". Fan found that digital tools reduce the cognitive load by providing manipulable visual feedback, while Yang proved that animation and interactive models can allow students to actively explore landform changes, not passive memory [3, 4]. Similarly, Titus and Horsman showed that spatial visualization training can improve students' spatial imagination and operational skills [5]. With the increase of interaction and feedback, these tools are becoming an indispensable part of effective geography teaching.

1.3. Theoretical and practical significance

Theoretical and practical geographical thinking including spatial location, spatial relations, systematic reasoning and regional understanding is the core of geography education [6]. International research has identified it as a common cross-curriculum reform goal [7]. However, in Chinese high schools, there is still limited research on how multimedia spatial visualization cultivates this kind of thinking. Theves revealed the neural connection between analogy and spatial processing, indicating that visual and interactive learning can promote higher-order cognition [8]. The research of Zhang et al. and Wang et al. shows that teaching based on multimedia can enhance the participation and transfer of spatial understanding [9, 10]. Based on the intersection of this theory and practice, this study explores how spatial visualization can transform students from "seeing and remembering" to "seeing and reasoning", contributing to the digital transformation of geography education.

1.4. Research logic and feasibility

The logic followed by this study is that multimedia spatial visualization tools and teaching strategies stimulate students' spatial experience and cognitive processing through visual, auditory and interactive channels, so as to enhance geographical thinking, including spatial location, systematic reasoning and regional understanding, and ultimately improve participation and learning effects. Based on existing academic research at home and abroad, this research does not require new experimental data. China's existing digital pedagogy and geographical thinking research and the international work on spatial visualization and cognition together provide a solid theoretical foundation. By integrating these findings, this study has developed a feasible analytical framework to study how spatial visualization based on multimedia can promote geographical thinking and support the modernization of geographical education in China.

2. Theoretical framework

2.1. Multimedia learning theory

Mayer's multimedia learning theory emphasizes that learners process information through two channels—visual and auditory [11]. Given the limited attention and working memory, teaching materials must balance these channels to support understanding and memory. In the geography class, combining visual materials such as maps, topographic models and climate maps with teachers' narratives helps to transform abstract concepts into concrete spatial understanding. Fan Xiaojing found that digital teaching tools reduce the cognitive load of learners to understand spatial structures through image and action feedback [3]. In addition, Mayer's design concepts, such as the principles of continuity and coherence, guide us on how to make learning materials. For example, when explaining the "earth's movement", animation is combined with oral interpretation, so that students can master time changes and space movements at the same time, so as to clarify the day and night and seasonal cycles [10]. Therefore, when analyzing spatial visualization based on multimedia, the focus of this study is on whether visualization really helps students see potential geographical logic rather than distracting them with too many visual elements.

2.2. Spatial visualization ability

Spatial visualization is the foundation of learning geography. It refers to the ability to mentally rotate, imagine and manipulate spatial graphics. Titus and Horsman pointed out that this ability directly affects students' understanding of core topics such as topography, climate patterns and regional relations [5]. In traditional classrooms, geography often appears in two-dimensional diagrams, allowing students to imagine three-dimensional structures by themselves. Multimedia visualization creates opportunities for "three-dimensional" learning. In a study on landform teaching, Yang Dongyue showed that animation and interactive models encourage students to actively explore the landform process rather than memorizing landform types [12]. European scholars [6] also believe that maps, images and models are not just display media; they are bridges to help students understand spatial relationships. Therefore, spatial visualization and graphics are not just learning the skills of geography; they are the starting point for cultivating geographical thinking. Multimedia technology enables students to transform spatial structure into understandable knowledge by "doing" and "seeing".

2.3. Cultivating geographical thinking

Cultivating geographical thinking is the core goal of geography education. It includes spatial location as well as systematic thinking and regional connectivity to understand the relationship between geographical phenomena. Bendl, Marada and Krajáková divide geographical thinking into three levels: spatial cognition, process understanding and scale awareness.More simply speaking, geographical thinking is about whether students can distinguish distribution, interpret mechanisms and flexibly switch perspectives between local, national and global scales [6]. In China, although high school geography emphasizes systematic knowledge, students often lack cross-level spatial reasoning. Xia Fei observed that it is difficult for students to combine time change with spatial distribution in comprehensive questions [2]. Yang Zhixiao and others proposed a hierarchical

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concept mapping method to help students establish logical connections between concepts [4]. This model provides evaluation perspectives for our research: does multimedia spatial visualization shift students from "reading map memory" to "reading map thinking"? Does it help them build a more systematic spatial understanding?

2.4. Constructivist learning theory

Constructivism believes that learning is not a passive acceptance but an active construction of meaning by learners. In geography, this means that students should explore, manipulate and reflect to understand spatial relationships rather than just relying on lectures. Zhang Zhenhua and others found that when students carry out geography-related exploration tasks on multimedia platforms, they are more likely to form a personal understanding path and show higher motivation [9]. From a cognitive perspective, Theves showed that analogy and spatial processing will recruit overlapping neural matrix, indicating that visual analogy learning helps to make abstract geographical relationships concrete and understandable [8]. Therefore, the multimedia visualization environment not only provides information, but also provides opportunities to learn while doing, in which students act, observe and reflect on iteratively to grasp the logic behind geographical phenomena.

3. Case analysis based on different teaching content

3.1. Use GIS for urban spatial analysis teaching

In multimedia spatial visualization research, GIS has been widely used to improve students' spatial cognition and geographical thinking. In "Using GIS to let students learn the relationship between urban elements through spatial analysis", Wang studied a middle school geography course which used ArcGIS to investigate the spatial relationship between house prices and urban characteristics [13]. This lesson concentrates on problems in daily life. For example, "Why are the house near the school or the subway line more expensive?". The lesson uses this kind of question to guide students to analyse spatial data. After introducing the spatial data type and its representation in GIS, the teacher led the students to build vector and raster layers and colour code attributes for house prices, traffic corridors, schools and hospitals. The core task is to use interactive map operations—scaling, layer overlay and attribute query—to observe clustering and distribution patterns, so that the neighbourhood and geographical causality are visible, helping to turn observation into reasoning.

During the activity, students gradually formed a "look-ask-explain" learning framework which constructed their exploration process. In the "look" stage, students intuitively checked the spatial patterns on the digital map and identified abnormal situations such as price clusters or discontinuity. In the "question" stage, they raised geographical questions based on these observations, such as whether urban accessibility or land use can explain these spatial changes. Finally, in the "explanation" stage, students integrated evidence from multiple map layers and attributes, put forward explanations and test their hypotheses, and link spatial distribution with socio-economic mechanisms. Through these iterative cycles of visualization, questioning and reasoning, students have developed a higher level of spatial cognition—from simple pattern recognition to relationship and causal analysis. Teachers reported that students began to verbally express spatial reasoning and use map-based evidence to prove their conclusions, which show a significant improvement in their depth of analysis and conceptual understanding.

In summary, the whole implementation is divided into three stages: pre-class GIS basic knowledge and problem framework; group-based spatial analysis in the classroom; after-class reflection reports and demonstrations. Research results show that students not only develop technical skills, but also have a deeper understanding of spatial interdependence. The survey shows that students believe that GIS transforms geography from memory to investigation, while teachers observe stronger concept formation and more advanced reasoning. The case indicates that multimedia spatial visualization transforms abstract spatial relationships into manipulable learning content and stimulates exploration, although communication is limited by licensing, teacher training and technical thresholds. Future implementation should simplify the operation, strengthen teachers' media integration ability, and make GIS a thinking framework, not just a display tool.

3.2. Design interactive E-school - labelling geographical resources

In addition to professional software, another direction is to build context-rich and interactive digital resources. In the project that called "The Design of Interactive Digital Learning Resource in Middle School Geography for E-School Bag Pilot School", Guo designed and implemented a Chinese middle school geography e-book package project to transform the content of textbooks into visual and operable learning situations on tablets [14]. A unit on "Terrain Evolution in Daily Life" embeds textbook ideas into a digital platform that conforms to Meyer's principles, integrating text, dynamic animation and interactive controls. Students click on images, run animations, and drag sliders to observe processes such as erosion and deposition or valley formation. The teacher did not lecture but encouraged exploration. For example, "Why is the lower course more flat?","What factors will affect the erosion rate?". In this way, practical experience becomes an explanation. The project was jointly developed by teachers and researchers, and after multiple rounds of pilots, students were allowed to complete group tasks on tablets and display the research results after simulation. The results showed that interest and participation increased significantly; teachers reported that animation accelerated the understanding of continuity and system dynamics in geomorphology, while students asked more questions and sought explanations. Limiting factors include limited technical support in some classrooms and the risk of distracting from overly complex interfaces.

The key insight is that the value of multimedia lies not in complexity, but in cognitive guidance. Teachers must balance learning objectives and interactive design so that multimedia can become a bridge for understanding mechanisms, not just visual wonders. In comparison between the two cases, GIS and e-School-Bag showed two different but complementary ways to support the transformation from perception to reasoning. GIS emphasizes real spatial data and pattern recognition, allowing students to discover geographical laws through real-world mapping and quantitative analysis. In contrast, the e-School-Bag platform focuses on process simulation and interactive visualization, enabling students to explore dynamic geographical phenomena and construct interpretations through manipulation and reflection.

Although these two methods are formally different, they both emphasize the basic cognitive transformation from observation and interpretation—from visual perception to conceptual understanding. In this transformation, teachers' questions and task design play a decisive intermediary role. In the GIS case, teachers guided exploration through problem frameworks and progressive questions, prompting students to identify spatial anomalies, hypothesise relationships and to use map-based evidence to prove conclusions. In the E-School-Bag case, teachers organize scaffolding exploration tasks and provide instant feedback in interactive operations to help students link the observed processes with geographical mechanisms. Therefore, although technology provides a medium, teaching design—how teachers shape problems, organize exploration and respond to learners—determines whether visualization really supports reasoning. Finally,

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accessibility and digital capabilities are still practical constraints and need to be adjusted locally to balance innovation and feasibility.

4. Pedagogical implications

4.1. Teaching design and classroom organization

For Chinese high school geography, spatial visualization based on multimedia should be organized around problem-driven, visual-supported and inquiry-oriented learning. Visual display alone does not guarantee understanding; what matters is whether the task will prompt learners to shift from observation to thinking [11, 13]. Teachers should first align the course objectives with the key dimensions of geographical thinking—spatial position, spatial relations, systematic thinking and regional connections, and reorder the content of the textbook into problem scenarios that trigger reasoning (for example, “Why is the lower course more flat?” “Why do urban functions gather?”). Visual materials must control the information density, follow the principles of cognitive load and coherence, and use maps, animations, models or GIS platforms to create a manipulable environment for students to observe, compare, explain and reflect [11]. As Fan pointed out, the function of visualization is to help students see changes and patterns, so that they can shift from emotional understanding to conceptual understanding [3].

4.2. The role and professional support of teachers

In the multimedia visualization course, teachers’ role changes from knowledge transmitters to designers and facilitators of learning. Their main responsibility is to transform technical tools into thinking tools. In order to achieve this goal, teachers must design visualization tasks directly related to conceptual structures and learning goals. The “big concept hierarchical mapping” proposed by Yang Zhixiao and others emphasizes that teachers should first clarify the conceptual relationship before choosing the appropriate media form (such as dynamic maps, interactive models or data overlay) to guide exploration [4]. In the process of implementation, teachers play a crucial role in constructing a sequence of exploration—asking layered and progressive questions and guiding students to interpret from observation [14]. Through problem-driven scaffolding and group collaboration, teachers can help learners identify spatial patterns, test hypotheses and clarify geographical reasoning. They should also prevent multimedia from becoming a passive “visual display”, but ensure that each visualization activity has a clear cognitive function to deepen students’ geographical understanding [9].

Although teachers’ design ability is crucial, systematic institutional support is equally important to ensure the sustainable and effective use of multimedia visualization. Schools and education authorities should provide targeted professional development, integrating technology and teaching levels. The training plan should include basic software operation, data processing skills and cognitive load management strategies [10]. In addition to technical proficiency, teachers also need opportunities for cooperative reflection, such as course study groups or peer seminars, to exchange effective visualization practices and align them with course objectives. At the policy level, investment in digital infrastructure, resource sharing platforms and continuous counselling can further help teachers transform multimedia technology into a real cognitive framework and cultivate a higher level of geographical thinking.

4.3. Student support and differentiation

Learners' performance in spatial visualization depends on their baseline spatial ability and operational fluency, so teaching must support different levels. Students with weak spatial skills need guidance and step-by-step operation; otherwise, the rich visual environment will make them overwhelmed [5]. Teachers can provide simplified maps or models to reduce layers and interference to cultivate core observation skills, while students with stronger skills can handle open analysis—custom parameters or extended areas—to cultivate creativity and comprehensive ability [12]. Constructivism emphasizes the time of hands-on operation and reflection [9]; group work makes it possible to compare and modify ideas. In view of the neural connection between analogy and spatial processing, teachers should encourage the analogy between observed patterns and life experiences to deepen understanding [8]. Through differentiated and exploratory design, students at different levels can find the appropriate rhythm and progress of reasoning from observation.

4.4. Assessment system and feedback

Assessment must match the goal of cultivating geographical thinking. Traditional selective response tests rarely capture the obvious thinking in visual enrichment learning, so it requires process and performance evaluation. The hierarchical mapping method can measure the growth of students' spatial relationships and systematic thinking when constructing conceptual/process diagrams that show causal logic [4]. Wang said that visual products (map layers, animation frames) are required to have a concise explanation, which helps teachers judge the depth of understanding [13]. Chen Zhibin suggested "immediate inspection microtasks", and teachers should evaluate the operation steps and oral reports in real time [1]. To ensure fairness and continuity, evaluate the ability to track operations, interpret and transfer. At the school level, reflective practice—course video review and peer review—can consolidate effective methods and improve ineffective methods. As Bendl and others emphasized, the reform of geography education is promoted not so much by the introduction of tools as by the establishment of an assessment system that shifts classroom culture to thinking [7].

5. Conclusion

Based on specific case analysis, this paper concludes that multimedia spatial visualization has great teaching value in Chinese high school geography education. By integrating tools such as images, animation, GIS and interactive models, teachers can transform abstract geographical concepts into concrete spatial representation, thus cultivating students' geographical thinking. The key mechanism lies in the cognitive support provided by multimedia: through visual and interactive participation, students build spatial characterization from vision to reasoning and establish a systematic understanding of geography. This method not only improves spatial perception and analysis ability, but also marks the transformation of classroom practice from knowledge transfer to cognitive construction.

However, there are still some challenges. The limited digital literacy of teachers, the unequal access to resources between urban and rural schools and the lack of longitudinal empirical evidence limit broader adoption. Future researches should include on-site classroom verification, checking the differentiated effects of students with different spatial abilities and strengthening professional training and curriculum support. In general, multimedia space visualization is not only a technological innovation, but also an important way to make geographical thinking visible and learnable.

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