Spatial Thinking and Technologies in the Undergraduate Social Science Classroom

STACY REBICH HESPANHA*, FIONA GOODCHILD** & DONALD G. JANELLE*

*Department of Geography, University of California Santa Barbara, USA, **California NanoSystems Institute, University of California Santa Barbara, USA

ABSTRACT Spatial thinking and analysis have greatly enhanced social science research throughout the past century, but explicit practice of spatial thinking in undergraduate social science courses is still quite rare. New computer technology to handle spatial information offers exciting opportunities that have been discussed at recent NSF-sponsored SPACE workshops on spatial thinking in undergraduate education. The authors discuss insights and strategies that emerged from these workshops in the context of the literature on spatial thinking in education and contemporary cognitive and learning theories. Practical suggestions regarding specific pedagogic approaches and assessment strategies that are proving successful in enhancing social science education are reviewed.

KEY WORDS: Spatial thinking, undergraduate education, social science, learning assessment, archaeology

Introduction—Spatial Thinking in the Social Sciences

Researchers who study human societies and cultures, both past and present, have recognized for some time that examining the distribution of objects and phenomena in physical space is a fundamental key to knowledge and understanding (Kantner, 2003). In fact, the recent history of social science is increasingly characterized by examples of important discoveries that were a direct result of such spatial thought (see CSISS Classics at http://www.csiss.org/classics/ for key examples). Recognition of the usefulness of spatial patterns as a basis for the integration of many social phenomena has certainly helped to enhance the explicit practice of spatial thinking in the social sciences (Goodchild & Janelle, 2004). As spatial thinking techniques and technologies continue to develop, their use is certain to contribute to important new discoveries. However, this development has not yet made any significant
impact on the undergraduate curriculum. In this paper, we focus primarily on the discipline of archaeology in order to provide concrete examples of pedagogical approaches that can be used to help undergraduate students develop spatial thinking skills. These examples are intended to provide social science educators with ideas that are tailored to match the content and perspectives of their respective disciplines. To make the connection with a variety of social science disciplines more explicit, we discuss ideas for problem-solving activities that span a broader range of content areas in the section on learning assessment.

**Example from Archaeology**

An example of spatial thinking from the field of archaeology is the longstanding technique of site mapping. Even within a field that has long given significant explicit attention to location, it took a revolutionary spatial thinker such as archaeologist Gordon R. Willey to transform the standards of thought and practice. During the 1940s and '50s, when most archaeologists had not considered the importance of space beyond basic site mapping or site location, Willey led a research effort in the Virú Valley in Peru that involved the integration of field observations with aerial photographs to create a detailed map of the valley’s archaeological features. Because he recognized that evidence of regional processes could provide important insights into what was happening at the local level, Willey used this comprehensive map to examine settlement patterns in the area. He demonstrated convincingly the value of considering regional circumstances when making inferences about a society’s adaptation to the natural environment, level of technological sophistication, and cultural and social institutions (Sifuentes & White, 2003). Increasingly sophisticated methods of spatial analysis are being used to develop a deeper understanding of archaeological evidence (Aldenderfer & Maschner, 1996; Jimenez & Chapman, 2002), such as in the reconstruction of past human behaviour from prehistoric roadways (Kantner, 2003) or spatio-temporal reconstruction and analysis of archaeological sites in southern Oxfordshire to provide insight into social processes (Daly & Lock, 2004).

The lack of focus on spatial thinking at the undergraduate level is not unique to archaeology but is seen throughout the social sciences, possibly a legacy of the historic costliness and inaccessibility of spatial data and technologies. As spatial technologies such as global positioning systems (GPS) and geographic information systems (GIS) have become less expensive and recorded field observations or remotely sensed data have become more accessible, it behoves educators to encourage their undergraduate students to appreciate the value of spatial thinking and to help them learn to practise some of the techniques that have proved so beneficial to the development of knowledge within their fields.

**Promoting Undergraduate Spatial Thinking**

The Center for Spatially Integrated Social Science began the Spatial Perspectives for Analysis in Curriculum Enhancement (SPACE) programme with the goal of increasing the awareness and practice of spatial thinking in undergraduate social sciences (see Janelle et al. in this issue for background information on CSISS and SPACE).

**Overview**

The themes for this paper reflect the insights gained through planning, developing and implementing the SPACE workshops. Beginning with a summary of the findings of...
researchers on the nature and functions of spatial thinking, we provide a brief overview of some general principles that have emerged from research on learning and education, and focus on ideas that are particularly important to the teaching and learning of spatial thinking. Finally, we present some practical ideas that could be useful in planning learning activities and assessments focused on spatial thinking skills and concepts.

What is Spatial Thinking?

Even though the use of spatial thinking is ubiquitous in everyday life as well as in scientific research, few people are aware of how much they depend on spatial thinking as they carry out normal activities. Most people learn to drive, rearrange their furniture, choose the best route to the beach, remember where they left their keys or locate what they are looking for in the grocery store. However, using spatial thinking to accomplish such tasks is not the same as what has been defined as spatial literacy (National Research Council, 2006). If few people are conscious of their own use of spatial thinking as they perform these tasks, probably even fewer can explicitly describe the spatial concepts or thought processes they use to engage in these and other more abstract spatial problem-solving tasks. We propose that undergraduate educators should focus some effort on helping students achieve higher levels of spatial literacy by designing tools that encourage students to engage in advanced problem-solving in a wide range of social science domains.

Because of recent rapid technological advances, the size of the world in which people interact is changing, spurring a need for a more advanced set of skills and tools for engaging with and learning about this growing space of interaction. The expanding array of location-aware devices now available to the general public, together with the increasing availability of spatial data on a wide range of topics, creates a need for spatial thinkers and a set of rewarding opportunities for those who develop spatial thinking skills. Spatially literate citizens will be able to use these support systems to make more informed decisions about their everyday tasks, professional and leisure activities and decisions concerning public policy.

Educational Developments

Educators who wish to encourage and provide practice with spatial thinking in their courses may benefit from enriching their spatial thinking vocabulary. A rich and precise vocabulary of spatial concepts and processes facilitates communication and exchange of ideas between educators as they work to enhance their curricula. It also helps instructors formulate learning objectives that are specific enough, first, to lend themselves naturally to validation through learning assessment and, second, to be communicated to their students as a part of feedback on their progress. Finally, precise language helps those who have developed curricula to illustrate to colleagues the value of a spatial approach in undergraduate education.

Learning to Think Spatially

A growing interest in understanding the role of formal education in the learning and development of spatial thinking concepts and skills is evidenced by the recently published National Research Council report on Learning to Think Spatially (National Research Council, 2006), the result of a multi-year collaboration among experts who span the fields of education, geography, earth and planetary sciences, psychology and cognitive science.
It provides an overview of the value of spatial thinking across the curriculum and presents a general framework for the nature and functions of spatial thinking. The report presents several different ways in which spatial thinking and spatial literacy are characterized. From one of these perspectives, spatial thinking is broken down into three different components:

- **spatial knowledge**, which includes concepts such as symmetry, orientation, rotation, scale, relative vs. absolute distance, and distance decay;
- **spatial ways of thinking and acting**, such as recognizing and using the similarity–distance metaphor, using diagramming or graphing in problem-solving, recognizing clusters and patterns in data, separating change over space from change over time, knowing how, where, and when to use the various spatial-thinking strategies, and being critically aware of the strengths and limitations of each of these strategies; and
- **spatial capabilities** that include the ability to use supporting tools and technologies such as spreadsheet, graphical, statistical and GIS software to help in problem-solving.

Another way these researchers characterize spatial thinking and spatial literacy is based on the distinction between three elements:

- **concepts of space** that include, among others, relationships among units of measurement (kilometres vs. miles), different ways of calculating distance (miles, travel time, travel cost), dimensionality, and the basis of coordinate systems;
- **tools of representation**, which require, for example, understanding of relationships among views (orthogonal vs. perspective), effects of geographic projections (Mercator vs. equal area), and principles of graphic/cartographic design (rules of legibility, visual contrast and figure–ground organization); and
- **processes of reasoning**, such as the ability to think about shortest distances in different ways (straight-line vs. route distances), extrapolate and interpolate, and make decisions based on spatial information. A third and final way the Committee on Support for Thinking Spatially describes spatial thinking involves breaking the process down into three component tasks: extracting spatial structures, performing spatial transformations, and drawing functional inferences. These and other researchers have also elaborated on various classifications for spatial thought (see Liben et al., 1981; Newcombe, 1989; Nyerges, 1991; Golledge, 2002; Tversky, 2005; Gersmehl & Gersmehl, 2007; Golledge et al., 2008a, 2008b) and provided insights into the development of spatial thinking.

**Teaching, Learning and the Practice of Spatial Thinking**

In the process of integrating an emphasis on spatial thinking into undergraduate courses, instructors may build on general principles about learning that are summarized in the National Research Council report on *How People Learn* (Bransford et al., 1999). In this section we briefly discuss some of these major themes and illustrate their importance in creating an environment for learning to think spatially.

**Learner Builds Knowledge—Teacher Creates Environment for Knowledge Construction**

One of the strongest findings to emerge from educational and cognitive research is the idea that knowledge cannot simply be transmitted directly from one person to another.
Rather, researchers have recognized the vital need to interact with available information and to construct a unique, individualized understanding of the phenomena in question. A learner builds new understanding through interaction between the knowledge possessed before learning takes place, the nature of the new information presented and the tools for thinking that apply to the information in question. In the case of learning to think spatially, this perspective on learning requires that students learn to practise a different way of thinking, not simply to remember a set of concepts or definitions.

Prior Knowledge, Prior Skills and Individual Differences

Prior knowledge strongly influences what individuals notice and attend to, as well as how they organize new information and apply it to solve problems. The most successful learning environments will build upon a solid understanding of what knowledge and skills each learner brings to make connections with the new information that she/he encounters (Bransford et al., 1999). Assessing prior knowledge is especially important in instruction focused on spatial thinking. Unlike other types of general thinking skills, such as verbal and mathematical reasoning, spatial thinking is seldom explored in school education in the US. As a result of this lack of emphasis on development of spatial thinking, students themselves are likely to be quite unaware of their own abilities in this area, or of the fact that spatial abilities can be improved through study and practice. In addition to the benefits of assessing prior knowledge for course planning, well-designed formative assessments provide learners with insight into the status of their own knowledge, and evidence of their progress along the learning pathway.

Because prior knowledge and skills may be unique to each individual, ongoing formative assessment informs the instructor’s decisions regarding curriculum development and accommodation of specific needs. For example, gathering evidence of what students understand about concepts like scale or methods of classification may help an instructor make informed decisions about how much and what types of information and practice students will need before beginning a project that involves collecting and analysing maps from different sources. For this reason, formative assessment that provides information about the degree to which a learner can think spatially within the specific context of interest is of vital importance. A more critical situation may arise when some members of a class do not possess the spatial thinking skills required to benefit from the spatial tools and representations being used. For those students with quite limited spatial thinking skills, alternative learning activities and learning goals may be necessary. The need to provide individual practice is reinforced by recent findings on the process of spatial thinking (National Research Council, 2006). Learners need to develop expertise with components such as discerning texture, recognizing colour and comparing size before they can demonstrate pattern recognition and complex spatial reasoning. Ideal learning activities are those that are flexible enough to (1) accommodate a variety of knowledge backgrounds, beliefs, learning strategies and levels of thinking-skills development and (2) allow for multiple levels of achievement. For example when focusing on abstract spatial concepts (e.g. frame of reference or distance decay), tapping into prior knowledge is an excellent means of making the concepts seem more relevant and accessible. Many instructors report that it is useful to draw on the local knowledge that students bring to the classroom.
Motivation and Self-directed Learning

In addition to prior knowledge, level and type of motivation will determine how much time a learner is willing to dedicate to learning a particular concept or skill and how persistent he or she will be when facing obstacles to understanding (Bransford et al., 1999; Svinicki, 2004). Research on motivation in the classroom suggests that an important factor is the adoption of mastery goals (e.g. “I’m spending a lot of time studying this because I want to understand it”) rather than performance goals (e.g. “I’m spending a lot of time studying this because I want to get a good grade”) (Svinicki, 2004). The wide availability of spatial datasets for an array of themes, locations and technologies (e.g. GPS) ensures that students can be offered the degree of control over their own learning that has been shown to enhance both motivation and understanding. The instructor who uses this approach must also take measures to ensure that that adequate information resources and technical assistance are available to help students to use advanced spatial tools (such as GIS or exploratory spatial data analysis software, e.g. GeoDa®). If students need to spend a lot of time troubleshooting technical difficulties, they will probably have less time to focus on practising spatial thinking and learning the target information. Furthermore, technical difficulties in the absence of adequate assistance can be incredibly frustrating. An instructor who is relatively new to these spatial technologies or who lacks teaching/lab assistants with relevant expertise is advised to begin with less complex activities.

Recommended Strategies for Assessing Content Knowledge, Spatial Concepts and Skills

Classroom Assessment Techniques (CATs)

A straightforward way to obtain information from students about what they know is to have them engage in short assessment activities while they are in the classroom. An instructor can adopt these flexible techniques to discover student knowledge of spatial concepts or ability to apply spatial thinking strategies. A wide variety of these brief assessment activities have been suggested (Angelo & Cross, 1993; Nilson, 2003); we provide a brief description of a selected few here.

Prior Knowledge Survey. At the beginning of a course, unit or lesson, students complete a survey that includes multiple-choice, true/false, short answer or essay questions about the material that will be presented subsequently. Questions that require use of spatial concepts or thought processes should be included with content-based questions. This technique may also activate prior knowledge and help students to become aware of the state of their own knowledge and abilities.

One-minute Paper. Following a learning activity such as a lecture or laboratory, students write a brief summary of the ‘most important points’ or ‘most useful points’ they learned from that activity. If time permits, students also include any questions that remain about the material. The instructor then evaluates these summaries for evidence of spatial thinking or deeper understanding of the material, and possible areas of misconception.

Pro/Con Grid. Students think about a decision that has been made and make a list of the pros and cons of this decision. A variation to encourage spatial awareness is to ask students
to list different features of a scene, as observed when viewed from two different spatial
perspectives (e.g. perspective view and ‘bird’s-eye view’).

Theory Comparisons. This comparative activity requires students to summarize the main
distinctions between two theories that describe the same phenomenon. When taking a
spatial perspective is important, the instructor may choose two competing theories: one
that is spatially explicit, and another that is not. Students who note this distinction in their
comparison show evidence of spatial thinking.

Self-confidence Surveys. Students anonymously evaluate their own knowledge and their
abilities to perform specified tasks. The instructor then offers targeted practice for tasks or
knowledge areas that have received low student self-confidence ratings. If students are not
confident in their abilities to perform simpler tasks that draw on essential background
knowledge and skills, they are provided with an opportunity to practise these skills before
moving to more complex problems.

Classroom Response Systems. A classroom response system consists of ‘clickers’ used
by the students to respond to multiple-choice questions, an infrared receiver that is
attached to the instructor’s computer to record responses, and software that automatically
generates and displays histograms of student responses. For evaluating spatial thinking,
students are presented with answer choices that represent the outcomes of varying degrees
of spatial thinking (Bruff, 2006, 2009). Angelo and Cross (1993) provide several
guidelines for making assessment activities successful. The first is to start small: beginning
very ambitious assessment activities or schedules may overwhelm both the instructor and
students. Second, instructors should clearly explain the rationale for the activities and
ensure that the instructions are clear. Finally, formative classroom assessments such as
these are most effective when the instructor responds to the information gathered and
communicates the outcomes back to the students.

Guided Problem-solving Activities

Problem-solving is one way to evaluate whether or not students have achieved meaningful
learning. Such assessment activities generally require that students go beyond recall of
information and apply their knowledge to making a decision in a novel situation.

 Examples from Social Science. A classic example of spatial problem-solving comes from
Jerome Bruner (1959). As part of the study of the north-central United States, Bruner gave
students a map of the region that showed only rivers, lakes and natural resources, and asked
them to decide where major cities are likely to be located. This approach can be adapted
for use in a wide variety of learning contexts through selection of appropriate datasets
(elevation, land cover, vegetation type, road and transit networks, thematic variables, etc.).
Some examples of problem-solving activities that are appropriate for learning and
assessing spatial thinking in the context of social science are presented below. Most of
these activities are easily extended into in-depth projects and analyses that rely on greater technological skills and availability; however, we limit our discussion here to activities that can usually be done using paper and pencil or overhead projection. More detailed descriptions of how to implement such activities using a GIS are described in Sinton and Lund (2007).

General Activities Applicable across a Wide Range of Disciplines

- Students are given a thematic map (e.g. choropleth or proportional symbol) and asked to make lists of variables the symbols could represent along with descriptions of their rationale.
- Students are given ‘layers’ of geographic data in low-tech (e.g. transparencies) or digital (e.g. GIS or web) formats. Students then use this information to make a decision, provide their rationale and identify additional types of information that could help them to make a better decision.

Archaeology

- Students draw a map of an archaeological site based on a site description, compare their map with other students, and then use these maps to make a collective decision about the direction in which to expand the dig. Students write up a description of their decision and explain their rationale.
- Students use relative artefact locations on a site map to infer artefact function, social structure or likely locations of other objects. Students report on their assessment and describe how they came to those conclusions.
- Students are given satellite imagery of a region of interest. They look for patterns that may provide evidence about past civilizations and write down the reasoning behind their identifications.
- Using thematic or reference maps of the world, continent or region of interest, students identify areas of world likely to contain ruins and report on the reasoning behind their responses.
- Students are asked to imagine it is the year 4006. Their task is to draw an imaginary site map for ‘X’ (e.g. a typical American suburb), compare their site map with the site maps of other students, and write a description of what they would expect to find in an excavation of the area, and why.

Sociology

Students view a map of administrative districts in which minority populations exceed a given percentage of total population and discuss possible reasons for observed distributions. As additional ‘layers’ of data (parks, recreation areas, hospitals, etc.) are added, students refine their explanations (Grady, 2007).

Economics

- Students view thematic world maps that show gross domestic product per capita, life expectancy and population growth, and discuss the variations and potential interrelationships between these variables (reported in Booker (2007), attributed to Ken Peterson of Furman University).
Students view a map that shows existing manufacturing facilities for a given industry, along with population density and transportation corridors. They discuss possible rationale for existing locations and propose new sites for future development, providing their rationale for each proposed site (based on an activity reported in Booker (2007), attributed to Peter Nelson of Middlebury College).

**Criminology**

Students view a choropleth map that shows the day of the week with the highest average reported crime density for multiple administrative districts and discuss possible reasons for any patterns they observe. They further refine their hypotheses after viewing additional ‘layers’ that show zoned uses (residential, commercial, industrial, etc.), transportation networks, public services, etc. (This idea was inspired by a map by J. LeBeau of Southern Illinois University, reprinted in Harries (1999), p. 73).

**Student Portfolios**

Many assessment tasks focus on capturing the state of a learner’s knowledge and skills at a particular moment in time. Portfolio-based assessment (Herman et al., 1992; Slater, 1997; France & Ribchester, 2004; Gülbaşar & Tinmaz, 2006), on the other hand, is focused on illustrating the incremental development of knowledge and skills throughout a course. Students assemble samples of their work over the course of study, including things such as notes, outlines, reflective comments, completed projects and supporting materials that illustrate the ‘history’ of the project, peer/instructor reviews, and examples of any other work students complete over the course of the term. Portfolios can be particularly illuminating in evaluation of the development of spatial thinking. To implement this process- and product-oriented evaluation approach, instructors ask students to collect a sequence of map analysis, map design and spatial decision-making activities (such as those suggested above) in the form of a portfolio. Portfolio assessment lends itself to peer- and self-evaluations in addition to instructor feedback, and provides an ideal venue for learners to improve on their work before it receives the final instructor evaluation. A contemporary version of the traditional portfolio is a student website: students collect examples of their work digitally on the web, and have the flexibility to include audio information as well as static and dynamic images.

**Summary and Conclusions**

Spatial thinking is a useful tool in the social sciences for the discovery and understanding of new knowledge. Advances in spatial technologies and the increasing availability of spatial data and low-cost data collection, analysis and representation tools have contributed to the application of spatial thinking in all areas of social science. Although researchers increasingly rely on spatial thinking tools for gathering, analysing and interpreting information about human activities and interaction with the environment, undergraduates in these fields seldom receive instruction and practice that encourages them to develop more advanced spatial thinking skills. Researchers in learning and spatial cognition have explored the factors that underlie the ability to think spatially, and they offer suggestions for how educators can help to foster development of these skills.
The SPACE programme, hosted by the Center for Spatially Integrated Social Sciences at the University of California, Santa Barbara, has sought to help undergraduate educators develop skills, materials and techniques that allow them to encourage spatial thinking in undergraduate social science.

This paper presents a number of pedagogical principles that have emerged from SPACE experiences and from research on education and spatial thinking, and offers ideas for the application of these principles in the development of undergraduate curricula for spatial social sciences. We commend those social science educators who are pioneers in the effort to integrate spatial thinking and technologies into undergraduate courses, and hope that the tools and resources developed and maintained by participants in the SPACE programme will serve as an inspiration and guide for other social science educators.

References


