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Stanford University is in the position not unlike many others across the United States in that it lacks a Geography Department. This absence has created both opportunities and challenges for those teaching spatial thinking and concepts to both undergraduate and graduate students. The most relevant opportunity is to include the ability to integrate spatial concepts directly into subject-specific classes making the examples and the work more relevant to the learner. Challenges emerge when there is a lack of coordination as to what should be taught to all students, the desire of students to jump into their research rather than to understand the theory, and the concern that spatial thinking is only presented to the students when the faculty thinks it relevant to do so.

It is clear from working with students in the map collections that most have little background in reading maps, much less understanding them as carriers of distilled information conveying a specific point of view. More so than with textual information, students seem to believe that what is presented on a map is factual and do not think to question it as they would with text. The same has been observed when they encounter geospatial data. Little has prepared them to understand the nature of the data with which they work. Students come to spatial data with scant knowledge of scale, projection, map reading, or spatial analysis skills. Without a systematic training program, the students pick up this knowledge in a haphazard, unstructured way, either on their own or through disparate teaching.

Stanford University presents an environment with entrenched silos of expertise. The culture encourages this even in the midst of a strong push towards interdisciplinary research. It is a culture of innovation and entrepreneurship that fosters independent thinking and the desire to quickly move into new areas of research. Over the past dozen years the campus has strongly embraced geospatial research and thinking in the curriculum. The sciences were the first to move in this direction followed by the social scientists and then the humanists. The classes offered throughout the university mirror this diversity.

- Civil and Environmental Engineering—Environmental and Water Resources Engineering Design
- Electrical Engineering: The Earth from Space—Introduction to Remote Sensing
- Geological and Environmental Sciences: Geostatistics for Spatial Phenomena
- Geophysics: Remote Sensing of the Oceans
- Political Science: Spatial Approaches to Social Science
- Anthropology: Cities in Comparative Perspective
- History: Spatial History—Concepts, Methods, Problems
- Classics: Modern Journeys in Ancient Lands—Building a Spatial History of the Grand Tour



While the classes all integrate aspects of spatial in their mix, they tend to focus on applied teaching rather than on understanding basic spatial concepts and analysis. The class “Fundamentals of Geographic Information Systems” taught by Patricia Carbajales, the library’s Geospatial Manager, counters this approach. The four unit class is the only one taught in the university (once a year) that provides a solid foundation in the principles of cartography, geographic data structures, statistical analysis of geographic data, spatial analysis, map design and GIS software. Students from across the schools take the course; it is required for urban studies students. While not required for students in Civil and Environmental Engineering, Earth Sciences, Political Science or History, many take it knowing they will need this background to do their work.

Branner Earth Sciences Library provides the backbone of support for geospatial data, teaching and software across the campus ([lib.stanford.edu/gis](http://lib.stanford.edu/gis)). The program, run by Patricia in conjunction with 30 hours of assistant support a week, supports over 600 users on the campus. We offer numerous workshops on a regular basis including Introduction to ArcGIS; GIS Data Creation & Management; Basic Spatial Analysis; Google Earth, Maps & Fusion Tables; Spatial Statistics; and ArcGIS Online, Business Analyst & Community Analyst. After taking the Introduction to ArcGIS workshop (3 hours), the students may book individual appointments for reference help.

Clear trends have emerged over time as we have worked with hundreds of students and researchers. First, it is hard to persuade students as to the importance of taking time to learn and understand the fundamental concepts of spatial thinking that underpins GIS. They want a rapid turnaround for their time and are under pressure to do things quickly. This is combined with software that is getting easier to use and more accessible to a novice user. One may be able to click a button and get results, but without proper training one cannot critically analyze the results. It takes time to learn about datums, projections, coordinate systems, data management, and the difference between raster and vector models, the concept of scale and its effect on the structure of the data, classification methods, and the importance of solid metadata. It is a challenge to work with faculty to enforce these training concepts when they themselves have not been trained to think spatially. It makes it difficult for them to know what to ask for and, at times, expect things to be easier or faster to do.

What can the library do to help fill the gaps in the teaching curriculum? First we are in the final stages of hiring a dedicated GIS Instruction and Reference Specialist. This position will oversee the introductory workshop program that is required of all students and researchers who ask for support for our unit. This basic, introductory workshop has proven indispensable in equipping our students with their first exposure to the fundamentals of GIS and also to the software tools available in our lab. The person will also manage the support staff, often students from the San Jose State University Geography Department, who handle the bulk of the general reference interactions. This will give us 70 hours of dedicated support in addition to the Geospatial Manager.

Second, we are also starting to build out a highly specific training program structured around different disciplines. Patricia piloted this program over the summer in conjunction with faculty in Political Science and in History. One set of classes took place over the course of a week and the other stretched over a few months. Our goal is to work with faculty to create robust, relevant training specifically geared to their students that become required training when working with spatial data and spatial concepts. Questions remain as to the ability to scale such an operation or the willingness of the faculty in diverse disciplines to work with us to develop relevant training materials. So far, the response has been overwhelmingly positive.

Finally, the centralization of geospatial support in Branner Library has, in some ways, been a boon given the distributed, siloed nature of the campus. It allows us to create a suite of services that are distributed in a consistent way with a well-thought out strategy for support. We centralize the training of assistants giving us the ability to know that outreach will be competent, thorough, and relevant to student and researcher needs. It is clear we are providing a necessary piece of the puzzle for those working to integrate spatial thinking into their teaching and research.

# A Design Perspective on Spatial Thinking for Spatial Thinking Across the College Curriculum

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In a recent *NY Times* op-ed piece, architect Michael Graves (2012) wrote, “Drawings are not just end products: they are part of the thought process of architectural design. Drawings express the interaction of our minds, eyes and hands.” That interaction between the minds and hands is an expression of the commonly held belief in undergraduate design education that drawing and designing are fundamental to developing spatial thinking. Whether studying 2-dimensional representations or working to better understand 3-dimensional space, architecture and landscape architecture students spend a tremendous percentage of their time in college improving their spatial cognitive skills. As accredited degree programs, design curricula are often structured around a larger credit load and higher faculty contact time, and even higher time commitment for student work compared to other undergraduate curricular approaches.

At the heart of design education is the design studio. This is an intense problem-based learning environment (Tulloch and Graff 2007), known on many campuses for its late nights and long weekends of work. Bearing in mind the underlying fundamentals of spatial thinking behind even basic design exercises, design studios require students to rapidly advance their spatial skills through an immersion in the studio environment. Aside from the rapid immersion and problem development, this environment is also characterized by the applied problems that constitute the core of most studio instruction and result in formative approaches to spatial problems requiring interventions. Because of the learning curve and broad knowledge required, about half of the undergraduate LA programs in the US are offered as 5 year degrees, adding greater depth to the immersion experience. In the same way that geometry and geography are clearly different, but both inform spatial cognition, spatial design, particularly landscape architecture, has a very large portfolio of unique experiences and lessons that should be integrated into any serious study of spatial thinking in higher education.

## Sensory learning

In studio settings, some commonly used preliminary exercises with this impact include: freehand drawing of forms, freehand drawing of negative space, rapid construction of small-scale models, rapid construction of large-scale models, measured drawings and field work. The effect is that, collectively, these lessons create a deep awareness of space and spatial relationships for many of the students, and they do it through a wide variety of sensory connections. Many of these exercises might only work in fairly specific settings, but they represent a large realm of educational experiences that warrant fuller exploration for spatial education.

Drawing exercises and courses represent a large category of these sensory exercises. Freehand drawing places an emphasis on creative viewing of our personal environments. As students explore edges and surfaces, they often engage in a freehand technique called contour drawing (decidedly different than contour mapping). To better develop a sense of space, they will also draw the “negative space” between complex, overlapping objects.

Measured drawings (i.e., mechanical drafting) might begin with traditional blocky forms, reduced to 2-d or represented in 3-d axonometric representations. Cross-sections and elevations are also among basic spatially-oriented drawing exercises. For a deeper experiential memory, some classes use early exercises of measuring and drawing existing landscape features based on field measurements. This might mean a detailed cross-section of a city street, capturing each change in material and surface. Or it might be a full-day effort to construct a measured quadrat drawing of a single tree. Taking these experiences a step further is the development of built scale models of both built spaces and natural landscape forms. While some of these skills are formally taught, many are simply learned through frantic immersion into a project with specific needs.

Perhaps more than other design fields, landscape architecture relies heavily on the field trip as a spatial education experience. Our program uses annual 4-day program-wide trips to pack our students’ sensory memory bank with experiences linked with spatial lessons. When visiting the FDR Memorial in Washington DC the muffled or reflected sounds of planes leaving Ronald Reagan National Airport create multiple opportunities in space and distance. The amazingly long, but relatively narrow, reflecting pool at Boston’s Christian Science Plaza allows students to compare plans with experience, to pace off a large object in the field. Students (and eventually professionals) find these memories of spaces to be tantalizingly vivid years later when they need to imagine a parallel space or experience or distance.

### **Design studio**

The design studio is one of the most identifiable icons of design education. These are commonly treated as required core classes for anywhere between 5 and 10 consecutive semesters, with one class sometimes being 6 credits for 12 contact hours over three days a week. While the formats vary somewhat, they often revolve around studio classrooms spaces that are accessible 24/7. For many, the entire semester might build on a single extended design project, employing methods sometimes described as problem-based learning, to address a spatially-explicit problem. With relatively limited introductory instruction in map-reading, students are quickly immersed in the process of using, drawing, and imagining space and form in ways that will take years to master.

Studio’s high contact time is meant to allow one-on-one interactions between faculty and students (desk crits). Since students are often asked to quickly display their current unfiltered spatial abilities, instructors can address some shortcomings individually rather than with the entire class. It is a much less rules-based and more needs-based approach to spatial learning, with clear shortcomings and benefits.

One of the most notable differences between design studios and lecture classes are the decisions that students make throughout the class. Confronted with an assigned problem, they

acquire knowledge of the site and the problem, develop alternative solutions to address the problem, and ultimately chose and refine a preferred solution. Since these are spatial problems, the exploration is also spatial. On large projects they may use GIS to develop inventory and analysis materials, but on smaller sites designers may rely more on personal observation and sketching. Landscape architects synthesize these complex spatial patterns and information (whether digitally or mentally or both) to inform their decisions. And those decisions, or designs, often require iterative development of alternatives. After 6 semesters of this, students have accomplished an impressive amount of spatial learning and yet find themselves far from the level at which practitioners often operate.

### **Evaluating spatial thinking talent versus skill**

With such specialized facilities and specific accreditation requirements, a number of the undergraduate design programs employ either a program-specific admission process (often in the guise of other names like “limiting enrollment”). The approaches vary widely. One architecture program offers a 1-day “exam” which tests both spatial thinking and creativity with unusual drawing exercises and construction paper puzzles which are then blind-reviewed by faculty. A student untrained in drawing may struggle with some exercises, but shine on others. At the same institution, the landscape architecture program relies mostly standardized test materials that test both visual and spatial acuity. Still others require a semester or more of instruction at their institution, which not only tests their spatial abilities but also tests their ability to learn spatial thinking.

These processes are based on a key set assumptions that are relatively untested. Are spatial cognitive skills inherent and testable without preparation? Are they universally learnable? Decades of design instruction have led a number of design programs to believe that, in some cases, spatial perception and thinking is demonstrable in a way that should change the course of students’ academic careers.

### **Overlap between geography and design**

It is not news that landscape architecture and geography overlap. But, reflecting on that overlap may highlight new areas of investigation. For instance, there has been a growing area at the intersection of these and other fields called geodesign. As geodesign has emerged (with a 4th annual meeting planned for January 2013), it has explored the shared territory and the key differences. An interesting divergence that came up at one of these meetings was that the two fields describe different scales using the same words but with opposite meanings.

An historic example of this shared experience is the spatial software innovation hub that was the Harvard Computer Graphics Lab from the mid-1960s to the early 1980s. This lab, housed in Harvard’s Graduate School of Design, benefitted from the depth of spatial theory in geography and the creative approach and goal-based needs of planners and designers in creating some of the most important spatial software in the world.

**Spatial education lessons and questions (as if they are different)**

These different approaches from landscape architecture all highlight a significant value in active learning. The self-guided explorations, coupled with tactile experiences, potentially lead to much deeper memories of the specific spatial lessons. And yet, the design approach is time consuming and difficult to justify in other curricula. While a well-trained geographer and landscape architect both have clearly demonstrable spatial abilities that have been learned, it remains unclear how similar their understandings of space and scale and dimensionality are or whether (as a group) they have similar abilities to analyze and synthesize spatial information in similar ways. Still, there may not be a more rapidly applied or more deeply-based immersion approach to spatial education, than what we see in studio.

We still don't know much about these approaches to learning spatially. From the time they commit to design, landscape architecture students have committed to interventions and what Graves calls "formative actions" while non-design disciplines start with more open inquiries and explorations. Does a focus on decisions and interventions alter a student's perspective on space? Do the realities of professional practice impose an urgency that forces clarity or carry a burden that limits critical spatial thinking? Ultimately, do the less literal exercises add or detract from spatial education?

Finally, there is merit in asking whether all students (or at least a substantial subset) should be required to complete a first-year class in spatial awareness. But an examination of design adds the possibility that some groups of geographers/cartographers might progress more rapidly after beginning with a drawing class or immersive design studio.

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# Spatial Thinking

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**S**patial thinking is not unitary but rather a complex of skills that not only can be cultivated but must be. Spatial thinking is key not only to professional life but also to everyday life, to understanding and using the multitude of maps, graphs, sketches, diagrams, and spatial descriptions, concrete and abstract, needed to carry on the business of life. Despite difficulties that children and adults have in aspects of spatial thinking, it is rarely taught.

Spatial thinking in various instantiations has occupied my research for years: objects, bodies, the space around the body, the space of navigation, the spaces people create to augment their own cognition and well-being. Putting ideas on paper, in sand, on stone, are ancient means for remembering, conveying, and manipulating ideas, concrete, like maps, and abstract, like mandalas and diagrams. We have studied the natural mappings people construct using place in space, horizontal, central, vertical, and simple marks in space, like dots, lines, arrows, blobs and configurations of them to represent structures, such as maps, buildings, and networks, as well as processes, such as explanations of how to do something or how something works. We have also studied how people interpret and understand visual expressions of thought and related diagram production and use to spatial abilities. Those high in mental rotation, for example, not only produced better diagrams for explaining processes but also more effective language for explaining processes (e. g., Daniel and Tversky, 2012). By contrast, those adept at finding embedded figures were better at finding new interpretations in ambiguous sketches, a component of creative thinking (e. g., Tversky and Suwa, 2009).

What if there is no paper? People draw in the air, that is, gesture. Like diagrams, gestures spatialize both concrete and abstract structures and processes using virtual marks in a created space. In two sets of studies, students, alone in a room, read descriptions of spatial problems and attempt to solve them (Kessell and Tversky, 2006; Jamalian, Giardino, and Tversky, 2012). Many of the students gesture while reading the problems and their gestures structure the spatial situation described. Those who gesture are more successful at solving the problems. Gestures can be incorporated into computer modules for teaching. Children's performance in mathematics was enhanced when the gesture actions were congruent with the thought actions (Segal, Tversky, and Black, submitted). In particular, addition was better with discrete gestures and number line estimation was better with continuous gestures.

Viewed gestures can also facilitate student learning if the gestures correspond to thought. Kang, Tversky, and Black (2012) used the same diagram and verbal script to teach the workings of an engine. Half the students saw gestures showing structure, half saw gestures showing action. Structure is usually easier to grasp than action, and both groups did well. The group who had

viewed action gestures performed better on action questions and conveyed more action information in their subsequent visual and verbal explanations, inventing their own gestures to do so. Jamalian and Tversky (2012) found that viewed gestures changed the ways people thought about time, specifically, understanding cyclicity, simultaneity, and temporal perspective.

Encouraging spatial thinking is easy to adopt in classrooms and has immediate benefits on student learning. Bobek and I (in preparation) taught junior high students lessons in chemical bonding and mechanical thinking. They were first tested, and then asked to construct either a visual or a verbal explanation of the processes, followed by a second test. All students improved on the second test without intervening teaching. Those who constructed visual explanations improved far more. In our view, the visual explanations were superior because they can map the processes to space. Diagrams provide a check for completeness, a check for coherence, and a platform for making inferences from structure to process. They also provide useful feedback for teachers.

Children (and adults) need to learn structure and process in many domains, STEM, history, literature, and more. Spatializing thought through diagram and gesture can be easily incorporated into the classroom, with clear benefits.















across a variety of disciplines. The course attracts over 100 students annually. It is important to note that, largely due to this course, the diversity of our student cohort remains relatively high. The female enrollment of our GIST GE course is typically 40% to 60%. According to a 2009 survey conducted by the GeoTech Center (<http://www.geotechcenter.org>), female enrollment in a non-GE GIST course is typically 25% to 30%. As one would expect, a general education course offering has the added benefit of attracting a more diverse student population (including underserved and underrepresented groups) into geospatial science and spatial literacy courses.

Our second method of recruitment is to “seed” geospatial and spatial reasoning curriculum within a variety of academic disciplines across the campus. By introducing geospatial learning module(s) into a diverse set of courses we are effectively introducing students to spatial thinking and exposing them to how geospatial technology is a part of “their” discipline. Spatial-thinking learning modules (using tools such as Google Earth, ArcGIS Desktop, ArcGIS Explorer Online, and a variety of Internet sites) are now being employed on our campus within 8 unique disciplines (in approximately 50 sections), touching more than 2,000 students annually (and this number is growing every semester).

Perhaps one of the best ways to tackle the lack of spatial thinking in college curriculum is to add “Spatial Literacy” to the list of GE categories. A Spatial Literacy GE category, along with the augmentation of spatial thinking modules into present curriculum, would go a long way to minimizing the spatial teaching gap at the collegiate level. Of course, the list of graduation requirements for students has seemingly been growing over the past decade. Short of creating a Spatial Literacy GE category, another option is to do as we did at Southwestern College: create geospatial awareness and spatial thinking coursework that satisfies a number of already established GE categories.

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