Understanding spatial literacy: cognitive and curriculum perspectives

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Introduction: spatial literacy in geography, earth and environmental sciences (GEES)

There are a variety of definitions of spatial ability or literacy all of which can be applied to activities and processes undertaken within the GEES disciplines. Linn and Petersen (1985) define spatial ability as a general skill in

> "representing, transforming, generating and recalling symbolic, nonlinguistic information".

Eliot and Smith's definition of spatial ability (1983: quoted in Ishikawa and Kastens, 2005) specifies

> "the perception and retention of visual forms and the mental manipulation and reconstruction of visual shapes."

With respect to geosciences, Kastens and Ishikawa (2006) describe spatial thinking as

> "recognizing, observing, recording, describing, classifying, remembering, and communicating the two- or three-dimensional shapes, structures, orientations, and positions of objects, properties, or processes;
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> mentally manipulating those shapes, structures, orientations, and positions by rotation, translation, deformation, or partial removal;
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> making interpretations about why the objects, properties, or processes have those particular shapes, structures, orientations, and positions;
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> making predictions about the consequences or implications of the observed shapes, structures, orientations, and positions; and
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> using spatial thinking as a short cut or metaphor to think about the distribution of processes or properties across some dimension other than length-space."

This latter definition reflects and expands on the key issues relating to spatial literacy discussed at the GEES Subject Centre summer conference. Mapping and maps were identified as fundamental to our subject areas and this linked into the issues of dealing with information in various dimension from 2D to 3D to 4D (including time).

Our discussions, mostly arising from an Earth science point of view, clearly indicated that spatial literacy is considered a fundamental concept in GEES (and one that is often troublesome to students). Interestingly, however, it is given relatively low significance in the relevant UK Quality Assurance Agency (QAA) Benchmark Statements (2006). Aspects of spatial literacy are articulated most strongly in the Geography Statement:

> "Geographers should show knowledge and critical understanding of the diverse manners of representation of the human and physical worlds. Maps have an important historic role as representations of the world, and geographers should be conversant with their modern forms and dimensions. However, geographers should have a similar depth of understanding of other representational forms, including texts, visual images and digital technologies (particularly GIS and remote sensing)."

Elsewhere, spatial literacy appears mostly implicitly within discipline-specific graduate skills. In the Statement for Earth Sciences, Environmental Sciences and Environmental Studies (ES3) the word 'spatial' only appears briefly to indicate that these disciplines are characterised by, amongst other things, "the range of the spatial and temporal scales that they cover." This is not intended as a criticism of the Benchmark Statements, rather an observation that spatial literacy is, perhaps, such an integral part of our subjects that we sometimes neglect to make it explicit.

So, spatial literacy is clearly a highly important skill for students of geography, earth and environmental sciences to master. Indeed, not only for our disciplines: spatial ability is a cognitive factor that has been linked to high performance in science and mathematics (Lord and Rupert, 1995).

Issues for students

Spatial literacy is seen as a fundamental skill of experts in GEES; hence, it is also considered a key aspect of the learning process for students. However, it is an aspect that many students have trouble with. In our discussion group's experience these difficulties include:

- Visualising / mental moving or translating between 2D, 3D and 4D (e.g. plan maps, cross-sections, stratigraphic columns, stereographic projections, etc.); and
- A sense of location on a map with respect to the real world (e.g. finding their location on a map when out in the field).

A difference between real understanding and just 'going through the motions' was identified. For example, in one colleague's experience all their students were able to follow instructions in a recipe style (e.g. in using stereonets) but only a few really understood what they were doing and why. Visualisation was suggested as a possible trigger of 'aha' moments. Several colleagues remembered their personal revelations on going into the field for the first time: on seeing the geology 'in real life' all around them they were better able to understand the theoretical descriptions in the classroom. Another participant in the group, however, described a much longer learning process in which the overall principles of earth science, including the spatial aspects, did not become clear until several years after graduation when many of the fine details of the subject had been forgotten: the fundamental concept had been clouded in a fog of terminology, nomenclature and classification.

The use of technologies such as GIS and GPS was discussed as a possible hindrance as well as a solution to developing spatial literacy skills. Concern was expressed that students became 'black box' users of the technology and blindly accept the answers produced without recourse to an understanding of what the answer means or whether it is accurate. The ability to locate oneself on a map by identifying landscape features, to use a compass to triangulate position, and other skills potentially usurped by modern technology provide both a 'safety net' should

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the technology fail and a quick check that the technology is providing roughly accurate information.

Does it matter if GEES graduates don't develop their spatial literacy skills? If they are to go into non-subject related jobs then maybe the 'recipe' approach will suffice. This issue was discussed by the group: although no resolution was found, there was a sense of discomfort about producing graduates with only a mechanistic approach to understanding their discipline.

If Lord and Rupert's observation on the link between spatial ability and success in science and maths (1995, quoted above) is correct, then perhaps GEES programmes need to focus more on developing skills of spatial literacy. Just because a graduate may not go into a job that is related to their course of study does not mean that the development of their spatial skills is unimportant. Having a general population that is cognisant of global issues is becoming increasingly important in our modern society. Indeed, Black (2005) suggests that spatial literacy is a skill that should be emphasised at secondary school level:

> "[It has been argued] that spatial ability has been neglected in traditional education. Although students with weaknesses in verbal abilities are encouraged and given a great deal of practice, usually no specific help is given to students with weaknesses in spatial ability. Such students may eventually abandon the study of spatially-related disciplines, such as mathematics and science, when those topics become more difficult in middle and high school."

Further, Geary (1998) writes:

> "Public understanding of Earth systems and the ability of citizens to think critically about them is increasingly necessary as new technologies illuminate interrelationships among those systems, and as human influences on Earth systems intensify environmental concerns. University graduates who are non-science majors may eventually occupy positions in business, law, government, communications, and education, and therefore may greatly influence public policy on Earth resource issues. As policy makers, some may influence important decisions more than the scientists who advise them."

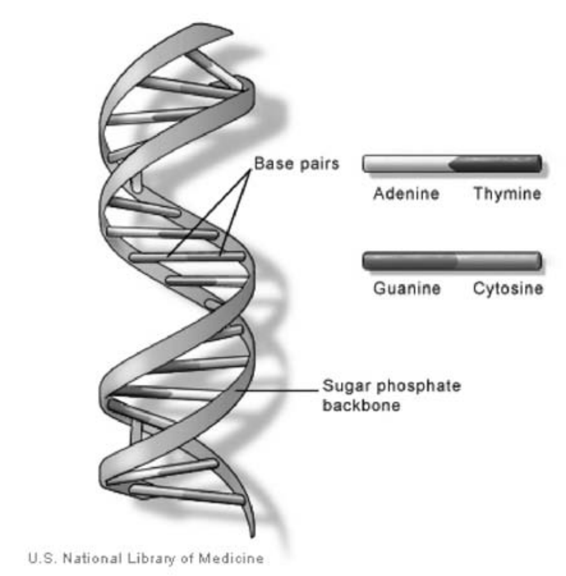
Issues for staff

Spatial literacy is seen as a fundamental skill of experts in GEES; however, in the conference discussion, colleagues repeatedly referred to the 'lack of time and space to allow students to develop skills related to time and space'. It was agreed that many curricula have been developed over a long period of time and new concepts or skills have just been added on to the existing structure. The resulting 'packed curriculum' allows little time for focusing on difficult areas and the acquisition of threshold concepts becomes neglected for the sake of transmission of details. This is, of course, a broad generalisation and many programmes do offer an experiential learning approach. Several colleagues identified examples of writing a new curriculum from a blank page (particularly at MSc level) and highlighted the benefits of a fresh approach.

Examples of practice and research

Visualisation

Immersion in the environment through fieldwork was highlighted in our group's discussion as a key element in supporting the



development of students' spatial literacy skills. In the classroom, technological visualisation tools can also be used for this purpose. However, the lecturer still maintains a key role as few, if any, tools are able to provide the comprehensive pedagogical environment required for the learning process. A huge amount of geoscience visualisation materials is available, with more materials being developed every year. Libarkin and Brick (2002) present a few examples of animations, physical and computer models together with ideas on how they are effectively used. Many additional resources can be found in the Digital Library for Earth Science Education (http://www.dlese.org).

Cognitive science and GEES

Several researchers in geoscience education have turned their attention to cognitive science as a tool for better understanding geoscience learning processes. Ishakawa and Kastens (2005) provide an insightful overview of relevant cognitive science research and illustrate ways in which it might be applied to the geosciences. In their review, they discover

> "much that resonates with the intuition of experienced geoscience educators: People vary widely in their ability at spatial tasks. People who are usually good at verbal schoolwork may struggle with spatial tasks, and vice versa. Different people may respond better to different strategies for mastering the same task. Locating themselves on a map and visualizing the hidden, internal portions of three-dimensional structures are difficult for novice learners."

In our discussion at the GEES Subject Centre's summer conference, we came to the idea of supporting the development of spatial literacy through taking apart an idea and rebuilding it again: take everyone back to a common denominator and then build a new common understanding of the concept. In principle, this seemed a useful process though we were at a loss to identify an example of how it might be done! Ishakawa and Kastens developed a similar idea, identifying that

> "Experienced geoscientists, especially those who have high spatial ability, tend to leap across such tasks in a single bound, and may be at a loss to articulate how they did what they did."

a new approach to learning geoscience might involve an emphasis on the key concepts of being a geologist rather than the fine details of doing geology

In order to help students develop their own skills, it is suggested that complex spatial tasks should be broken down into 'constituent understandings' or 'constituent strategies.' Their paper (available online for free download) then reviews a variety of cognitive science research, applies it to the geosciences and provides brief ideas on the educational implications.

Conclusions

Spatial literacy is seen as a fundamental skill of experts in GEES and yet it can be particularly troublesome for some students to master. A brief overview of the literature suggests that spatial skills should not be thought of as practical skills that can be easily taught, but as an academic process that needs to be mastered through a wide variety of interventions and lots of practice. As Black (2005) comments:

> "Perhaps the neglect of educators to foster spatial ability is related to its history of association with practical, rather than academic, skills. Perhaps educators have assumed that nothing can be done to improve spatial ability. The known association of success in science with spatial ability underscores the importance of additional research and of attempting a more deliberate and informed focus on spatial aspects of science concepts by K-16 teachers."

Our discussion group highlighted the difficulties associated with the 'packed curriculum' and suggested that a new approach to learning geoscience might involve an emphasis on the key concepts of being a geologist rather than the fine details of doing geology. Across the GEES disciplines, spatial literacy is a crucial skill for practitioners; as Bednarz (2005) suggests:

> "spatial thinking is the lever to enable students to achieve a deeper, more insightful understanding of subjects across the curriculum. It is a pervasive way of thinking that crosses disciplinary boundaries. It is not an ADD-ON but a missing link."

To inform such a change in emphasis a better understanding of how experts conceptualise key models is required: "Does a 'best practice' in teaching exist that can help students move from naïve mental models to conceptual frameworks?" (Libarkin *et al.*, 2003). In addition, further research into spatial ability in relation to the GEES disciplines would provide an invaluable basis for curriculum development. As Libarkin and Brick (2002) suggest:

> "The study of spatial skills has a rich history in cognitive science, and has experienced renewed interest stemming from science, mathematics, and engineering education. The unique set of skills required for studying geologic phenomena suggests that the Earth Sciences is an ideal field for studying spatial and visualization skills in a real educational setting. Worthwhile future research could consider a number of questions, including: (1) What is the relationship between spatial ability and geologic visualization skills, and how can we begin to test these geology-specific skills?; (2) How does familiarity with geological phenomena influence spatial ability?; and (3) How is the use of technology-based visualization tools improving upon learning achieved by more traditional teaching methodologies?"

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