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Thinking spatially in the science classroom

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Much scientific thinking is spatial in nature, and even non-spatial information is often communicated using maps, diagrams, graphs, analogies and other forms of spatial communication. Students' spatial skills are correlated with their success in learning science, both concurrently and predictively. Given that spatial skills are malleable, can spatial thinking be used to improve science education? This article reviews two ways in which we might proceed. Strategy 1 is to enhance students' spatial skills early in life, or at least prior to instruction. Strategy 2 is to make more effective use of spatial teaching techniques that allow for spatial as well as verbal learning, even by students with weaker spatial skills. Recent evidence suggests optimism about both approaches.

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Introduction

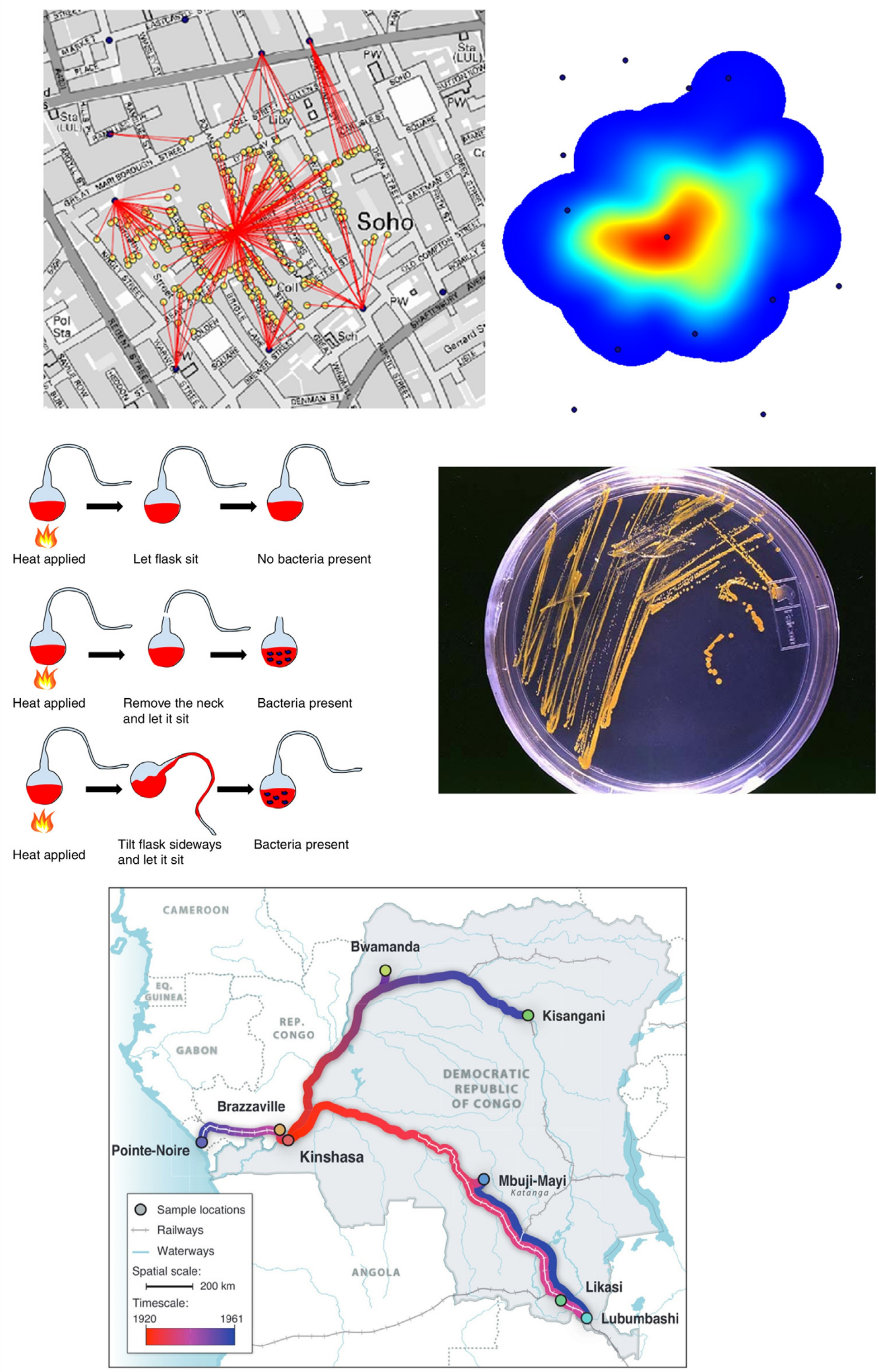
An important aspect of many scientific discoveries stems from the spatial nature of the relevant data. Consider, as an example, the history of understanding infectious disease. Ignaz Semmelweis, a careful observer with a brilliant hunch, made a start by observing in the 1840s that washing hands between examining obstetric patients reduced the incidence of puerperal fever. But *why* should washing help? One step toward a germ theory of disease was taken in the 1850s, when John Snow put his observations of cholera cases in London on a map in juxtaposition with the location of water pumps, showing clustering around the pump on Broad Street (see Figure 1, top panel, for two modern visualizations of the data). Visualizations continue to play a role in scientific work on infectious disease, as shown in research on the history of the HIV virus (Figure 1, bottom panel). In addition, scientific education often uses spatial displays to communicate key ideas. Continuing with the science of infectious disease as an example, in the 1860s, Louis Pasteur conducted experiments on pasteurization, effectively shown in a modern diagram as often found in science textbooks (Figure 1, middle left). Also in the 1860s, Robert Koch figured out how to grow bacteria on agar, using a microscope for visualization (an example of such a preparation is shown in Figure 1, middle right).

If scientific thinking is spatial, could spatial learning be harnessed to support more effective education in science and mathematics? There is in fact empirical support for the idea, based on various observations, for example, the fact that students with higher spatial skills show better learning of topics such as kinematics [1] or a finding that gender differences in spatial ability mediate gender differences in science achievement in middle school [2••]. However, this general idea could play out in two different ways in the educational system. Strategy 1 might be to enhance students' spatial skills early in life, or at least prior to instruction, to enable better science learning. Strategy 2 might be for science educators to make more effective use of spatial teaching techniques that could allow for spatial as well as verbal learning, even by students with weaker spatial skills. That is, the focus would be on the curriculum, not on the learner. These possibilities are not mutually exclusive — both strategies might be important and effective. In that case, they could either be used together, or choices could be made between them on practical grounds, such as whether time and resources are available for pre-instruction spatial skills training. The purpose of this paper is to review recent evidence on these two strategies: (a) whether improving spatial skills affects science learning, and (b) how to spatialize the science curriculum.

Strategy 1: Improving spatial skills

Strategy 1 would be a non-starter if people were born with some innately-determined fixed level of spatial ability, with some individuals destined to be spatial geniuses while others are doomed to a permanent spatial fog. Fortunately, this belief, though common, is a myth. Meta-analysis of a wide variety of spatial training studies shows that spatial skills can be improved, for both men and women, and for adults as well as children. Furthermore, these improvements seem to be durable and transferable [3]. These findings give rise to the hope that right-shifting the distribution of spatial skill in a population would increase the pool of people qualified to become part of the science and technology workforce ([3,4]; see Figure 2). Interest in the malleability of spatial skills is growing, and experimenters continue to design engaging programs for spatial training suited to various ages and different spatial skills [5].

Figure 1



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At top, two examples of modern visualization created from John Snow's cholera data http://qgissextante.blogspot.com/2012/10/analyzing-john-snows-cholera-dataset.html. In the middle panel, a diagram of Pasteur's experiment on the left and bacteria growing on agar on the right https://en.wikipedia.org/wiki/Petri_dish#/media/File:Agar_plate_with_colonies.jpg. At bottom, how the HIV virus spread and changed http://www.wired.com/2014/12/best-science-graphics-visualizations-2014/#slide-12.