commentary

Is a picture worth1,000 words?

Exciting new illustration technologies should be used with care.

Julio M. Ottino

A quick look at *Nature* or *Science* immediately shows how the role of images in science has increased over the past 20 years. It is now rare to find a research article that has no images. Indeed, it is hard to remember that colour is a relatively recent addition to scientific publishing. This increase in illustrations is undoubtedly due to the widespread use of computer graphics — images can readily be enhanced, modified and morphed. It is now relatively easy to draw figures with shadows and multiple reflections between mirror-like surfaces.

Although scientists may like to think they are immune to figures, this resistance may be a remnant of past thinking that has portrayed visual-aided arguments as less than rigorous. Physics and mathematics have been held as primary examples of domains where images play no role. But this view is far too narrow — visual imagination is a central element of scientific imagination[1]. Seeing and representing are inextricably linked to understanding. Galileo's sketches of the Moon (Fig. 1) are possibly the most celebrated example. But there is little doubt that the role of images has changed significantly since Galileo's times. The question is, are we now getting ahead of ourselves?

Figures fall into several categories. At one extreme there are those that convey data; at the other, scientific illustration. When images are 'the' experimental result, photo editing opens up the distinct possibility of overmanipulation and misrepresentation. The hard line, that any unreported manipulation constitutes fraud, is short-sighted. If shades of grey in an image range in levels from 134–147, they would all look the same to our eyes. But rescaling these pixels so that 134→0 and 147→255 readily reveals the differences to the human eye. Well-established tools[2] such as deconvolution (used, for example, to interpret fluorescence images) enhance the human ability to 'see'.

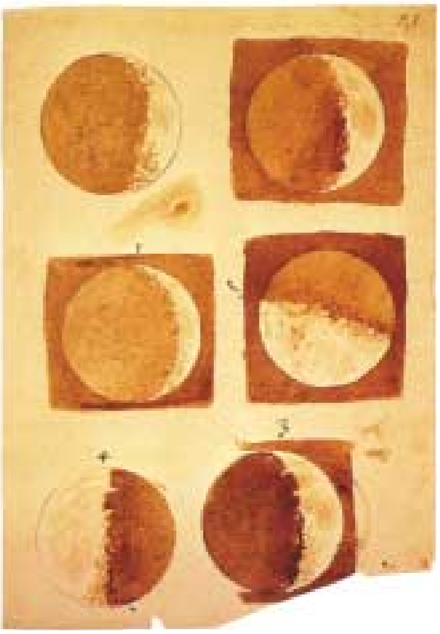

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Figure 1 **Pictures in perspective: Galileo's sketches of the Moon are more than mere illustrations — they convey relevant scientific information.**

My objective is, rather, to tackle the seemingly less scientific topic of scientific illustration. Such images enter the equation, for example, to depict mechanisms: how a cell is attacked by a virus; when a DNA helix is unravelling; or when an asteroid plunges into Earth (Fig. 2). Representations of how something might or could be built fall into this area — the many sketches of Leonardo, or more recent examples such as the 'nanolouse' and nanocircuits of Figs 3 and 5. At a more basic level, scientific illustration shows how something is — the Moon in Galileo's times — or how it can be imagined — Bohr's atoms, or how two molecules might interact.

Figures used to be part of the thought and discovery process. For Leonardo, Galileo and mathematicians such as Riemann, the image was part of the thought process[3,4]. The same instrument penned words and drew lines. This seamless integration is more than a quaint sentimental point. A line is tentative; in a line drawing one hears the voice of the author: "this is what I think happens…" or "this is how I imagine this mechanism works". One can see a mind at work, switching from word to image (Fig. 4). It is hard to argue that replacing Leonardo's drawings in the codices with computer-gen-

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Figure 2 **More real than reality: artistic impressions, from atoms to asteriods, can be striking, but do they aid scientific understanding?**

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Figure 3 **Could this device function? This award-winning computer-generated image of a nanolouse initially looks realistic, but close inspection reveals an element of 'artistic licence'.**

erated images is really progress.

These days, of course, text and figures are handled in different ways. In many instances, figures are left in the hands of artists and illustrators (Fig. 2). There is a real concern that the practice of using artists' impressions or mock-ups denies the physics of the situation, or is so convincing that the line between fantasy and reality is blurred. Examples abound in science, most lately in the emerging discipline of nanotechnology.

Rules of the game

This all means that publications should establish guidelines of what manipulation or enhancement is permissible. I believe that we need to evolve a system that is the scientific equivalent of that for films, analogous to David Lean's expansion of "directed by" to "edited and directed by". Attribution and clarification of image manipulation[5] will make the figure truly 'scientific'.

A sensible first rule would be that pictures must not be divorced from science and scientific plausibility. Images should not conflict with or violate known physics. Of course, one should not take this too far — it is pointless to criticize the circular orbits in Bohr's model of the hydrogen atom or the practice of colouring atoms in molecular models.

It is hard to pick good examples of bad pictures in this regard. Poor images do not tend to receive wide exposure. We are looking for pictures that have been singled out as being particularly good, even dazzling, artistic depictions, perhaps selected for covers and art prizes — images expressly picked on artistic merit, but also for attracting attention. In illustrations, the observer generally assumes that the level of information in the figure is uniform — if something in the figure is intended to be 'realistic', then the rest

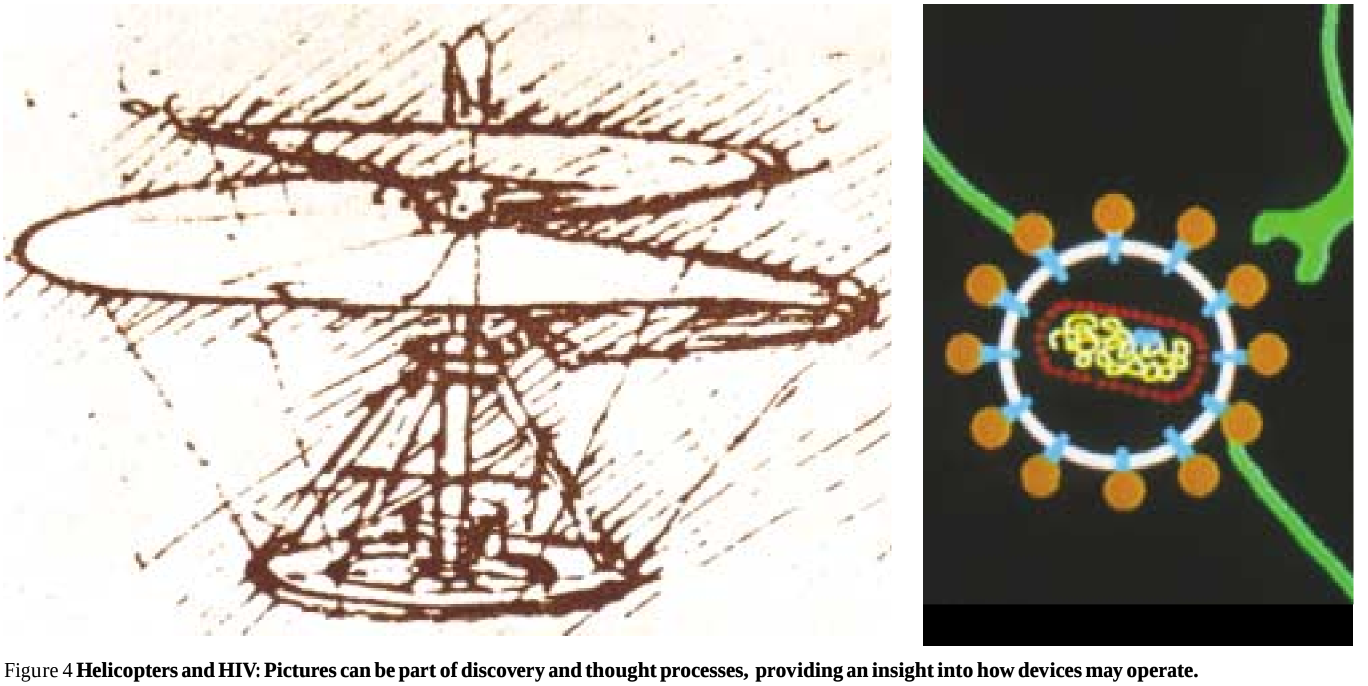

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Figure 4 **Helicopters and HIV: Pictures can be part of discovery and thought processes, providing an insight into how devices may operate.**

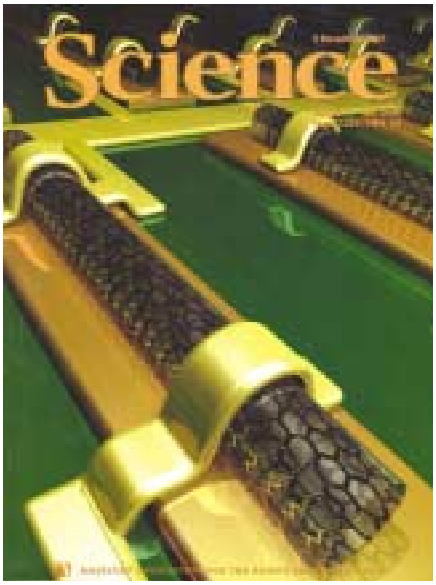

Figure 5 **A nanocircuit from the cover of *Science*. This picture purports to offer scientific insight — but if the carbon atoms are visible, then the much larger gold atoms in the structure should also be on view.**

Figure 6 **Science as art. Clearly not intended to be a realistic portrayal, this image of two molecules is unbalanced as it includes too much unnecessary detail in arrows and too little on the molecules themselves.**

of the figure should be as well. If this is not the case, the caption should make this clear. For example, in the cover figure of the nanocircuit in Fig. 5, as one can see carbon atoms in a nanotube, one should also see gold atoms in the support (ratio of masses more than 10, ratio of diameters about 2). An experimental figure in the paper[6], which the cover illustration purports to represent, shows gold atoms whereas the nanotube itself can barely be discerned. The necessary requirement that no physics is violated is broken by Fig. 5, which shows shadows, reflections and so on as they would occur in everyday life, which most definitely do not occur in quite the same way at the nanoscale.

Aesthetic rules would also be useful. Images, just like text, should not be more complicated than they need to be. The image in Fig. 6, for example, is clearly not intended to be confused with reality, it simply purports to show the coupling between two molecules that can give rise to new spectral features. However, is it really necessary to have so much detail: full, three-dimensional solid-like arrows with shadows, when just a few lines will do or when the molecules themselves are depicted in a clearly schematic way?

Another rule is needed to address the extrapolation of everyday physics to molecular and mesoscopic scales. We should resist the temptation to prejudge answers, recalling Richard Feynman's 1959 challenge to build a very small motor, and its realization only a year later. This rule needs to be particularly clear and explicit in dealing with images of what must be imagined and cannot be seen. Pictures often precede devices; they indicate how something might look without it having been built, which can influence how the effort might actually be attempted.

Consider the beautiful image of the 'nanolouse' — the micromachine with significant functionality which is the size of a red blood cell (Fig. 3). This image won first prize in the 'Science Concepts' section of the 2002 Visions of Science Awards. The image looks so real that it is easy to imagine a viewer being fooled into believing it has already been built. This is important in terms of public reaction, especially in the backdrop of scenarios such as in Michael Crichton's new novel *Prey*, which portrays swarms of self-replicating nanomachines destroying all other life forms that they encounter.

But could the nanolouse in Fig. 3, in fact, be real? A bit of 'physics' thinking helps. The image itself shows features such as tubing systems that are about 200 nm in size. One would never see this level of detail in a light microscope (features at this scale get fuzzy, as 200 nm is the Rayleigh resolution limit). In addition, colour would not show up in a scanning electron microscope. So, if this picture is 'real', it must also be heavily enhanced and manipulated.

The important question concerns the device itself. The nanolouse manoeuvres to get close to a red cell, then grabs it with glass-like pointed claws, and injects a needle.

> Pictures must not be divorced from science and scientific plausibility.

The picture projects an aura of planning, purpose and serenity, very much like the space shuttle docking with a space station or a crane grabbing a steel beam. But life is not serene or deterministic at these length scales. The size of red blood cell is 7 μm. Below these scales, thermal motions provide a randomizing effect and the tips of the pincers may fluctuate. Surface forces, such as van der Waals forces, electrostatic forces and perhaps the interactions between the device and the cell would be critically important. If both the cell and the glass were negatively charged, for example, the cell would repel the claws. A very sophisticated control process would be required to position the claws around the cell, especially when considering random brownian contributions and attractive or repulsive forces. How would the device get this information? Processing information and injection both require energy — where would this come from? How is the micromachine propelled? As the effects of viscosity completely dominate dynamics at these scales[7], the mechanisms of propulsion are unlike those that work at macroscales[8].

Figures influence people, sometimes subconsciously. Would an image such as Fig. 3 influence someone trying to design a nanolouse? If the objective is to design a micromachine to inject a substance into a red cell, the resultant device would not look like the one portrayed in the figure.

Finally, scientists publishing figures as part of their research papers should always ask some general questions. What is the point of the image? Is the objective to teach, to excite or to show how things could be? How can this objective, whatever it might be, be made clear to the viewer? There are many new tools for making beautiful drawings, but if good use is to be made of them, scientists and artists should collaborate closely. Going all-out with computer-generated images without asking questions like those discussed here may be a perfect example of confusing progress with progression. ■

Julio M. Ottino is at the R.R. McCormick School of Engineering and Applied Science, Northwestern University, Evanston, Illinois 60208, USA.

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