Trends in Immunology

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Special Issue: Communicating Science

Scientific Life

The Scientist as Illustrator

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Proficiency in art and illustration was once considered an essential skill for biologists, because text alone often could not suffice to describe observations of biological systems. With modern imaging technology, it is no longer necessary to illustrate what we can see by eye. However, in molecular and cellular biology, our understanding of biological processes is dependent on our ability to synthesize diverse data to generate a hypothesis. Creating visual models of these hypotheses is important for generating new ideas and for communicating to our peers and to the public. Here, I discuss the benefits of creating visual models in molecular and cellular biology and consider steps to enable researchers to become more effective visual communicators.

A Historical Perspective

From looking through the history of science, it might seem that being a polymath (excelling in the arts as well as the sciences) was a major criteria for success. This was likely due to the fact that scientific progress depended heavily on not only scientists' powers of observation and deduction, but also their talent at illustration. It follows that many acclaimed scientists in history were also highly skilled artists and draftsmen. Perhaps the most famous is Leonardo da Vinci, the quintessential 'Renaissance man', who made important contributions in art, science, and technology. Leonardo's careful study of human anatomy and interest in proportions was demonstrated in the *Vitruvian man*, one of his most famous drawings.

With the rise of the printing press, scientists could reach a larger audience with whom they could share their findings. In *Sidereus Nuncius*, Galileo Galilei was the first to publish observations made using a telescope. A polymath who excelled in astronomy, mathematics, and physics, Galileo had also studied medicine and had once considered a career in painting [1]. His manuscript included over 70 detailed illustrations, including the first realistic depictions of the craggy and pitted surface of the moon. Around 50 years later, Robert Hooke, a polymath scientist who had also trained to be an artist in his youth, published a book detailing his observations of 'minute bodies', including a flea and the point of a needle, made through a microscope. With numerous large, intricate illustrations, *Micrographia* became a bestseller and is credited for inspiring a new generation of microscopists and biologists.

For centuries, the ability to create detailed illustrations continued to be an important way for scientists to communicate their findings and hypotheses with their peers. Santiago Ramón y Cajal, widely considered to be the father of modern neuroscience, drafted hundreds of detailed drawings of neurons and neural tissues over his research career, many of which are still used as references in modern neurobiology textbooks. His observations and meticulous drawings brought about a paradigm shift, convincing many of his colleagues that the neural system comprised individual interconnected cells rather than a continuous membranous network.

With the rise of imaging technology, it is no longer necessary for researchers to take up a pen or paintbrush to record and share their observations. However, I would argue that scientific progress remains just as dependent on the skills of visual communicators as it ever was in the past.

Drawing to Understand

In molecular and cellular biology, our understanding of processes is typically based on experimental data that are indirect, abstract, and collected by different laboratories using an assortment of techniques over the course of decades. To understand processes that are taking place at scales smaller than the wavelength of light, biologists must synthesize diverse data to generate a working model or hypothesis. In contrast with scientists of the past, we must rely on visualizations not to record and share our observations, but to create and communicate our deductions.

We might be interested, for example, in a protein that we know from genetic analyses to have an important role in communication between different immune cells in specific tissues. Light microscopy data show that this protein is localized primarily at the plasma membrane, and changes its localization dynamically over the course of the cell cycle. From biochemical studies, we know that this protein has several binding partners and a specific catalytic activity, and X-ray crystallography studies have provided a detailed understanding of the structure of protein domains that appear important for its function. To make sense of these disparate data, it is necessary for researchers to take up the role of the storyteller, synthesizing the known information to develop an explanation of how and why. While some elements of the story may be fully described using only text, information that is visual in nature, including molecular structure, dynamics, stoichiometry, and localization, is more easily and accurately described using illustrations.

Creating visualizations can serve numerous purposes. At their most basic level, visualizations help us to better understand a new idea. The act of creating a quick, rough sketch can be a creative and exploratory process, allowing us to refine a hypothesis and develop new lines of questioning. Many decisions must be made when committing an idea that previously existed only in one's mind to a visually rendered form. What do the proteins look like, and how do they fit together to form a complex? What are the steps that are needed to complete the process? What data do we need to be able to draw a clearer picture?

Another major role of visualizations is to communicate our hypotheses to our peers. Examples of these types of illustration are the model figure [2], which is commonly presented as the last figure of a paper, as well as the 'graphical abstract' that some journals now request. In an idealized form, these illustrations should efficiently and quickly communicate a complex idea, and also be aesthetically pleasing. I emphasize the importance of aesthetics here because an illustration that is pleasing to look at will naturally encourage our peers to spend a longer time studying it, which will, in turn, increase their understanding of, and appreciation for, the subject.

Scientific visualizations also have a critical role in engaging and inspiring the public. The power of images has been especially notable in the field of astronomy, where images, such as those of the surface of Mars, routinely make front-page news across the globe. As beneficiaries of public funds, we also have a responsibility to communicate our findings with the public. Although it can seem significantly harder to drum up public excitement about molecular biology, microscopic images of cells and digitally rendered molecular landscapes can be as visually arresting as those of stars and space. The use of powerful visuals is especially important for biologists, because these images can have a key role in making molecular and cellular research more accessible to broad audiences by providing a jargon-free and engrossing view of a microscopic or submicroscopic world.

When constructing a public-friendly editorial illustration, I often consider creating visual metaphors as well as providing a broader biological context that might help viewers to better understand the scientific story. To accompany a story on bacterial iron piracy [3], my collaborators and I worked on two illustrations, one showing a pirate map with the structures of the relevant proteins as islands (Figure 1C), an example of a visual metaphor, and another illustration showing biological context, in this case, the proteins at the surface of a bacterium contextualized within the bloodstream (Figure 1D).

Through a variety of public-facing venues, including lectures, books, and social and mass media outlets, a compelling image has the potential to inspire and influence broad swathes of the science-curious public. Social media sites, such as Twitter and Facebook, are becoming an increasingly important means to communicate scientific findings to the public in a timely and direct way. Studies have shown that the inclusion of an image or video can drive up viewer engagement dramatically[i], especially where posts or entries are limited to a small amount of text.

Beyond Pen and Paper

As we gain an increasingly detailed understanding of molecular and cellular processes, it is important that the visualizations we create reflect this body of data. This means that, ideally, hypotheses that involve dynamics should be represented by dynamic visualizations (through the use of animation, simulation, and video, for example), and hypotheses that involve 3D structures should be rendered using 3D graphics rather than a 2D line drawing (Figure 1B).

Fortunately, it is becoming easier to create visualizations that move beyond two dimensions, as evidenced by the steady increase in the use of both animated and 3D graphics within the scientific community. This includes 3D PDFs, which allow users to interact with a 3D object (such as a molecular or anatomical structure [4]) or even play an animation within a published manuscript using the standard Adobe Acrobat PDF reader [5]. The use of 2D and 3D animations has also exploded over the past decade, first primarily within the context of educational and outreach efforts, but now increasingly within the research sphere as well [6]. Creating animated or digital 3D models of dynamic biological processes often require specialized training and a significant time commitment, but recent software developments (some of which are discussed in greater detail in recent articles [7,8]) can help to significantly decrease the learning curve.

Training Scientists to be Visual Communicators

There is a great need for biologists to become better visual communicators. All too often, I have seen researchers use 'recycled' or 'borrowed' model figures as the sole visual means of conveying their specific hypothesis. While these illustrations may have worked well for the context for which they were originally designed, they often fail to communicate the nuances of new findings and ideas, particularly when used to convey the research of different groups. Moreover, repurposing old illustrations represents a missed opportunity, specifically, the thoughtful exploration that is required when drawing a model from a blank slate.

Understanding how to create information-rich and coherent graphical representations of our hypotheses is central to scientific progress, and should be a part of the training curriculum for young scientists. Coursework should include discussions about effective data visualization and presentation, with emphasis on both visual modeling of molecules and cells as well as visualization of large multidimensional data sets. An excellent teaching resource for these topics is the 'Points of View' article series, written largely by data visualization expert Bang Wong and published in *Nature Methods*, which covers broad topics, including the effective

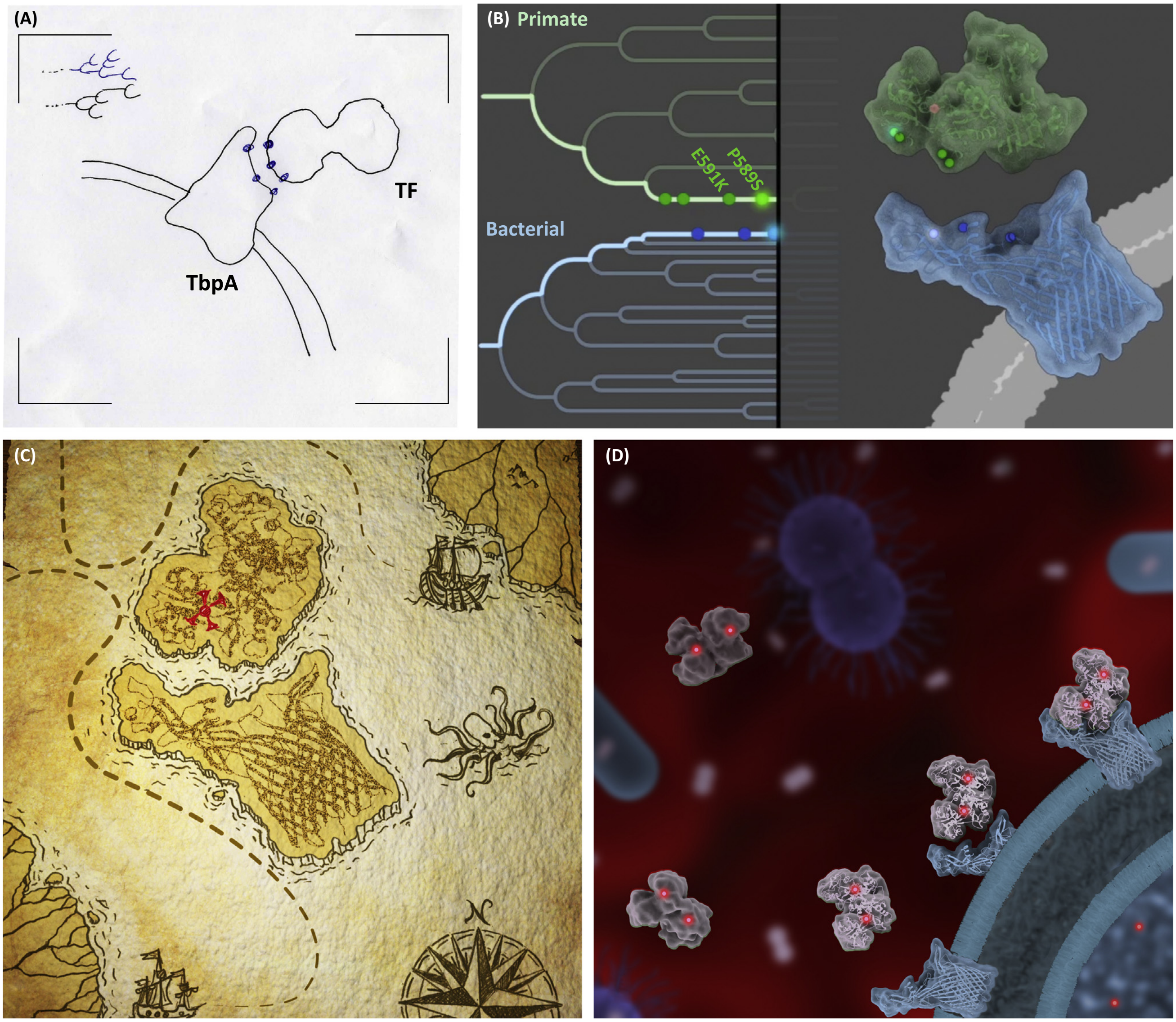

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Figure 1. Illustrating the Evolution of Iron Piracy. A series of illustrations and animations made in collaboration with Nels Elde and Matthew Barber (University of Utah) depicts how a bacterial transferrin receptor, TbpA, is involved in a molecular 'arms race' with the iron-carrying host transferrin protein [3]. (A) A hand drawing of transferrin (Tf) binding to TbpA, located on the bacterial membrane. Dots indicate sites of mutations and compensatory mutations on the binding protein. (B) A still image from the finished animation depicting an evolutionary tree on the left side and the molecular structures on the right side. (C) An editorial illustration on the theme of iron piracy, showing proteins as islands on a treasure map. (D) An editorial illustration showing a contextualized view of the story. In the bloodstream, TbpA is shown on the surface of a bacterium in the lower right, sometimes capturing iron-bound transferrin proteins.

use of color [9] and visualizing multidimensional data [10]. There are also several helpful reviews on the challenges and available tools for visualization of various types of biological data, including 'omics and image data [11].

An effective science communication course should also include an overview of different methods and software that could be used to create different types of visualization, and explanations of when one type of visualization might be preferred over another (for example, when a line drawing might be preferred over a 3D animation). Students should also engage in hands-on activities, such as designing and iteratively improving on a visualization based on peer feedback. Ideally, visual communication coursework would be completed during the first 2 years of training, allowing graduate students to incorporate custom visualizations into their thesis proposals and journal club presentations. A shorter version of a visual communication course could also be incorporated into a workshop and opened to faculty, postdoctoral fellows, and other researchers.

Researchers should also consider collaborations with specialists, such as artists, animators, and designers, to create more effective visualizations. A prominent historical example is the long-term collaboration between artist Irving Geis and crystallographer Richard Dickerson. Geis was an illustrator with *Scientific American* when he was asked to create a detailed painting of a 3D model of myoglobin, the first protein to have its structure solved by X-ray crystallography, in 1958 [12,13]. Geis went on to work with Dickerson to create iconic paintings and drawings of numerous molecules that have graced the pages of textbooks and journals.

Conferences that bring together experts in different fields can seed new collaborations and provide a venue for insightful discussions. Meetings of particular interest for biological visualization and communication include VizBi[ii], the Gordon Research Conference on Visualization in Science and Education[iii], the IEEE Scientific Visualization (SciViz) Conference[iv], and the annual meeting of the Association of Medical Illustrators (AMI)[v].

Visualization is a vital component of modern scientific research, allowing us to both better understand the processes we study and engage broad audiences. Our community has much to gain by encouraging scientists to create more and better visual models, whether by pencil, stylus, or mouse, and to share them openly with one another and with the public.

Resources

[i] https://blog.twitter.com/2014/what-fuels-a-tweets-engagement

[ii] http://vizbi.org/

[iii] www.grc.org/programs.aspx?id=14029

[iv] http://ieeevis.org/

[v] http://ami.org/annual-meeting

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