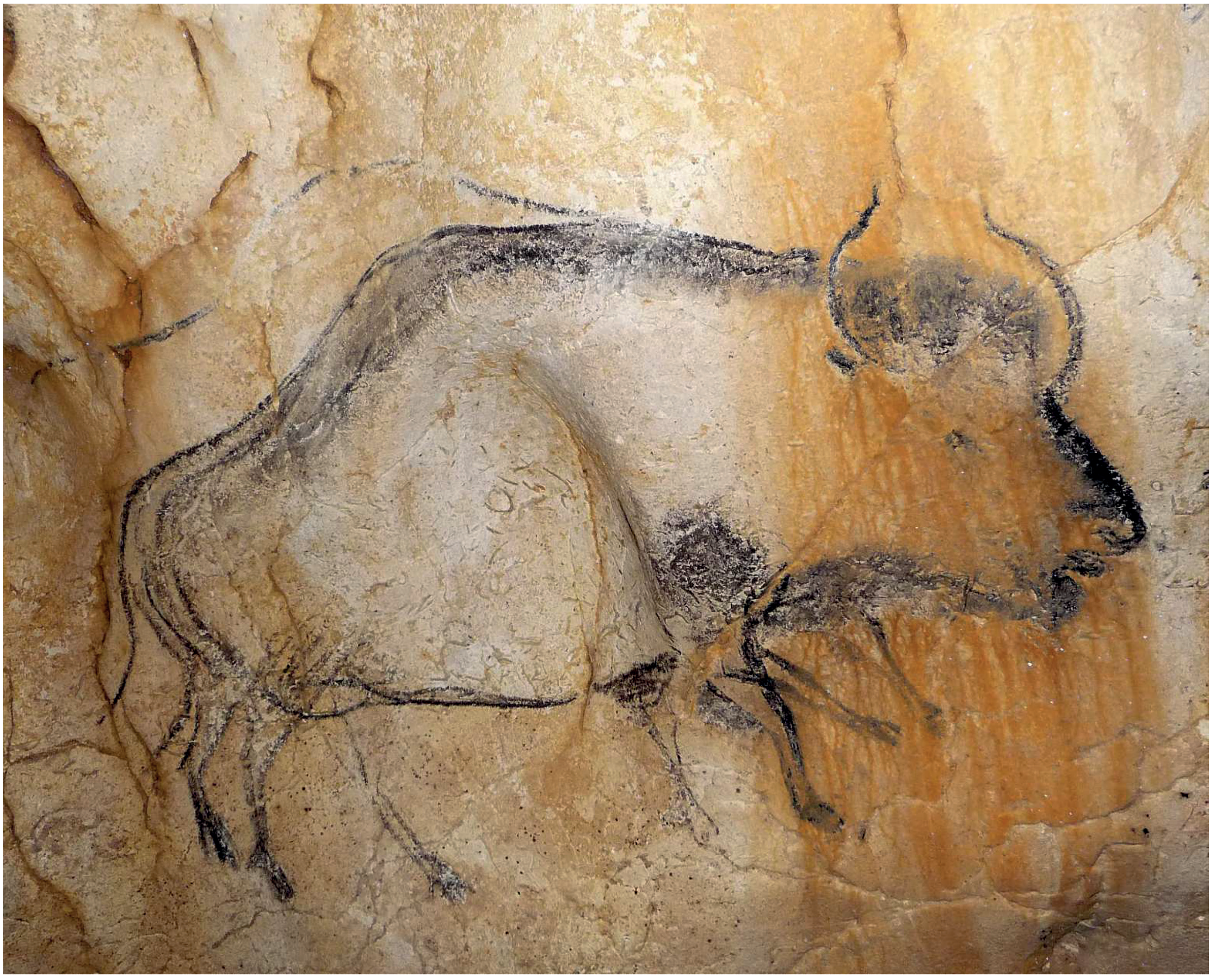
Meeting of the Minds

CHERYL LYN DYBAS

Biology and art find common ground



Scientists used ancient DNA in fossil bones to discover the existence of a bison species—only to find that it had long ago been recorded on the walls of caves across Europe. Photograph: Jean Clottes.

Thirty thousand years ago, ancient humans left their mark on Chauvet Cave, a system of interconnected dark caverns that lies in the valley of the Ardèche River in France. The cave, it turns out, holds one of humanity's earliest examples of the melding of biology and art.

Discovered—or rediscovered—on December 18, 1994, by spelunkers, including Jean-Marie Chauvet, the cave is filled with paintings, engravings, and drawings of mammoths, cave lions, rhinos, cave bears, foxes, and bison.

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A modern-day European bison, also called a wisent (*Bison bonasus*), in the Białowieża Forest in Poland. Photograph: Rafal Kowalczyk.

Archaeologist Jean Clottes of the French Ministry of Culture (retired), whose research on the site is featured in the 2011 documentary *Cave of Forgotten Dreams*, headed the team that dated the oldest paintings to more than 30 millennia ago. "These early artists lived in a world full of animals," says Clottes. "They knew them well as they observed them every day. Their drawings are a consequence of that intimate knowledge."

From ancient cave paintings to today's molecular biology studies of the Zika virus, biology and art have long been intertwined. In recent years, scientists, artists, and educators have studied ways these seemingly very different disciplines may strengthen each other.

Branches of the same tree: STEM to STEAM

A new National Academies of Sciences, Engineering and Medicine (NAS) report, *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree,* emphasizes that all forms of inquiry are, as Einstein stated, "branches from the same tree." The effort is known as transforming STEM to STEAM: science, technology, engineering, the arts, and mathematics.

Faculty members and administrators, states the 2018 report, "are advocating for an approach to education that moves beyond the general education requirements found at almost all institutions, to an approach that melds knowledge in the arts, humanities, physical and life sciences, social sciences, engineering, technology, mathematics, and the biomedical disciplines."

The report refers to this new direction as integration. "Advocates of integration see all human knowledge as connected, a network of branches arising from a trunk made up of human curiosity, passion, and drive, but also generative, as new branches split off and grow from old ones, extending into new spaces and coming into contact with other branches in new ways."

Take the idea of in-course integration. That can range from a class that includes a component of another discipline, such as a neuroscience lecture series with an assignment to write a haiku (a 17-syllable poem) about synapses, or an entire course such as design engineering. In such "left brain meets right brain" efforts, integration works well.

In one undergraduate neuroscience course, students who were required to make a 3–5 minute film outperformed students who learned concepts solely through conventional approaches. A course in biochemistry that featured sculpture building based on how proteins fold allowed students to develop


Among Harvard University's most famous treasures is its collection of Blaschka glass models of plants, known as the "glass flowers." The collection contains more than 4,000 models representing some 830 plant species, including* Brownea rosa-de-monte *(West Indian mountain rose) and* Nymphaea odorata *(American white waterlily). Photographs: The Archives of Rudolf and Leopold Blaschka and The Ware Collection of Blaschka Glass Models of Plants, Harvard University Herbaria.

a new understanding of the complex concepts of protein structure. And in a University of Mississippi Field Station course, Biology and Art, students learned botanical illustration techniques and conducted research on the Mississippi Gulf Coast ecosystem.

Early artists-cum-biologists

In Europe's long-ago caves, the painters were also ecologists who took note of their environs, then rendered the results of their "field expeditions" on the walls of Chauvet and other caves, reported geneticists Alan Cooper and Julien Soubrier of Australia's University of Adelaide in *Nature Communications* in October 2016.

"The accuracy of the ancient depictions is remarkable, far better than most of us could manage crouched under a sloping damp wall with flickering light cast by flaming bundles of vegetation and fat," state Cooper and Soubrier in an article in *The Conversation*, also published in October 2016.

What the artists depicted would ultimately recast scientific understanding of speciation. DNA research shows that the Ice Age artists recorded an unknown-to-science hybrid species of bison and cattle. The mystery species, which Cooper, Soubrier, and colleagues named the Higgs bison because of its elusive nature, originated tens of thousands of years ago with the hybridization of the extinct aurochs—the ancestor of modern cattle—and the steppe bison, which ranged across Europe's then-cold grasslands.

That hybrid species eventually became the ancestor of the modern European bison, or wisent, which today survives in protected areas such as the Białowieża Forest in Poland and Belarus. "The genetic signals from ancient bison bones were very odd, and we weren't quite sure a new species really existed, so we referred to it as the Higgs bison after the elusive Higgs Boson," says Cooper. "Finding that a hybridization indeed led to a completely new species was a real surprise."

To trace the genetic history of the animal, Cooper's team studied DNA extracted from radiocarbon-dated bones and teeth found in caves across Europe, the Urals, and the Caucasus.

"The bones revealed that our new species and the steppe bison swapped dominance in Europe several times during major environmental changes," says Soubrier. "Several French cave researchers told us there were two distinct forms of bison art in Ice Age caves. We'd never have guessed that the cave artists had helpfully painted pictures of both species."

The cave paintings show bison with long horns and large forequarters, similar to the American bison, which is descended from the steppe bison. They also show an animal with shorter horns and small humps, like today's European bison. Radiocarbon dating of the artworks showed that one bison type was drawn when steppe bison were present some 18,000 years ago—the other, when the later hybrid species began to dominate Europe 17,000 years ago.

"Despite the huge bison fossil record and drawings of both species displayed on cave walls," state Cooper and Soubrier, "it took us until now to get the story straight."

How many other species are hiding in plain sight, asks Cooper, "helpfully catalogued by prehistoric cave artists?" The importance of art to biology, and biology to art, he believes, is "vastly underappreciated."

Opposite ends of the spectrum?

Fast forward to Leonardo da Vinci's time, the late 1400s. As a 1999 article in *The Economist* explains, the polymath advanced the notion that although images travel from the front of the eye to what was known as the *imprensiva*, now called the retina, they are actually formed in the *sensus communis*, the imagination or the brain. As later scientists looked at how vision works, they found that Leonardo was right, and that artists intuitively use this information in their creations.

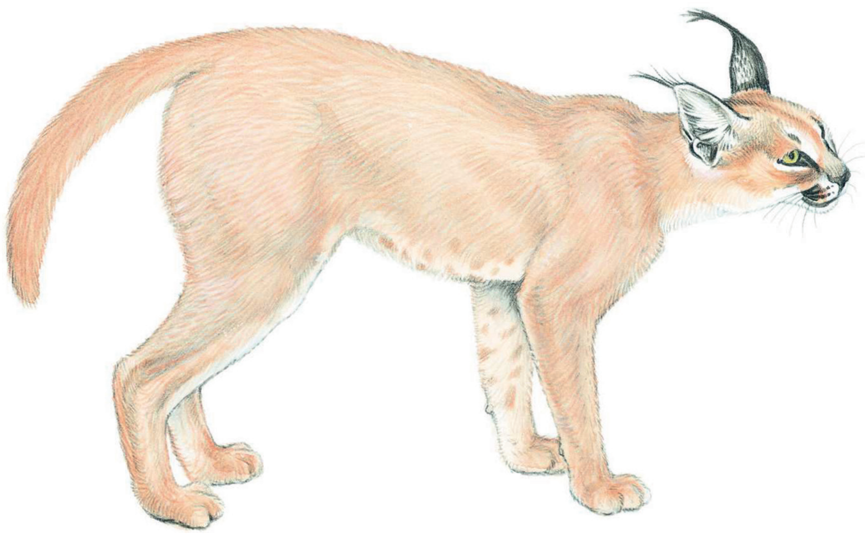
Today, biologists have developed increasingly powerful imaging instruments, and art can be transmitted across the globe in nanoseconds. More than 600 years after Leonardo, where is the common ground? How can biology and art have a meeting of the minds? The only limit, it appears, is our own creativity.

Indeed, a child's painting or piano lessons may someday lead to the next scientific breakthrough. Research conducted by Michigan State University (MSU) scientists shows a link between childhood participation in arts and crafts activities with patents generated and businesses launched as adults. The results were published in a 2013 issue of the journal *Economic Development Quarterly*.

In the study, MSU students who graduated between 1990 and 1995 and majored in a STEM field, then went on to own businesses or receive patents, had eight times more exposure to the arts as children than their unexposed peers. "The most interesting finding was the importance of sustained participation in those activities," says Rex LaMore, director of MSU's Center for Community and Economic Development and a paper coauthor. "If you started as a young child and continued into your adult years, you're more likely to be an inventor as measured by the number of patents generated, businesses formed, or articles published."

Artistic endeavors may foster out-of-the-box thinking, according to these researchers. Indeed, these high-achieving students reported using skills such as analogies, intuition, and imagination to solve complex problems.

The findings could be pivotal to rebuilding the US economy, the researchers say. "Inventors are more likely to create high-growth, high-paying jobs," says LaMore. "We need to think about how we can support artistic capacity, as well as science and math activity."



The caracal cat, sometimes called the "desert lynx," as depicted by zoologist–artist Jonathan Kingdon. His well-known drawings of African mammals vividly portray the connections between an animal's form and function. Illustration: Jonathan Kingdon.

LaMore is right on target, according to data released this year by the US Bureau of Economic Analysis and the National Endowment for the Arts. According to the two agencies, the arts contribute $763.6 billion to the US economy—more than agriculture, transportation, or warehousing—and employ 4.9 million workers across the country with earnings of more than $370 billion. And the arts exported $20 billion more than they imported, a positive trade balance.

Interest in the intersection of art and biology is blossoming. Take, for example, the glass flowers on exhibit at Harvard University, which attract more than 100,000 visitors each year.

The glass flowers of Harvard

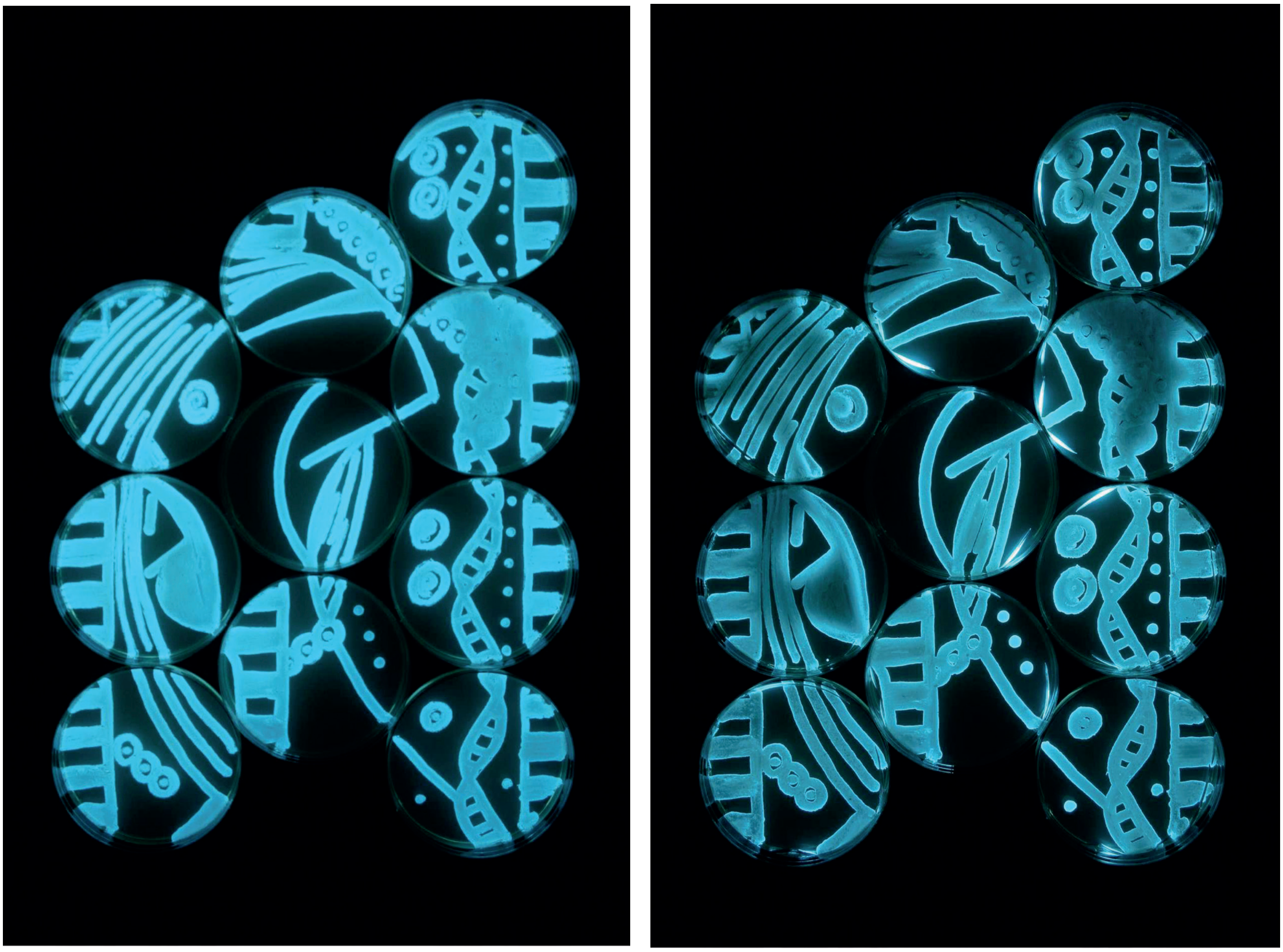
Harvard's love affair with glass flowers began in 1886. George Lincoln Goodale, then director of Harvard's Botanical Museum, set out on a trek from Cambridge, Massachusetts, to Dresden, Germany. Goodale was scheduled to meet with Leopold and Rudolf Blaschka, a father and son who had produced exquisite glass models of marine invertebrates for museums around the globe.

Goodale wanted plants for the Harvard museum that would "convey the beauty and vitality of the plant kingdom, and through which he could interest a large viewing audience," state Richard Evans Schultes and William Davis in their book *The Glass Flowers at Harvard*. Typical plant replicas of the late 1800s did not show accurate detail, Goodale believed, so he hoped to convince the Blaschkas to produce glass plant models. They agreed to take on the task.

The resulting glass models have been described as artistic marvels in science, and scientific marvels in art. The first glass plants the Blaschkas made are now more than a century old, and other than their time on display in exhibits, are primarily used in botany lectures. "The glass flowers, in addition to being stunningly accurate to the smallest detail, are 'in flower' year 'round and consequently make superb teaching tools," write Schultes and Davis. Today, the flowers are the largest public attraction at Harvard University.

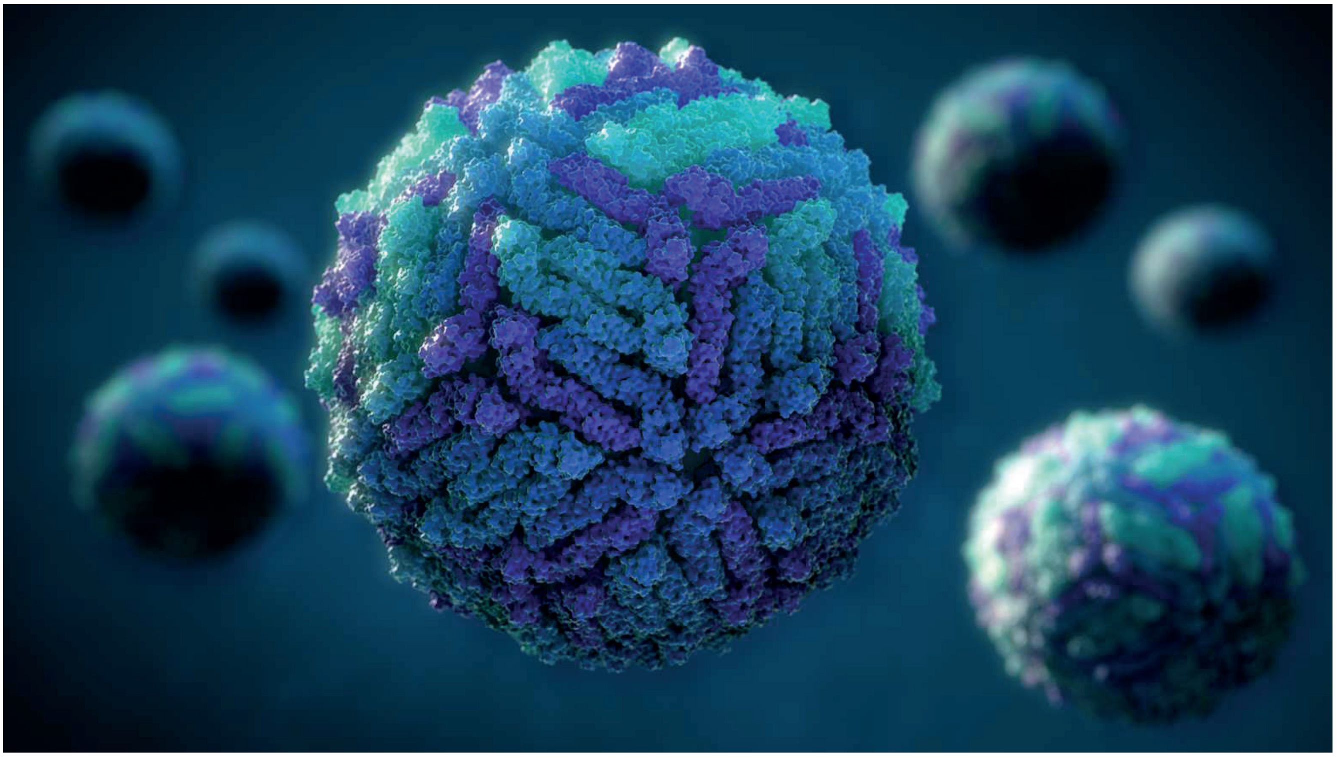
In the eye of the beholder

The Blaschkas turned what they saw in nature into lifelike glass replicas.



Bioluminescent bacteria become art. With a paintbrush, a biologist–artist draws the bacteria into different shapes, then photographs them. Pictured here: her own DNA. In the second stage, the bioluminescence has begun to dim. Images: Hunter Cole.

A medical physicist films the inner workings of animals and plants, turning them into X-ray art. Here, a snipe that drowned in a garden pond, and a polecat mother and pup found, as pictured, outside the city of Amsterdam in the Netherlands. Images: Arie van 't Riet.



An illustrator joined a team of biologists searching for a Zika virus cure. The collaboration led to coauthored papers in such journals as **F1000Research**. *Image: Copyright John Liebler,* **www.ArtoftheCell.com**. *All rights reserved. Used with permission.*

"The humblest field record is always an act of translation," writes zoologist-artist Jonathan Kingdon of the University of Oxford in the book *Field Notes on Science & Nature*. "Whatever is recorded, whether animal behaving, plant yielding, dawn revealing: all have to be processed by human senses and translated into words, numbers, sketches, photographs, or any one of many other communicative conventions or devices that serve to inform other humans."

Kingdon, born in Tanzania, is well known for the precise drawings of African mammals that grace the pages of his books, including *The Kingdon Field Guide to African Mammals*. His use of drawings as a complement to scientific observation began with a "desire to assemble an 'atlas of evolution' that doubled as a mammal inventory of East Africa," he says. "Drawing seems to me to be as appropriate an expression of thought as mathematical formulae or tables. The probing pencil is like the dissecting scalpel, seeking to expose relevant structures that may not be immediately obvious and are hidden from the shadowy world of the camera lens."

Take Africa's caracal cat. The caracal, as Kingdon describes it, uses small movements of its head and its black-tufted ears to send information to other caracals. "Caracal ear- or head-flagging is intricately crafted," says Kingdon. "I believe drawings can be a clearer medium for exploring such visual Morse code than laborious written accounts or quantified records."

In a tribute to Kingdon published in the *Journal of East African Natural History*, Francesco Rovero of the Museo delle Scienze in Trento, Italy, states that Kingdon's "capacity seems to rest on an exceptional attention to details, a capacity he developed literally firsthand by observing wildlife and drawing animals in their habitats, revealing the intimate connections between animals' forms and functions."

Further reading.

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Drawing with living light: Bioluminescent bacteria

Kingdon's precise drawings are rendered with pencil and paper. Biology and art have come together in a more high-tech way in the "paintings" of Hunter Cole. A geneticist affiliated with Loyola University New Orleans, Cole produces work that is inspired by science but literally lives as art through the otherworldly glow of bioluminescent bacteria.

The biologist–artist creates liquid cultures of bioluminescent bacteria, then, using a paintbrush, draws the bacteria into different shapes in a Petri dish. Next, Cole photographs the luminescent petri dishes to create what she calls modern works of provocative symbolism. Her subjects include lilies, insects, and humans, including her own DNA, all seen by the light of bioluminescent bacteria.

"Art and science have always been mutually inclusive for me," says Cole. "Biology serves as a vehicle for expressing my creativity and artistry. Art serves as a motivation to interpret our living world."

Earlier this year, a multimedia display at Chicago's ARC Gallery—"Living Light: Photographs by the Light of Bioluminescent Bacteria"—featured her creations. The exhibit showcased Cole's bioluminescent artworks developed between 2005 and 2017. In addition to looking at bioluminescent photos, visitors watched a time-lapse video of luminous bacteria growing and fading, accompanied by a musical score based on protein sequences in the bacteria.

Drawing with bioluminescent bacteria is a tricky endeavor, Cole says. "First I make a culture of the bacteria, dipping a paintbrush or Q-tip in the liquid and painting on agar in a Petri dish. But it's like painting with invisible ink. You need to wait until the next day to see it glowing." She photographs the paintings as the luminescent bacteria grow and die over a period of days.

Now Cole has developed a Loyola course called "Biology Through Art." The class offers students an opportunity to create their own bioluminescent bacteria drawings while working in a biology laboratory. "It's amazing how much the arena of art-and-biology has expanded," says Cole, "with so many more practitioners over the last few years."

Capturing inner beauty with x-ray art

Biophysicist-turned-artist Arie van 't Riet in the Netherlands agrees. A medical physicist, van 't Riet has long worked in a hospital, giving him the foundation for what would become art. For van 't Riet, X-ray machines became paintbrushes; radiation, the paint. He now "films" the inner workings of animals and plants, in the process turning them into x-ray art. "My X-ray images of nature are not made in the hospital, though," he says. "I have a studio with X-ray equipment and a license to take X-rays."

The animals he works with have all passed on. "In my opinion," van 't Riet says, "it's not justified to expose living animals to the risk of X-rays for art." His X-ray art is not composed of different layers or different X-rays, "so no stacked images," he says, "and not assembled. The complete set-up of the natural scene or biorama is built and X-rayed in one session."

In a darkroom, the exposed X-ray film is taken out of its envelope and inserted into a film processor. The film is then automatically transported through a developing bath, a water bath, and a dryer. "The total procedure takes about 2 minutes," says van 't Riet. Ultimately, a digitized X-ray image is edited with Photoshop, gray levels are adjusted and color is added to some areas.

The result? Images like those shown here. A snipe found drowned in a garden pond and a deceased polecat mother and pup discovered in an urban area, live again through X-ray art.

Fighting Zika with animations

While biologist Arie van 't Riet's artistic career began in a hospital, John Liebler of Art of the Cell in Guilford, Connecticut, and colleagues are using their creativity to try to keep people out of one.

Liebler is a biomedical animation specialist known for the highly regarded video "The Inner Life of the Cell." He became interested in creating a 3-D model of the Zika virus, inspiring pharmacologist Sean Elkins, CEO of Collaborations Pharmaceuticals in Raleigh, North Carolina, to develop models of Zika proteins.

Their combined efforts, which now include the work of infectious disease researcher Carolina Horta Andrade of the Universidade Federal de Goias in Brazil, led to a coauthored journal paper. "Illustrating and homology modeling the proteins of the Zika virus" was published in *F1000 Research* in 2016. Homology models are computational, three-dimensional renderings of proteins, and are especially useful when protein structure is not known, as is the case with the Zika virus.

The research fostered the OpenZika project, which aims to identify drug candidates to treat the virus. Scientists are using software to screen millions of chemical compounds against the proteins Zika likely uses to spread. "As knowledge of this virus increases and key proteins are identified," says Andrade, "the OpenZika team will use that information to refine the search." The viewpoint of a graphic artist, she and Elkins say, has been an integral part of their quest to find a cure.

The Zika collaboration, Andrade believes, is a model for those working to solve the increasingly complicated problems society faces. Teaming up with artists has altered scientists' designs and methods. Similarly, write Aaron Ellison of the University of Massachusetts Amherst and colleagues in the *Bulletin of the Ecological Society of America*: "collaboration with scientists has helped artists delve deeper into issues, gain insight into processes, and tackle more complicated concepts in their artistic practice. These partnerships may change and enrich the way we do both science and art."

Award-winning science journalist and ecologist Cheryl Lyn Dybas (cheryl.lyn.dybas@gmail.com), a Fellow of the International League of Conservation Writers, often covers conservation biology for BioScience.