Scientists Create Bonds with Artists

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Artists and scientists cross the disciplinary chasm to produce something beautiful.

Images are essential to analytical chemists, which is why they grace the cover and virtually every paper published in this journal. Yet, the connection between chemistry and art has typically been tenuous for the last half of the 20th century.

Art and science were once intertwined by necessity because observational data and experimental setups could only be rendered by hand. Introducing photography and modern imaging technology to the lab essentially made capturing images routine. As a result, the aesthetic process of carefully producing images, which can lead a researcher to examine and think about a

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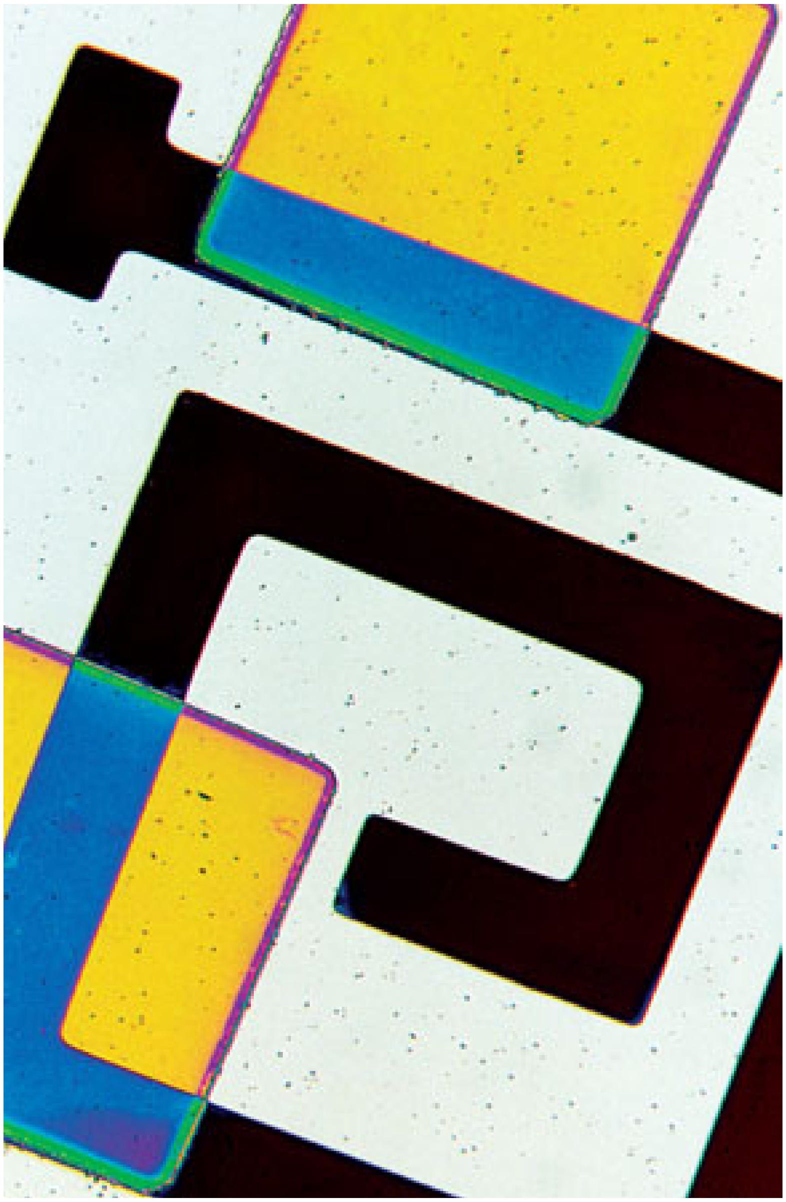
ZERO@WAVEFUNCTION. (above) A participant uses his shadow as if it were the tip on a scanning tunneling microscope and causes the "buckyball" to deform. (left) Children play with buckyballs projected on a wall at the Zero@Wavefunction exhibit at the Biennial of Electronic Arts in Perth, Australia, in August 2002.



FELICE FRANKEL, *ENVISIONING SCIENCE*

POLYMER PATTERNS. Felice Frankel created this image of two layers of patterned polymers, which were prepared by Kathy Vaeth at the Massachusetts Institute of Technology, using a photographic technique called Nomarski contrast, which accentuates form and adds color. Nomarski contrast is a compound microscope technique, which creates contrast from differences in the index of refraction caused by an object.

topic, is now often overlooked. Today's digital world also offers researchers temptations such as new shortcuts to "enhancing" images that raise ethical questions (see sidebar on p 170 A).

In recent years, several pioneering researchers have teamed up with artists to bridge the chasm between art and science. In addition to making science more accessible to the public, these collaborations may prove valuable to researchers. "It will help [scientists] communicate with all the other people [in other disciplines] and will help them to think a little bit beyond their own area of science," says James Gimzewski, a nanotechnology researcher at the University of California–Los Angeles (UCLA).

Collaborations

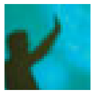
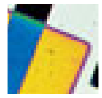
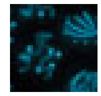
Examples of these collaborations can be seen in projects at universities around the country, such as UCLA, the Massachusetts Institute of Technology (MIT), and Montana State University–Bozeman (MSU).

Zero@Wavefunction at UCLA. Gimzewski met Victoria Vesna, an art professor and director of media arts at UCLA who had studied Buckminster Fullerene's architecture for her doctoral thesis, at a November 2001 symposium for artists and scientists. Gimzewski granted Vesna access to his lab, and this led to the interactive computer simulation called Zero@Wavefunction, which refers to the Schrödinger equation (*5*).

The simulation generates images of "buckyballs" that are projected onto an extremely large screen. If a person steps between the projector and the screen, his or her shadow essentially "becomes" a scanning tunneling electron microscope (STM) tip. As the person's shadow approaches a buckyball on the screen, the image will deform and move as if it were being pushed by an STM tip.

The arrangement reverses the normal size relationship, allowing the participant to become smaller than the sample and providing a unique view of the nanoscale world. "Here you are sensing this 'thing,' and you are exploring it by the way you deform it, which is very much like the nanomechanics people do with force spectroscopy," says Gimzewski. "It's almost like on the scale of nanometers. Everything is different. [Participants] find that their shadow actually influences the buckyball, distorts it and moves it, but in a manner that is very different than common human experience."

The first version of the system treated the buckyballs as soccer balls. "You touched it and it bounced around like [something in] a Nintendo game," says Gimzewski. However, movements are very different at the nanoscale level; the buckyballs

have so little mass that the momentum normally imparted by touching a soccer ball is almost nonexistent.

The finished product fascinated everyone, even the director of research from Intel, says Gimzewski. "We exaggerated some of the stuff," he adds. "I want to just give them the sense that it is a different world."

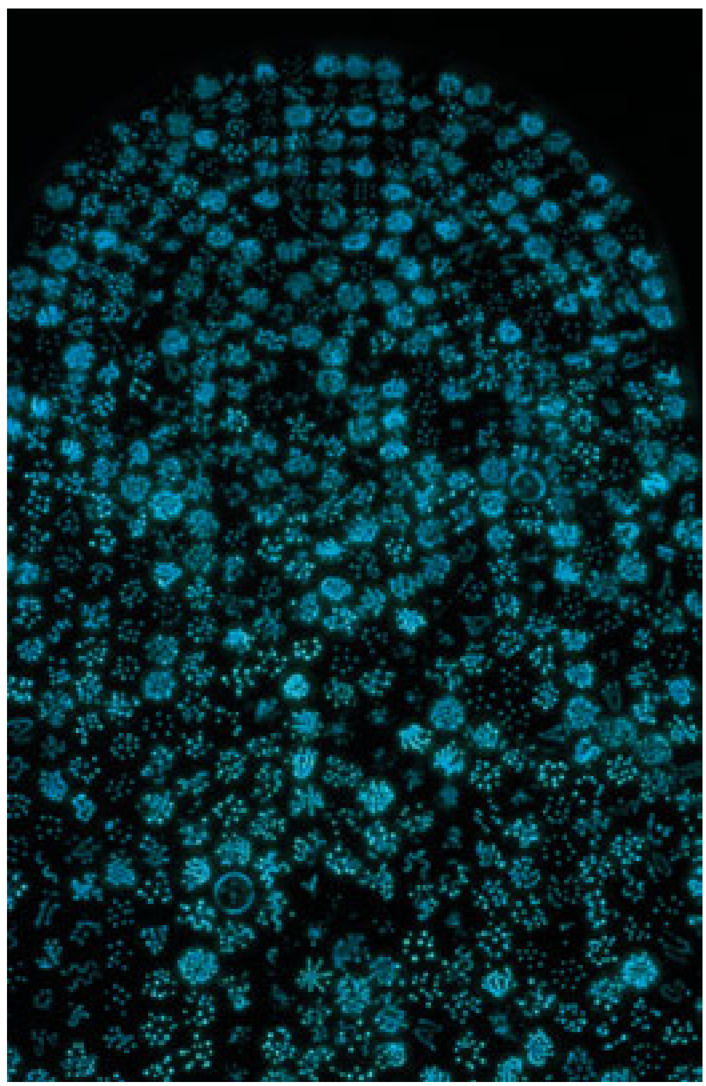
"On the surface of things" at MIT. George Whitesides, a chemistry professor at Harvard University, and Felice Frankel, a photographer and research scientist at MIT, began collaborating on science images in the early 1990s. Inspired by the world of materials science, they published *On the Surface of Things* in 1997; Whitesides wrote the text and Frankel produced the images (*6*).

Frankel picked up photography as a hobby while working as a lab technician in New York City. She eventually became a landscape and architectural photographer and earned a Guggenheim fellowship at Harvard. While there, her interest in science resurfaced and she attended science lectures, including a class taught by Whitesides. Shortly after the two began working together, Frankel and Whitesides created an image of water drops on a hydrophilic self-assembled monolayer, which appeared on the cover of *Science* in 1992.

Frankel and Whitesides are currently working on a new book about nanotechnology. "We are trying to communicate this extraordinary world by bringing people metaphors of what they can comprehend," Frankel says. "My images will be about what is going on in the laboratories, but [I'm] also creating images that are visual metaphors so that people can understand their world around them and connect to the phenomena going on at the 'nanolevel'."

Frankel has collaborated with other researchers, and her illustrations adorn the covers of several journals and magazines, including *Nature, Journal of Physical Chemistry B,* and *Scientific American*. "I am absolutely convinced that the process of making a visual representation of something clarifies the concepts behind that idea," says Frankel.

Bioglyphs glow at Montana State. Betsey Pitts, a research associate at MSU's Center for Biofilm Engineering (CBE), was enthralled by the visual properties of biofilms long before she and others at MSU–Bozeman launched the Bioglyphs exhibition (*7*). "I had something like 30 agar plates on the bench top, all containing colonies of different bacteria isolated from toilet bowls," says Pitts. "They were all different colors; some were slimy, like 'boogers'. If you smelled them, you thought, 'Fritos' or 'dirty feet' or even 'minty'."



ILLUMINATED BIOGLYPH ARCH. Researchers from MSU and students of Robert Sharp at Manhattan College created this 5 × 9 ft arch from bioluminescent bacterial films grown in specific patterns on petri dishes for a second Bioglyphs exhibit held in December 2002 at the O'Malley Library at Manhattan College in Riverdale, N.Y. (The first exhibit was held in Bozeman, Mont., in April 2002.)

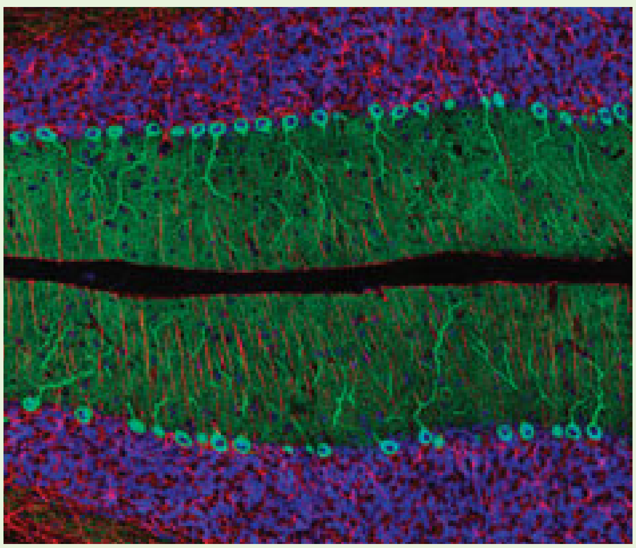
MSU–BOZEMAN BIOGLYPHS PROJECT, 2002

Digital enhancement creates shades of gray

When James Hayden, a microscopist at the Wistar Institute in Philadelphia, asked his Nikon representative to recall the last time she sold a microscope with a film back, she had to think. The representative told Hayden that, in the past 4 to 5 years, everyone purchased digital equipment.

Nearly all scientific images have succumbed to the digital age. Digital imaging technology—including digital cameras, scanners, and software—provides faster turnaround time and distribution between collaborators, but it also allows a researcher to "enhance" an image, which presents ethical questions. Whether this creates a problem depends on the ultimate context of the image. Research data, journal and magazine covers, and science-related art displays fall into very different categories.

Hayden recalls that famous examples of questionable digital enhancement began to emerge more than 20 years ago. In 1982, *National Geographic* "moved" the Pyramids of Giza closer together to fit the narrow dimensions of its cover, without telling readers (*1*). Controversy brewed again when nature photographer Art Wolfe duplicated a picture of six zebras to make the herd look much larger for the cover of his book *Migrations* (*2*). He thought of it as art but was criticized for presenting information that was inconsistent with migration patterns.



THOMAS DEERINCK

PRIZED AND DIGITIZED. This photomicrograph of the sagittal section of a rat cerebellum earned first place for Thomas J. Deerinck of the National Center for Microscopy and Imaging Research, University of California–San Diego, in the 2002 Nikon International Small World Competition. He actually composed 30 different images acquired at 40× magnification with fluorescence under a confocal microscope. The contest has no rules against digital enhancement.

In the scientific literature, most researchers and photographers agree that an image in a research paper is data and therefore subject to scrutiny and the standards of scientific reproducibility; yet an overall enhancement, such as adjusting the contrast or color to ensure that the image represents reality, is generally accepted. For example, Hayden says, using the wrong film or voltage can produce photos with a yellow tint after processing. In the "prelude to the digital age," such adjustments were done in the darkroom, but now computers make global changes much easier. However, he says, "If you think you can use Photoshop to fix up the artifacts, you have to get into a discussion of what is an artifact, and that is where [the ethics] can get fuzzy."

"If a scientist is thinking, 'Should I digitally enhance this image or piece of data?' the question to ask after doing it is: 'Is this objective or has this enhancement only skewed it to show what I want to show?'" says Hamid Ghanandan, president of The Linus Group, an advertising agency, and a former biochemist. Hayden will not make adjustments that alter the internal relationships in the image, such as removing artifact lines from a gel. In the past, altering images was difficult. Researchers had to redo the experiment or explain any artifacts and data abnormalities in a caption, which "sort of kept people honest that way," Hayden says.

In this regard, the peer review system has exposed some image frauds. For example, Hayden recalls that several people working in a German lab reported that a researcher was fabricating new data from old data (*3, 4*). A committee analyzed his work and agreed, finding that gel images in more than 90 of his papers were digitally fabricated.

Are journals or colleagues responsible for checking if image data is original and legitimate before publication? Felice Frankel, a photographer and research scientist at MIT, believes that researchers would take their images as seriously as their experimental methodologies if journals required a full disclosure in print or on the Web of how each figure and photo was created and enhanced.

Scientific images appearing on journal and magazine covers constitute another shade of gray. "The purpose of a cover is not the same as the purpose of an image in the body of a paper," says Hayden. Data in a paper needs to be reproducible; covers generally illustrate themes, he adds. Most covers are used as marketing tools to attract readers, so aesthetics get high priority. When Ghanandan creates covers for scientific journals, he "wants to express the art and the science at the same time." Dealing with proteins, for example, usually means illustration because "even if you look under a microscope, it will look like a white glob," he says. In that case, he has no issue with creating an imaginary world in a 3-D illustration program, taking a "snapshot" and enhancing it for aesthetic reasons. Maisie Todd, director of photography for the popular scientific magazine *Discover*, says her staff alters images intended for conceptual or illustrative purposes like covers, but they would never alter pictures from scientists that are critical to research.

On the other hand, digital platforms and enhancements are welcome in photomicrograph contests and science-based art exhibits. Even respected scientific imaging events like the Nikon International Small World Competition are not setting rules against digital enhancement or even requiring disclosure (see image at left). Hayden, a competition judge, adds that the submission rules were recently changed to include digital images because few people use slides.

Biofilms are composed of bacteria that take on different characteristics when they grow as a film. They are quite common; the best-known example is the plaque that grows on teeth. Pitts showed her biofilm collection to Peg Dirckx, a visual communicator at the CBE, and they discussed the possibilities of using it for art. But it was not until 9 years later, and with the cooperation of some MSU art professors, before the project took off.

The art professors visited the CBE labs, and one of them, Sara Mast, became fascinated with fluorescent *E. coli*. Because *E. coli* is infectious, the researchers decided to use the harmless ocean bacteria species, *vibrio*, which forms bioluminescent biofilms at certain densities.

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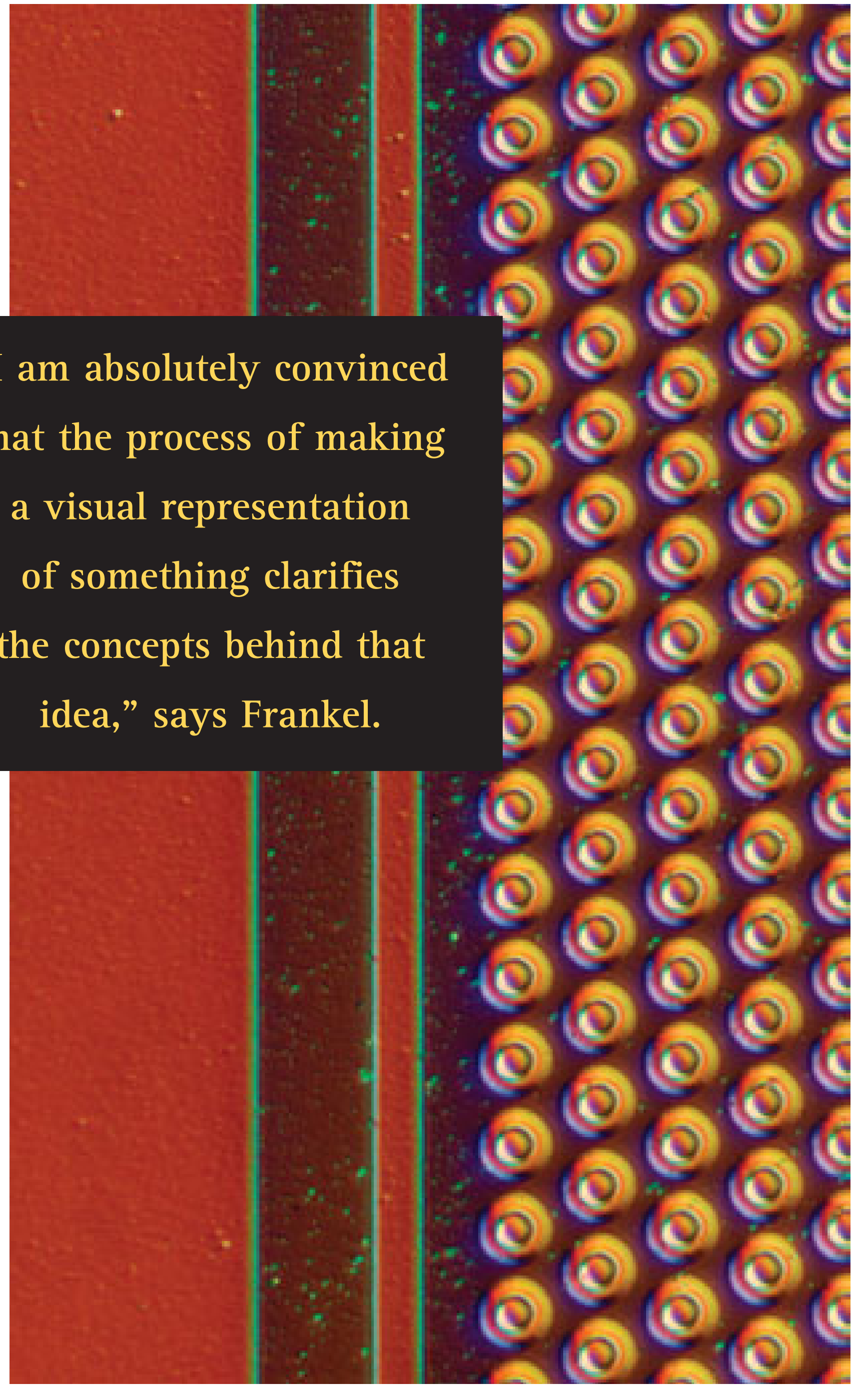

MICROREACTOR ART. Felice Frankel created this close-up shot using Nomarski differential contrast, which is a compound microscope technique that creates contrast from differences in the index of refraction caused by an object. The chip shown contains microreactors constructed in Klavs Jensen's lab at MIT.

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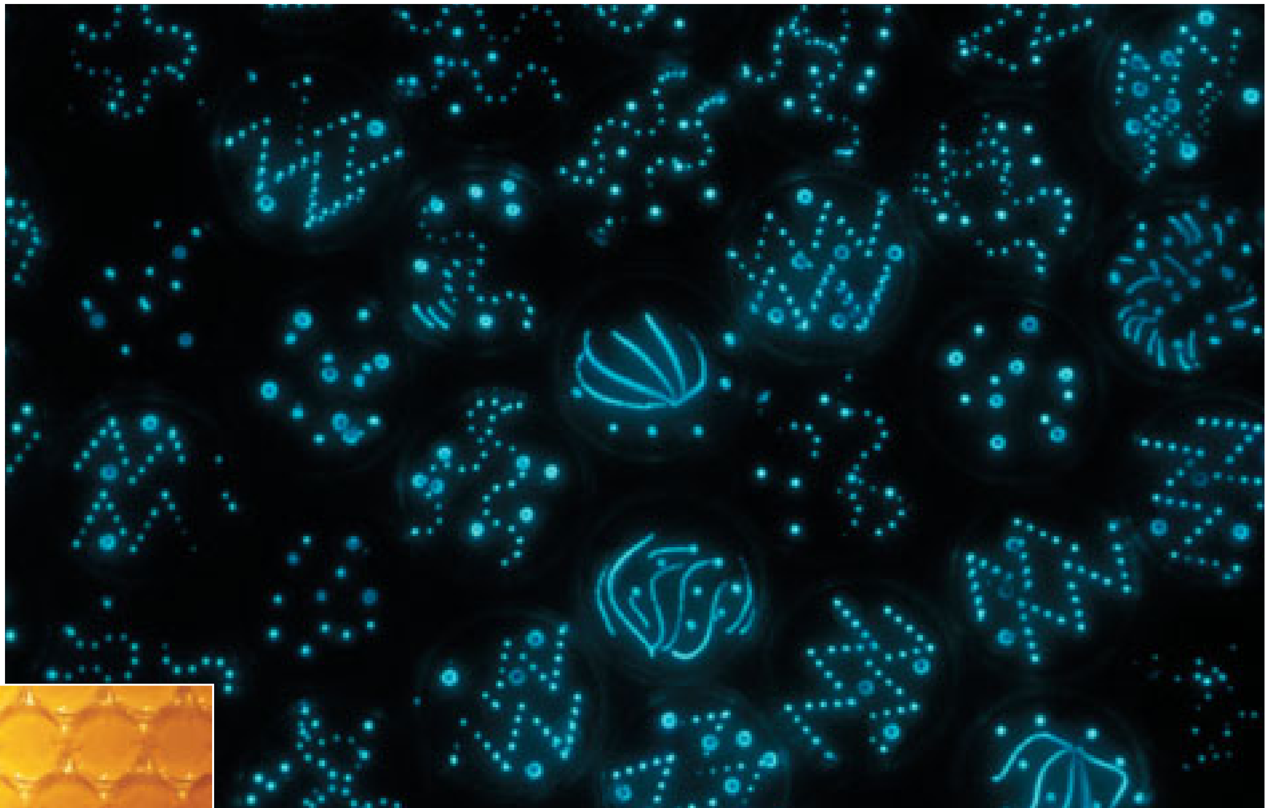
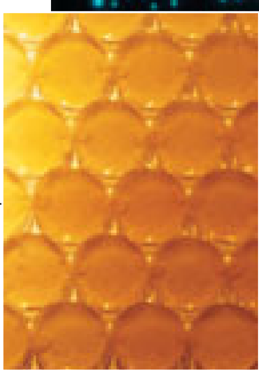
The Bioglyphs exhibitions ended up being collections of *vibrio* "paintings". Designs were literally applied on petri dishes using nutrients and *vibrio* as paint. These were then glued to the wall to form larger designs. The petri dishes are visible when the room lights are on, but when they are off, the bacteria glow in patterns within each dish and form a new, larger image. "We found that certain densities of bacteria live longer than others," says Dirckx. "So then certain plates [appear to] come forward because they are brighter, and certain plates start to recede because they get darker."

To create the exhibition, graduate and undergraduate art students came up with designs and then worked with the researchers to create the bacteria cultures. "The [art students] had to learn microbiology," says Pitts. "They had to put lab coats on—and they liked that, actually. [Artists and researchers] had to learn how to paint with this 'invisible ink', so we all worked together learning how to paint with this new medium." Dirckx adds, "The science students really appreciated seeing the inventive ways that art students used laboratory tools."

Pitts recalls that the gallery attendees asked many science-related questions: "Why do the bacteria make light? What advantages do they have? When will they die? You're not projecting this on the wall?"





MSU–BOZEMAN BIOGLYPHS PROJECT, 2002

BIOGLYPHS UP CLOSE. Upon closer inspection of the Bioglyph art, unique patterns in each petri dish can be seen. These patterns were produced when the bacteria and nutrients were painted on each individual petri dish. (inset) A section of Bioglyph art shown with the room lights on.

Finding mutual respect

Although some artists and scientists have begun working together, such collaborations are not the norm. One obstacle has been the common misconceptions that scientists have about artists. Dirckx, who is also an artist and has worked at the CBE for 13 years, says, "I got the feeling sometimes when I first got here that some people might be stuck on the stereotype that 'all artists are flakes.' And you have to not get defensive about it, because a few of them are." Gimzewski agrees, "I even had an engineering student say, 'Why do you work with an artist? How can a scientist work with an artist?' He was incredulous," he recalls. "So [the responses] vary from unbelievably positive to people who just think I am [playing] around, wasting my time basically." Cynthia Pannucci, founder and director of Art & Science Collaborations, Inc., (ASCI) (*8*) adds, "[Working together] does require—and I want to stress this—a mutual respect, and that is what we, in the artistic field, have felt a real lack of."

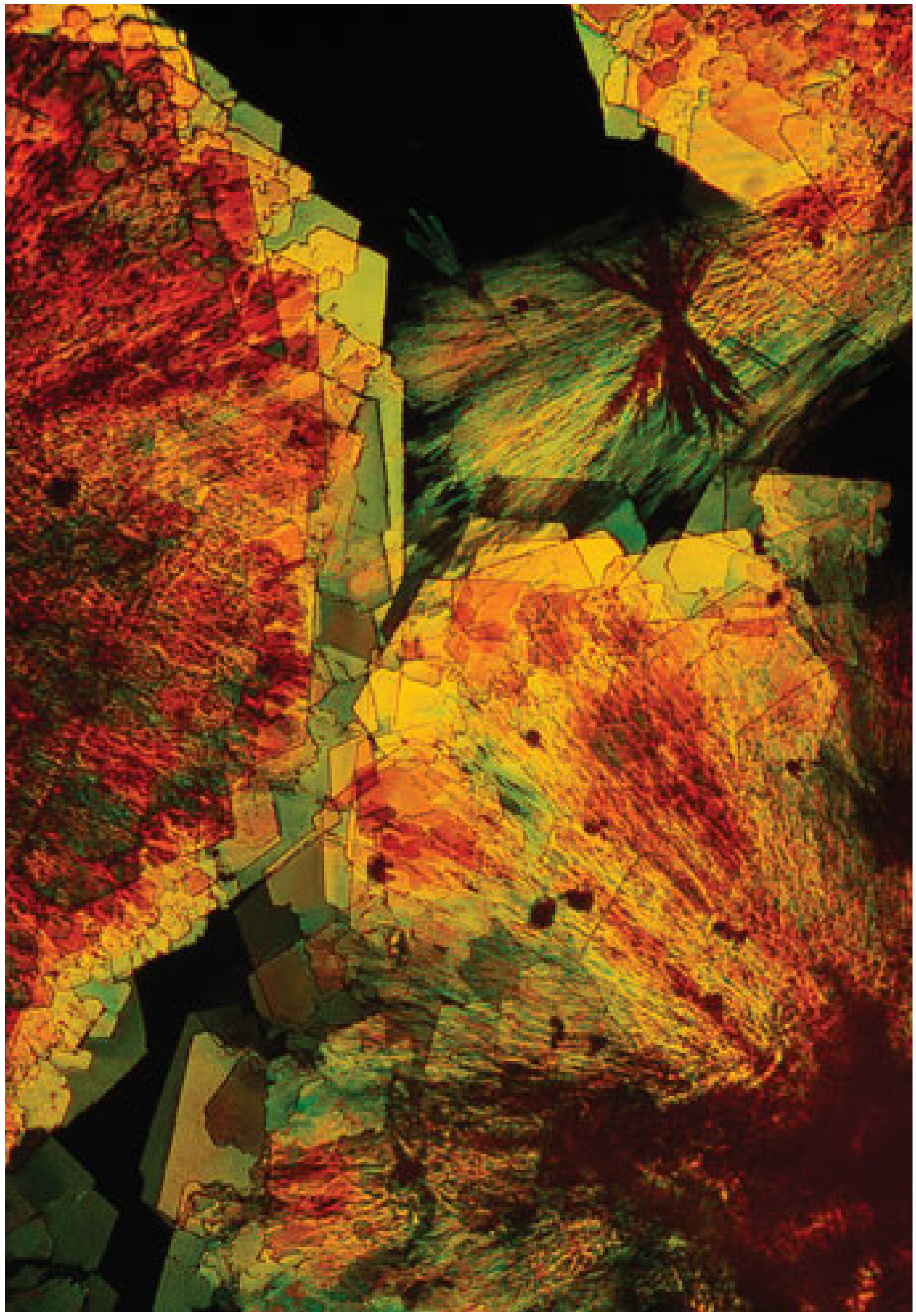
Many artists are very interested in and knowledgeable about science. Pannucci says that some artists "spend all of their time reading science books, science magazines, and going to science museums." She adds, "We don't go to art museums; we are in love with science." Dirckx says, "I like the intellectual stimulation of having daily access to new scientific information. Working with researchers on images, I can share the values of the scientists and absorb their enthusiasm."

Opportunities outside the box

The collaborations highlighted here seem to be bridging some of the gulf between science and art. After the Bioglyphs project, Pitts says, colleagues approached her and asked, "What are you going to do next time? Can I get involved?" Gimzewski says, "There are many people, if the opportunity [to work with artists] existed for them, they would probably take it. But just because the opportunity does not exist, they do not step outside the box."

Undergraduate classes started by these interdisciplinary pioneers may help. Ruth West, a molecular biologist-turned-artist at UCLA, recently taught a course on genetics and culture that was part science course and part art appreciation. It brought science and art students together for some lively discussions. "I think that there has been quite a value in that cross-pollination [between artists and scientists]," says West. She hopes to incorporate art–science practices into new undergraduate curricula being developed at UCLA. Gimzewski says undergraduate interest in a seminar course called Technology and Fashion (in which he was a guest lecturer) was so strong that three times as many students enrolled as there were seats in the classroom. Frankel has proposed an initiative to teach visual communicators on the MIT campus "to basically help bring back on campus what used to be a requirement, [which] is drafting."

Analytical chemists have several avenues to find connections with the art world. ASCI (www.asci.org) has started a service called the ArtSci INDEX to connect scientists and artists on the basis of interests and skills. "It's sort of like a personals matchmaker," says Pannucci. In addition, Frankel recently published a book, *Envisioning Science*, which is arranged like a textbook on how to create more illustrative and communicative images (*9*).



FELICE FRANKEL, *ENVISIONING SCIENCE*

CADMIUM SELENIDE BEAUTY. Felice Frankel captured this image of CdSe crystals. Moungi Bawendi's lab at MIT prepared the crystals using a thin film of an *n*-alkanethiolate to stabilize their surfaces. The colors observed by using dark field illumination correlate to the material's properties: The yellow color results from depolarized luminescence, the green from birefringence, and the red may be from crystal grain boundaries.

Whatever the approach, more collaborations and connections between artists and scientists could help bridge the chasm between their seemingly disparate fields. Science can surely benefit from the creativity generated by these interdisciplinary endeavors.

Michael Felton and Rachel Petkewich are associate editors of Analytical Chemistry.

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