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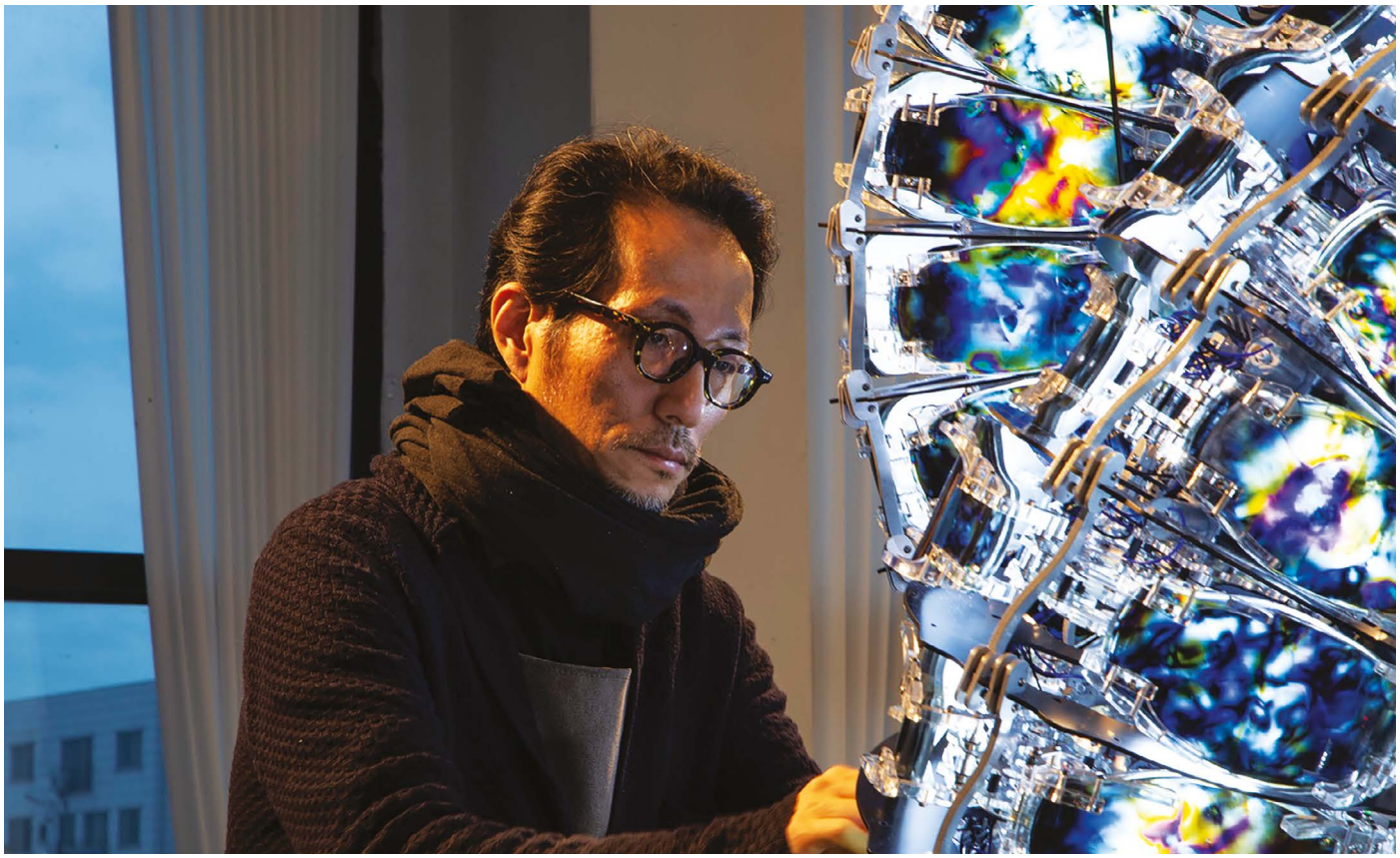

YEONGHO KIM, COURTESY OF THE ARTIST

Seoul artist Yunchul Kim assembles his latest work, *Chroma*, a 15-metre-long structure of laminated polymer in the form of a torus knot.

HOW TO FORGE A PRODUCTIVE SCIENCE–ART COLLABORATION

Researchers and artists reflect on partnerships that have invigorated their careers and deepened the public understanding of science.

Art can be a powerful medium for exploring the deeper meaning of scientific endeavours. Collaborations between scientists and artists are under way around the world, and daily postings to social media with the #SciArt hashtag suggest that the often-disparate domains are merging in fresh and exciting ways. Although many such collaborations aim mainly to engage and educate the general public about science, scientists and artists are recognizing that creative partnerships can turn science into captivating art.

High-profile funders — including the US National Science Foundation in Alexandria, Virginia, the Simons Foundation in New York City and Wellcome in London — have promoted arts-and-science projects on a wide range of topics, including climate change and artificial intelligence. Yet artists and scientists often inhabit different worlds, making it difficult for them to find potential collaborators. And, once a team comes together, it takes time to build a productive partnership that can meaningfully exchange ideas and set expectations for the final product.

Nature Careers sought top tips from art-minded scientists and science-minded artists for launching and maintaining collaborations that can challenge entrenched ideas.

YUNCHUL KIM
DO YOUR HOMEWORK

I started in electronic music in Seoul before moving to Germany in 1999 to study media arts in Cologne. A lot of young artists there wanted to share ideas with scientists, but it's not easy to get access to the institutions or to professional scientists. Over time, I was able to open communications with engineers and physicists. For example, scientists based at the Leibniz Institute for Astrophysics Potsdam came to my solo show in Berlin, around 2010. They were

interested in two pieces that demonstrated hydrodynamic flow using magnetic fields to create unique patterns of dispersed nanoparticles in fluid (see go.nature.com/hydro).

They invited me to their institute and showed me what they were working on. The experience of meeting and talking with them about dark energy and dark matter influenced how I use fluidity in my work. We developed a collaboration that led to a conference and an exhibition in 2012 (see go.nature.com/fluid).

In 2017, I was awarded a two-month residency at CERN, Europe's particle-physics laboratory near Geneva, Switzerland. People think that scientists teach the artists, but I really wanted to share my ideas as well as learn. The first steps were not easy because our professional languages were very different. I read a lot about theoretical physics to try to understand what subatomic particles are, what an accelerator does, and what scientists want to find with these detectors. It's important for artists who want to collaborate with scientists to make the effort to understand the scientists' research.

Ultimately, I wanted to build my own functional particle detector that could demonstrate how these invisible forces work. I met some scientists who were sceptical and some who were really engaged. Helga Timko, a theoretical particle physicist at CERN, worked with me intensively. Every day for two months, we met and talked about her research and my ideas. Over time, we explored how I approach a topic and how the scientists approach it, talking through the creative and problem-solving processes. I worried that I took more from her than she did from me, but she said the experience gave her a much richer perspective on her research and on the Universe.

After I finished my residency, I came back to my studio in Seoul and started to build my own detectors for my artwork. I was inspired by cosmic rays entering the atmosphere, colliding with air to produce ubiquitous, negatively charged particles called muons. I created *Cascade*, an installation of three interconnected kinetic sculptures that use light and liquid to detect and visualize muon movement.

Argos, one of the three sculptures, is a cosmic-ray detector consisting of 41 channels of ionization-producing tubes. It sends a detection signal to a second sculpture, called *Impulse*, that pumps fluid into the 18 metres of tubes in the third sculpture, called *Tubular*. That has micro-tunnels that appear and disappear depending on whether liquid is moving inside them.

The nice thing is that many of the pieces I produced following my time at CERN have travelled around Europe, giving me an opportunity to discourse on how art and science are deeply intertwined with contemporary art.

Yunchul Kim is an artist and composer in Seoul.

FERNANDA OYARZÚN

Sculptor and marine biologist Fernanda Oyarzún in Chile works on a rendering of an octopus.

FERNANDA OYARZÚN
DEFINE SUCCESS AND EXPECTATIONS

Artists should know not only that scientists are interested in making their work more accessible to the public but also that grants often require outreach or public engagement. For artists, it is becoming more important to work with scientists if they are to have a voice on issues such as climate change.

I grew up in Chile, and explored both art and science as a teenager and undergraduate. During my PhD programme on larval ecology at the University of Washington in Seattle, I did a science-illustration programme. As I studied how functional morphology affects evolution, I took a course in ceramics because I wanted to make 3D images of marine larvae. I now divide my time roughly into three categories — science, art and art–science collaborations.

I advise interested scientists and artists to go to virtual spaces — Instagram or Twitter, for example — to follow people who do arts and sciences. Most of the time, scientists get really excited that someone is interested in what they are doing. And artists have nothing to lose by sending scientists an e-mail.

One common mistake that scientists make

is to invite artists to their laboratory, to get inspired, without building any sort of relationship first. A partnership has to start with trust and respect. Each person needs to be humble about what they know. The overarching goal is the process of creating something new together — and the resulting exchange and reshaping of ideas.

At the start of a collaboration, it's important to define some tangible outputs. This seems obvious, but it is not. Sometimes artists and scientists might have different goals, which is fine, but it's good for both parties to make that clear. Second, the goals will probably not remain the same throughout the collaboration. They will change. If they're not changing, the collaboration might not be working. I find that scientists are often surprised by how interactions with artists can shift their perspective on their research. The bottom line is to keep communicating. If that stops, so does collaboration.

In the past decade, I have noticed a substantial increase in interest in science–art collaborations, and last year year was no exception. If anything, people and institutions have been more open to innovating and exploring because of the pandemic, in an effort to be creative while reinventing how they teach classes and communicate information. I have been invited to give at least three or four times as many talks on art and science as usual — at schools, universities and for the general public, both in Chile and in the United States.

Mutual respect is crucial. There is no way someone is going to collaborate with you if you are standing above them. Frequently, a scientist will say something like: "I know everything, and let me tell you about this." That kills a collaboration right away.

Fernanda Oyarzún is a scientific sculptor and marine biologist at the Coastal Social-Ecological Millennium Institute, SECOS, and is based in Puerto Varas, Chile.

MUZLIFAH HANIFFA
MAKE RESEARCH MULTI-SENSORY

I don't have an artistic background, but I had an interest in transforming my research on skin cells into something that might resonate with the public, by making it accessible to the senses of touch, sight and sound. In 2015, I attended a public-engagement programme held by Wellcome, a British biomedical funding charity, and happened to have lunch with the Scottish poet Linda Anderson, who is a faculty member at Newcastle University, UK, and teaches modern English and American literature. She introduced me to a world of artists. After I explained my research to them, we crossed language and cultural barriers. I invited a range of artists to my laboratory, where they watched my team do flow cytometry and cell imaging, and I went to poetry readings and art exhibitions held by the artists who came to the lab, and by others.

For an intense eight months, six of us worked together towards a multi-component, interactive event, called *Inside Skin*, which was held for one week at a Newcastle University campus building. A digital-sound engineer turned the gene expression of immune-system cells into sound and light. Attendees could step into a booth and feel that they were being destroyed by a macrophage, a white blood cell responsible for killing foreign microbes or removing dead cells. British poet Linda France wrote a sonnet, which has 14 lines, for the occasion — which was appropriate, because skin cells are 14-faced polyhedrons. Tech-savvy artists created a circuit board that represented how the cells communicate under the skin. Inspired by my comment that it's hard to separate my roles as a scientist and a mum, a photographer took pictures of my son in a white lab coat playing with a glove as a balloon.

The experience changed how I perceive and do science. I think a lot about how to present scientific concepts by providing analogies that anyone can relate to. For example, to convey to the public how and why cells migrate to the lymph nodes, which are almost like a dance floor — because that's where all the cells gather to try to find a partner — we created an image called *To the Disco*.

Scientists should know that artistic collaborations can take a lot of time, especially right before an exhibition. I was slightly put off because I didn't want my research to suffer, but I found this collaborative, intensive approach to public engagement deeply personal and rewarding. It allowed me to share my work with different groups of people and to have a meaningful dialogue in which I gained new insights and changed how I think about my own science. In a way, the experience allowed my children to understand my research better.

I'm now involved in a bigger, 18-month effort to accompany the Human Cell Atlas, a project to map the 30 trillion cells in the human body. The Human Cell Atlas endeavours have taken multiple formats, including animations, a time-lapse film, commissioned art pieces, and an online venue to stimulate conversations between artists and scientists, both at the Wellcome Sanger Institute, near Cambridge, and at universities. Because of the pandemic, we've had to move quite a lot of it to online formats, but the level of interest has not diminished at all, and the virtual platform has been fantastic. It enables us to reach a broader audience and engage in wider collaborations.

Muzlifah Haniffa is a Wellcome senior researcher in dermatology and immunology at Newcastle University, UK, and an associate faculty member at the Wellcome Sanger Institute in Hinxton, UK.

AOIFE VAN LINDEN TOL
CREATE A TWO-WAY EXPERIENCE

My art often involves explosives, so I was in my element during my European Space Agency (ESA)–Ars Electronica Futurelab residency in Linz, Austria, in 2017. It was life-changing. I had always been interested in art, chemistry and mathematics, and I had explored the physics of light and how it travels through the Universe. When I arrived at ESA, I had what I needed most — time. I had an office on the same block as loads of amazing scientists, specializing in everything from solar flares to magnetic fields. I got to spend time with them, in the spaces where they work. I got immersed in their way of life, which is very different from taking information and turning it into artwork. Most importantly, I did things to create a two-way experience. I'm quite a private artist, and don't usually show work in progress, but I held several open-door sessions to get feedback and input from the scientists to help steer what I was doing.

The final ESA product was a one-off event in 2017, called *Star Storm*, held at the Ars Electronica festival for art, technology and society in Linz. Participants walked through a series of explosive events, each representing a process taking place across the Universe. It was meant to be a journey through order, chaos and discovery. Some of the scientists I worked with were there to see it. One wept.

The crucial elements of a successful art-plus-science partnership are interaction and true collaboration. I advise scientists to make time for that interaction, and to treat the experience like their work, like a scientific project that needs time to develop. It's helpful if scientists allow for open-ended interactions with artists, to explore creative possibilities.

One of the pitfalls of these artist–scientist partnerships is not knowing the other person's expectations. Mine were to get involved with my scientist collaborators and to do some actual scientific experiments. That turned out not to be possible, but I did fight hard to do interactive workshops with scientists and artists. For example, I organized an event where scientists could make a small bomb of lemon juice, detonate it while stating aloud their research intentions, and create a piece of art from the resulting impact splats. It was a fun way for me to invite them to recall and affirm their original career motivations, which often get lost over time.

Scientists may seem hard to access, but I advise artists to simply reach out to them,

and to come prepared: to research their area of interest and really know it, so that the dialogue can flow in a natural and deep way without a constant need to explain everything. Now I have the confidence to contact science organizations anywhere in the world. I realized there is no barrier, and I feel empowered to contact other organizations to ask for a tour of their facilities, or to see whether I can give a talk.

The most common misconception that scientists have about artists is that they are chaotic, or are simply illustrators helping to educate the public about science. What gets lost is the deeper meaning that the artists could give to scientists. Artists are trained to educate themselves on a variety of topics so that they can offer critiques on life, society and politics, and those skills are transferable to science.

Aoife van Linden Tol is a London-based artist and vice-chair of the International Astronautical Federation's Committee for the Cultural Utilisation of Space in Paris.

STEVE BOXALL

Arts curator Xin Liu tests a costume made from recycled ocean waste, during a parabolic flight.

XIN LIU
TAKE RISKS

In my role as a curator, I help to connect artists and scientists. It's hard to know who will work well together until you try it. There is some risk. But, ideally, there is no power differential between the artist and the scientist. That said, it can be difficult to work with artists who have no exposure to science and technology — although, often, an artist is fascinated by what a scientist does, and a scientist can enjoy and feel inspired by an artist's thinking. The only way a collaboration can be sustained is if each person has a deep respect for the other's work and feels inspired by them.

After training as a mechanical engineer, I interned at Microsoft — first in Beijing, in 2013, and then in New York City, in 2015. In 2014, I worked as an independent contractor conducting research at Google in Mountain View, California, before working on a master's degree in media arts at the MIT Media Lab (part of the Massachusetts Institute of Technology) in Cambridge, Massachusetts, and subsequently being hired as its arts curator.

Whenever I was hired as an engineer, I made sure the expectations of that role were met, but I also played with concepts of design, technology and art. I've always wanted to do work between those spaces. Even in my internships, I created opportunities to do artistic projects and present them at venues other than conferences; for example, at festivals, design weeks or exhibitions. Those experiences helped me to compete for more-formal collaborations such as grants or artist-in-residency programmes, which are typically for people who are more established. Normally, early-stage young artists don't get grants.

In 2019, as part of the MIT Media Lab's Space Exploration Initiative, I designed and made a robotic sculpture using unique locomotion technology to carry a wisdom tooth to space. I documented the whole thing and created a virtual-reality film from the tooth's perspective. The endeavour was called *Living Distance*. Last March, as part of the same initiative, I launched *Sojourner 2020*, a rotating structure that carried work from nine groups of artists to the International Space Station and back.

In a collaboration, I want to see both artists and scientists taking some risk, rather than quickly retreating to old techniques that are safe. It's important to be vulnerable with your collaborator, rather than being the 'expert', which can push collaborators apart.

Xin Liu is an artist-in-residence at the SETI Institute, Mountain View, California, and arts curator in the MIT Media Lab's Space Exploration Initiative in Cambridge, Massachusetts.

ABRIAN CURINGTON
ADD EMOTION TO SCIENCE

My fantasy adventure comics have always had a scientific angle (see www.bluecatco.com). My work blends mathematical and scientific elements into fiction. I've even put physics equations in the footnotes. Interested in new experiences, I applied to the Schmidt Ocean Institute in Palo Alto, California. I was an artist-in-residence aboard the Schmidt research vessel *Falkor* for two weeks in 2019 as part of a mission to find meteorites on the sea floor. I ended up making illustrations of what happens there, as well as producing a comic travel journal. It shows the ship's operations in progress, as well as many of the creatures we encountered along the way.

A lot of artists are afraid to approach scientists. Some think that any conversations they might have will go over their heads and be full of jargon. And scientists are worried that artists won't understand their science. But there are fewer barriers than people think. Half the battle is finding the opportunities. I have been working with a new platform called Lifeology, which helps science and art communities to come together to create engaging, science-backed educational materials. I've recently illustrated a course on the coronavirus (see go.nature.com/3p5jq) and one on digital-storytelling basics (see go.nature.com/3jykc) for scientists.

I do a lot of research in preparation for spending time with scientists I work with, so that they know I'm serious. For example, I make clear how I stay true to original source material, which helps me to build trust. When I interact with scientists, I also stress that visual communicators add emotions to the facts, which helps the general public to retain the information and get excited about it. Igniting that spark is my goal. I'm adding to the science, not taking away from it.

Abrian Curington is a graphic novelist and cartographer in Fircrest, Washington.

Interviews by Virginia Gewin.
These interviews have been edited for length and clarity.