The Practice of Art and Science

ARS ELECTRONICA

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art & science
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Anticipatory Art Science: Networks to NanoSystems

Individual / Collective / Micro / Macro

"The further art advances
the closer it approaches science...
and the further science advances
the closer it approaches art."

Leonardo da Vinci, quoted in R. Buckminster Fuller,
Nine Chains to the Moon, 1963

Things have sped up, everything is moving ever faster and what we would have deemed impossible even 20 years ago is happening now. We are in the midst of a major paradigm shift and are bound to land in a whole different world sooner than we think. At this particular juncture, there is an urgency that is collectively shared as reductionist models of science collapse, the established art world caters to the wealthy few, and we are at a brink of an ecological disaster. There is some hope however as we see more and more artists, scientists, and many others seeking to blur the traditional disciplinary boundaries, and our youth are rightfully demanding this in their education. The young Leonardos who will inherit this planet need support and the tools to work with so they can survive and prosper. Educational institutions around the world—for the arts, sciences, and humanities—are leftovers from the Industrial Age mindset and the remaining crystalized structures are difficult to shift. But we have no time to perpetuate the old models as our world is on the brink of a collapse and we urgently need minds from every discipline to come together and envision alternatives.

Divisions of people and disciplines inevitably lead to the creation of stereotypes that contribute to perpetuating their separation, whether intentionally or not. The current educational system is set up to develop these roles and, if one is successful in understanding the archetypical image that is being summoned and shapes him/herself accordingly, it strengthens the possibility of success in that particular field. The problem of course is that gender and race cannot be shape-shifted and so we have large segments of the creative population who do not fit into the established stereotypic mold of the art and/or science worlds.

Bad Math Teacher / Bad Art Teacher

When I teach my *Introduction to Art & Science* course[1], we always start by sharing stories going back to the intersection on our educational path where we had to make the decision—at the fork of two cultures. Science students often tell stories of how they loved art or music but their parents would have never let them pursue this as a serious study. Or, worse, an art teacher told them that they do not have the talent for art. For many artists, including myself, there would be stories about the awful chemistry or math classes. But, inevitably in everyone's case there was at least one good teacher who passed on his or her passion for a subject and helped determine the path. From both sides, although we often try to fill the educational gap, many give up and never cross over to the "other side." We see this now in the growth of the DIY movements and the growing number of workshops outside of academia offering what is missing—mixing up the science lab, art, and music studio practice. Add to that social media and "how to" online courses and it is apparent that educational patterns are changing outside of academic walls. A new generation of teachers will hopefully have the willpower to create the environment that will prepare the youth for contemporary complexity.

At UCLA (University of California, Los Angeles), the large campus is clearly divided geographically between the north side (arts and humanities) and the south (engineering and science). Institutional divide is further amplified by the distances, and students have to travel with their schedules jam-packed—even the most energetic, more often than not, end up giving up. Students who attempt interdisciplinary majors also have no roadmap and end up having to do twice the work, if persistence prevails.

Traveling around the world and visiting many academic and research institutions as well as art festivals and events, I have witnessed this same divide everywhere. For instance, I was recently a guest professor at the Interface Culture program[2] of Linz University of Art and Design, teaching a lighter version of the *Introduction to Art & Science* class to masters students. After everyone shared their stories, I asked where the scientists in the University of Linz are and the response was: "Across the river, at Kepler University." This was so obviously symbolic that the next day we packed up and crossed the river to enter the sciences and also visit one of the student's friends who works there in a mechatronic lab. They were all amazed at how similar their interests are but it was clear that, at this stage, it is still difficult to collaborate.

For many years, I separated my artwork from my parallel interest in science. I produced and directed an award winning documentary, *Unfolding the Pyramids of Egypt Using Modern Physics* (1988), conducted interviews with Nobel Laureates such as Murray Gellman and Glenn Seaborg about their creative process (1989), and directed a CD-ROM production of *Life in the Universe with Stephen Hawking* (1996).[3] I did not consider this part of my artwork and only started connecting the two worlds in 2001 when I finally met a scientist who was going to collaborate in earnest and not expect me to visualize his / her work. Here I tell about a sequence of events that led me to pursue with passion art & science in my work as well as in education. I elaborate on how a large exhibition, *NANO,* determined my path and also was a precursor to the work that followed in my own practice as an artist and educator.

Networks to Nanosystems

"I am quite sure we are going to get research and development laboratories of education where the faculty will become producers of extraordinary moving-picture documentaries. That is going to be the big, new educational trend."

R. Buckminster Fuller, *Education Automation, 1962*

During my PhD studies, I was fortunate enough to meet Allegra Snyder-Fuller who gave me access to the Buckminster Fuller archives, auspiciously situated in Santa Barbara at the time. After our first meeting she sent me a copy of *Education Automation: Comprehensive Learning for Emergent Humanity,* a book written by her father who was a passionate believer in the influence of information technology on education.[4] The short book is a transcript of a 22 April 1961 lecture, and preceded J. C. R. Licklider's famed memos on computer networks in 1962. As I delved further into his work, I learned about the discovery of the third allotrope carbon, C60, and was particularly fascinated with the story of how this molecule came to be named Buckminsterfullerene.[5]

Soon after 9/11, in November 2001, I organized a symposium entitled *Networks to NanoSystems: art, science & technology in times of crisis,* in coordination with my colleagues in the UC system[6] and Roy Ascott's Planetary Collegium PhD student meeting and residency at UCLA[7].

It was important for me to have at least one scientist who worked on nanotechnology in the symposium and I had trouble finding someone who would be interested in real dialogue. Luckily, a colleague and fan of Bucky Fuller, Maroon Tabbal, told me about a scientist who had just arrived to campus from IBM Zurich Research Laboratory—James Gimzewski. I sent him an email and was surprised to get a quick and enthusiastic response. During his lecture I was thrilled to find out that the IBM Zurich Lab he came from actually developed the Scanning Tunneling Microscope (STM)[8]. But even though he worked with bucky-

balls, he did not know who Buckminster Fuller was or the story of the naming of the C60, so this became the basis of our productive exchanges. We arrived at the same point from the opposite sides of the pendulum—I was learning about the science and he about the cultural background. After a year of sharing our ideas and discussing philosophically, the pros and cons of this new science and the manipulation of the molecular realm, *zero@wavefunction: dreams and nightmares* was created.[9] The project premiered at BEAP, Perth in 2002 and gave me an opportunity to visit the SymbioticA art lab being set up in the biology department at the University of Western Australia. It was inspiring to see artists, humanists, and scientists sharing the same space exploring biotechnology.

NANO

Due to the successful buckyball installation, we were given a unique opportunity by Los Angeles County Museum of Art (LACMA) to create an "experimental space" or laboratory at the Boone's Children's Gallery. The museum was confronted with a programming vacuum when a radical renovation proposed by Rem Koolhaas fell through. Ironically, we enacted what he envisioned with the *NANO* exhibition. In 2001, this is how his team described their proposal: "Once, all continents formed a single whole. Then they drifted apart. We propose to undo LACMA's "continental" separation. Imagine an almost utopian condition where the history of the arts can be told as a single and simultaneous narrative showing moments of chronological coincidence, autonomy, influence, and convergence. After decades where accommodating the "modern" led to a situation of glut and fatigue, the idea of the all-embracing has a new appeal."[10]

The chances of a museum allowing the kind of experimental exhibition and series of events we staged with *NANO* in such a large space for close to a year are to this day almost nonexistent. Usually their calendar is set years in advance, and established names or topics are what are to be expected. But we found ourselves in-between space and time and the opening became an inspiration to develop a conceptual framework that would address the impact of nanotechnology on culture and society. I set out to imagine a series of interconnected installations that would play with scale and be activated by the audience's presence and interaction. Gimzewski and I worked closely together on imagining the experiences and we invited theorist Katherine Hayles to join us. We had art, science, and humanities working together and envisioning an interactive experience based on scale, dreams, and nightmares of nanotechnology.

Retreats, Residencies, Social Events

With a tight time frame and budget, we had to envisage and realize a conceptual framework that would inspire others to join us. The three of us organized a series of "Sinaptic Blow-out" brainstorming meetings which included our brightest graduate students. The retreats took place at a house on the Malibu Point

Dume State Beach with no agenda, and very quickly those who wanted a structured plan backed off. After a few sessions, the group that was left was composed of people who really wanted to be there and got along on a human level. Professors, students, photographers, and friends were having fun envisioning installations while discussing at length social and cultural implications of this new science.

These retreats were purposely outside the academic or gallery context and were definitely the most productive way to initiate and develop such large interdisciplinary projects. To this day, I organize those kind of social gatherings when an ambitious project is about to come together. In collaborations that span disciplines and different languages and methodologies, the human connection is the most important creative glue. Inspiration is clear of disciplinary programming.

During the year, we involved architects, theorists, designers, musicians, choreographers, dancers, and engineers in the development of the exhibition. Students from all areas were involved and it was like conducting an orchestra to bring all the different sides together. Architects Johnston Marklee worked with us to develop large structures based on Buckminster Fuller's model of the Dymaxion map. Using shapes that resemble molecular nanostructures, the folded three-dimensional surfaces created interlocking layers of enclosed and semi-enclosed "cells" and "sense spaces." The entire space was designed to play with scale and disturb our usual relationship to the material realm with unexpected behavioral responses. At the entrance, the audience was confronted with many surveillance cameras that captured their images and added into a growing number of projected hexagons over the ten months that the exhibition lasted. Entering the center cell, one could manipulate buckyballs with ones shadows and the floor consisted of a hexagonal projection that was responsive to the movements of people walking as well as large robotic spheres that were being manipulated by the audience remotely. This resembled the graphene single atomic layer before it was discovered in 2010.[11] People walked through a "quantum tunnel," where two identical mirrored spaces bounced granulated images and sound and when another visitor passed through the tunnel connecting the two rooms, seemingly non-sensical reflections and disturbances were created. Moving further, one would enter a room with a bed of sand with a projection of a sand mandala which evolved in scale from the molecular structure of a single grain to the recognizable image of a Chakrasamvara mandala created by Tibetan monks in another part of the museum.

NANO was open for a period of ten months and become a fertile space for collaborations and experimentation. Katherine Hayles edited a book, *Nanoculture: Implications of the New Technoscience,* written by her students who participated in the process of the installation, wrote about the subject in it, and contributed text to the exhibition.[12] Dance PhD student Nora Zuniga-Shaw together with choreographer Marianne M. Kim worked with master performers. Harmony Bench choreographed a performance within the installations with dancers wearing white clothes designed by fashion design students from Otis

design school under the eminent NY fashion designer Isabel Toledo.[13] This allowed the models to play with the installation projections and meld into the environment. Together with Bucky aficionado Maroon Tabbal, we organized public educational workshops at the museum that connected to the installations, including a few evenings with DJs and parties around the installations. Hayles and her students selected scientific, art, and sci-fi books related to the exhibition theme and made them available to the public. Media arts, dance, fashion, music nanotechnology, engineering, and humanities graduate students worked together helping with the creation and installation where they learned through experience while making strong peer connections. Anne Niemetz, an MFA student working with me, staged within the installation her MFA project together with PhD student Andrew Pelling in Gimzewski's lab.[14]

NANO evolved as an emergent system as the outcome of a directed self-organizational process and I started really believing in the importance of this form of collective/collaborative work. It at once challenged the way both art and science museums operate.

The experience of directing these collaborative artworks changed my perception of what an artist working with large interactive installations can offer in addition to the exhibition. It became a space where graduate students worked together in the process of creation and also staged their own work, undergraduates helped with the installation, learning in the process, and the public was taught about the scientific concepts by the professor and students. But, most of all, the children experienced all of the above without the art or science being dumbed down. This was my prime motivation for envisioning the Art|Sci Center in 2005 and two years later I designed the curriculum for the *NanoLab Summer Institute* for high school students.

What do the Scientists get out of it?

This *NANO* exhibition was a major commitment for Gimzewski and his students, taking a lot of time and energy. However he noted that those who participated later went on to produce more publications and adopted a creative side in their scientific research. Indeed, in later projects we collaborated on publications that arose out of the synergetic relationship with the artwork.[15] This did not go unnoticed by other scientists on campus who started being more open and engaging in dialogues with artists visiting the Art|Sci Center, inviting them to their labs, and even delving into deeper collaborations. Today, we see this trend having significant momentum in many science and art programs becoming official and funding programs like the National Science Foundation (NSF) in the US and the STARTS program established with the EU. This is all very encouraging but still has to be approached cautiously as it can at times be artificial in the connections made or superficial when not enough time is given to allow the work to emerge naturally. Arranged marriages sometimes work but generally lack the passion and dynamics of a relationship based on natural attraction—and there is no formula for this, you just have to allow it to happen.

It is particularly encouraging to witness a new breed of young scientists who have embraced art science collaborations early in their education. When a senior professor encourages the students in their labs to be open to working with artists and the center further promotes the work, we see comprehensive, creative scientists emerging. Another example is Takashi Ikegami, a physicist from Tokyo University who I currently collaborate with on a highly interdisciplinary and complex project initiated by evolutionary biologist Charles Taylor[16]. Ikegami went a step further and invited sound art and philosophy students to join his lab. He rightfully believes that this gives him a wider view on his research into artificial life and other complex systems that do not operate successfully in a sterile reductionist environment. Combined with institutions such as Ars Electronica that promote and celebrate this approach, is clearly a positive sign for the future. But most of all, we have to pay attention and encourage the really young art scientists who are about to enter university. There is still no solid curriculum that promotes art and science intersections and unfortunately much still has to happen on the fringes in between and outside of academia.

Sci|Art NanoLab

"There are children playing in the streets who could solve some of my top problems in physics, because they have modes of sensory perception that I lost long ago."

J. Robert Oppenheimer, 1967

By the time students are accepted into college, their expectations of what academia offers as an educational environment has been set. *NanoLab* program was designed for students at the intersection of the two cultures—just at this critical point that determines their future educational path, recognizing that it will take some time to change the academic structures. Our goal is to show the students all the possibilities of how to navigate different disciplinary boundaries and how to push the limitations of the existing system.

The teenage phase of life often involves risk seeking and irrational behavior. This is an ideal time to focus that wild energy and include them in new areas of exploration. I have experienced this first hand with my two daughters who participated in many art installations and who particularly loved *NANO*. Looking for suitable high school summer programs for them gave me the idea to conceive a new program for students about to enter college. While developing the curriculum, I had two honest and tough beta testers and I eventually developed a program that this summer is celebrating its tenth year. We contacted some of the many students who went through our program to find out where they eventually landed. Many went on to the medical professions, one is working for Space X, and another is forming his own nanotechnology company. There is no doubt that catching them early and showing them the possibilities of having a

wide angle lens and a divergent view while pursuing their studies in a research university provides a key advantage later in life—no matter what path they decide upon.

NanoLab is an intensive two-week program based on a college level class that is normally taught in ten weeks. This means non-stop immersion in a broad, comprehensive study that is not dumbed down, and students get college credits that are transferable. Once established in 2007, Adam Stieg, who was at the time a graduate student in Gimzewski's lab and an active participant in *NANO,* became the director.[17] I continue to be involved with the planning and recruiting students from Design Media Arts and Gimzewski and Stieg brought in graduate students from the sciences. We team art and science graduate students and guide them in developing their classes and workshops. This provides them with an opportunity to learn from each other and it has strongly contributed to lasting collaborations and the emergence of some great projects. Undergraduate students are also called to task as counselors and helpers with their assignments. This way they learn about various topics and how to take responsibility in the running of the program.

"Students everywhere are confronted with yesterday's science fiction operating as today's fact."

R. Buckminster Fuller, *I Seem to Be a Verb*, 1970

NanoLab takes place at the California NanoSystems Institute and the day begins at the auditorium with a lecture about a particular topic, typically commencing with nanotechnology. This is followed by a hands-on workshop where students build their own optical microscope using cheap webcams, and they also learn about different imaging systems. After lunch, they go to visit various imaging laboratories and see how scientists work with the Scanning Tunneling Microscope (STM), Scanning Electron Microscope (SEM), and related research tools including advance optical microscopes. After that, they hear a lecture of a visiting artist who works with imaging technologies and are given a hands-on demo. After dinner, they watch a sci-fi movie related to the same topic and write about their impressions. Throughout the two weeks, science, art, music, movie, and literature are interspersed and they very quickly understand that only the methodology of development is what really separates these disciplines. We take them out to museums, the beach, and the LA river to test the water quality and encourage their curiosity about their environment. After a week of this kind of immersion, they are asked to self-organize into small groups and develop project prototypes and proposals based on the science they learned about and we ask them to imagine the "impossible." Once their final projects are presented, we tell them that they successfully created an "artwork" and if they want to commit the time to make it a reality, they will be doing "science." To achieve this, they have to essentially invent their own methodology that is peculiar to their vision rather than what is typically taught in science classes. The methodology we teach is "Anything goes."[18]

Face the Future now

The generation of youth growing up today is inheriting a world we are not even able to imagine, so how do we prepare them for the uncertain future?

If we take a 100-year marker and briefly rewind our film back to 1917, literacy was just 23%—today it is 80%, WW1 was raging, the Russian revolution was in full swing, Kazimir Malevich presented the controversial white on white painting, Marcel Duchamp exhibited the urinal as sculpture. Those works to this day resonate and inform the art world. D'Arcy Thomson wrote *Growth and Form*—a book still influential to biologists and artists alike; Einstein wrote his famous paper that predicted stimulated emissions (beam of a laser) and we know the massive applications in all walks of life; Freud came up with his ideas of the unconscious—think of the subsequent advances in brain / consciousness research. War technology was making fast progress through use of airplanes and even gas attacks—now we have drone attacks and much more. In 1917, women were fighting for the right to vote, only 6% of Americans graduated from high school, now we are arguing whether artists should do a PhD. We had 1,9 billion people on the planet, today it is 7,9 billion. It took three grueling months of travel from London to New York, now we complain when the plane is an hour late. Ford Motor Company was in full speed with the newly introduced idea of mass assembly line production ushering in the car as transportation available to the middle classes. Today electrical cars are finally hitting the road in large numbers.

In parallel to all this creative innovative art, science and technology, multiple political events occurred in 1917. Europe's Great War was transformed into the First World War, America entered the stage, Asia was mobilized, Mahatma Gandhi and his followers established the first experiment in self-rule, and with Lenin's coup, an entirely new ideological politics and geopolitical order emerged. The overthrow of the tsar in Russia triggered a wave of sympathy around the world and this year had a moment of democratic, not socialist, excitement.[19]

Growing up with a father who was a diplomat for former Yugoslavia, I was bounced around from Washington D.C. to Belgrade, to Jakarta to New York City by the time I was twelve. At each location I was taught a different version of World War II history and quickly realized that these were stories told from different global and political perspectives. But, one thing is for sure—no one could have predicted how the world changed and the direction we collectively took over the course of the last hundred years. We first saw our planet from a distance in 1969—that is not that long ago. That same year we made the first network connection from UCLA to UCSB and Stanford with the first message "LO," starting the process of communication across the globe and slowly becoming world citizens.

We feel something brewing, we are in the midst of a paradigm shift and the wave is already sweeping us along. The icebergs are melting and many are ignoring the alarm sounds of the scientific community predicting environmental disasters upon us, or the potential dangers of artificial intelligence. All of us are anticipating a new era with CRISPR/Cas9 gene editing technology promising

to reprogram life as we know it. New developments in artificial intelligence, artificial life, robotics, sensors, networks, synthetic biology, materials science, space exploration, and more knowledge about our brain, mind, and consciousness appear every day. However, every great proposition has an equally great opposition and the world is polarized more than ever on a global level.

Many of the things we discuss when it comes to education and academia are not even an issue with today's youth. We can see this happening all over with an ever growing number of workshops and DIY meet ups offered by young artists and scientists and the new generation that grew up around art, science, and technology. A good example is seen in the children growing up in Linz who are exposed to cutting edge art installations and science through Ars Electronica. One example is the young artist, Lisa Buttinger (born 1997), who received the Golden Nica of Prix Ars Electronica u19 category and the STARTS Prize Honorary Mention this year. Seemingly effortlessly she combined her knowledge of natural sciences with an artistic output and created a work that is surprisingly mature. Seeing these young Leonardos working on creative projects gives us hope for the future as we can anticipate the third culture truly emerging with no disciplinary separation as we know it. The main challenge is to avoid having them caught up in the de-geniusing machines of yesterday.

Neuroscientists agree that we use around 5% of our brain and that most of what we do is actually unconscious, although some even believe it's closer to 1–2%. Regardless, it is clear that scientists are faced with increasing complexity that cannot be addressed with traditional methodologies. This is the important role that artists can play as the few that are trained to think in comprehensive ways. As Anticipatory Design / Art Scientists, we can put up what John Cage calls our "antennae to the future" and present to the world alternate visions, counter to what is being fed through our media daily. It is an exciting time, it is a dangerous time, certainly unpredictable but we can anticipate and prepare ourselves. Dramatic shifts can happen in a nanosecond—this is the nature of self-organized criticality.[20]

Victoria Vesna (US) is an artist and a professor at the UCLA Department of Design Media Arts and Director of the UCLA Art|Sci Center. With her installations she investigates how communication technologies affect collective behavior and perceptions of identity shift in relation to scientific innovation (PhD, University of Wales, 2000). Her work involves long-term collaborations with composers, nano-scientists, neuroscientists, and evolutionary biologists, and she brings this experience to students. Since 1997, she is a speaker at Ars Electronica symposia, has served as a juror several times, and in 2017 she showed *Bird Song Diamond* at Deep Space and curated the Campus Exhibition.

1. Introduction to Art & Science in the UCLA Department of Design Media Arts course started as a large General Education lecture course in 2006 and gradually shifted to an online hybrid class. Students from every discipline imaginable take this class and participate in the events organized by the Art|Sci Center giving them an opportunity to meet in a more relaxed social environment. Because of its wide outreach, I consider this course an important aspect of shifting away from the two-culture divide on campus.

2. The Interface Culture program at University of Art and Design Linz, Department of Media was founded in 2004 by Christa Sommerer and Laurent Mignonneau. Sommerer received her PhD from Ascott's Planetary Collegium in 2002.

3. In parallel to exhibiting my artwork, I was making a living as a video producer and focused on scientific content for a period of 10 years—1987-97. *Life in the Universe with Stephen Hawking* CD-ROM—art direction and production, UC Santa Barbara in collaboration with MetaTools Inc. 1996, (unpublished); *The Internal Language of the Brain Translated into Music*. Video (produced and edited) Xiadong Leng and Gordon Shaw, University of California Irvine, 1993, (unpublished); *System for Aneutronic Fusion Energy* (S.A.F.E.). UCI / Advanced Physics Corp, 1992 (unpublished); *Discovery of Strangeness*. Dr. Murray Gell-Mann, Nobel Laureate, 1989, (unpublished); *The Science of Preventing Wars*.The Physicist Who Changed Gorbachev's Mind (unpublished); *Biochemistry of Emotions*. Norman Cousins, 1989, (unpublished); *Unfolding the Pyramids' Secrets Using Modern Physics,* directed by Victoria Vesna and awarded a CINE Golden Eagle for Best Science Documentary, 1988, (unpublished). Produced by the Tesla foundation.

4. "Education Automation on Spaceship Earth: Buckminster Fuller's Vision. More Relevant than Ever." Allegra Fuller Snyder and Victoria Vesna. In *Leonardo, Vol. 31, No. 4* (1998), pp. 289-292, MIT Press.

5. Buckminsterfullerene discovered by Harold Kroto, James Heath, and Richard Smalley in 1985. One of his designs of a geodesic dome structure bears great resemblance to C60; as a result, the discoverers of the allotrope named the newfound molecule after him. The general public, however, sometimes refers to buckminsterfullerene, and even Fuller's dome structure, as buckyballs. See "Naming of Buckminsterfullerene by E.J. Applewhite," in *The Chemical Intelligencer,* July, 1995 (Vol. 1, No. 3)

6. UC DARNET – University of California Digital Arts Research Network was a collective of media artists and professors in the UC system – UC Berkeley, Santa Cruz, Davis, Los Angeles, Irvine, Riverside and Sand Diego (1997-2009).

7. The Planetary Collegium was first established as the Centre for Advanced Inquiry in the Interactive Arts (CAiiA) by Roy Ascott in 1994 at what is now the University of Wales, Newport. I was one of the first five PhD students along with Jill Scott, Bill Seaman, Miroslaw Rogala, and Joseph Nechvatal (1996-2000). In 2003, Ascott relocated the platform to Plymouth University, renaming it the Planetary Collegium, where it is now located in the Faculty of Arts and Humanities. Over 80 doctoral candidates have graduated.

8. A Scanning Tunneling Microscope (STM) is an instrument for imaging surfaces at the atomic level. Its development in 1981 earned its inventors, Gerd Binnig and Heinrich Rohrer at IBM Zurich, the Nobel Prize in Physics in 1986. Gimzewski pioneered research on mechanical and electrical contacts with single atoms and molecules using scanning tunneling microscopy (STM) and was one of the first persons to image molecules with STM.

9. *Zero@wavefunction* as described in 2001 in the exhibition catalog at BEAP festival in Perth, Australia: "Zerowave explores the dreams, nightmares and visions in a manner similar to quantum mechanics. The particle that penetrates the quantum wall has a probability to reflect to transmit through the barrier with a zillion possible outcomes in between. To the artist and the scientist this becomes the magnetic realm worthy of exploration. It is a set of wave functions of human existence, of technology and science woven together in a dynamically transforming landscape with probabilities of Being and Non-Being, of Time and No time. The project represents an exploration of the unpredictable where both artist and scientist are willing to be conceptually changed in their vision, hopes and fears."

10. OMA office work website: *http://oma.eu/projects/lacma-extension*

11. Andre Geim and Konstantin Novoselov received a Nobel Prize in Physics for their discovery of a thin flake of ordinary carbon, just one atom thick. They have shown that carbon in such a flat form has exceptional properties that originate from the remarkable world of quantum physics.

12. Hayles, Katherine, ed. *Nanoculture: Implications of the New Technoscience*. Intellect books, UK, 2004.

13. I was invited to work together with fashion designer Isabel Toledo as part of the mentorship program in the Otis School of Design in Los Angeles. The dresses produced by students were part of the NANO exhibition as well as an annual fashion show at the Beverly Hilton hotel. *https://www.otis.edu/fashion-design/past-mentors*

14. *Dark Side of the Cell* premiered at the LACMA as part of the NANO installation and was Anne Niemetz's final MFA project. It was based on Gimzewski's research showing that yeast cells oscillate at the nanoscale. Andrew Pelling, PhD student in his lab, amplified the oscillations making them audible and Anne created an installation inspired by the cellular tensile structures. *http://www.darksideofcell.info/about.html*

15. Co-authored with Gimzewski in relation to the exhibition: "The Nanomeme Syndrome: Blurring of fact and fiction in the construction of new science." *Technoetic Arts* journal, May, 2003 "NANO: An Exhibition of Scale and Senses." *Leonardo Vol. 38, Issue 4,* August 2005.

16. *Mapping the Acoustic Network of Birds* is a research project that was funded by the National Science Foundation and the art project that emerged is *Bird Song Diamond*. The leaders of this large and complex collaborations are evolutionary biologist Charles Taylor, artist Victoria Vesna, physicist Takashi Ikegami, and engineer Hiroo Iwata. *http://birdsongdiamond.com*

17. Adam Stieg directed the program until 2015 when he assumed additional research responsibilities at California NanoSystems Institute (CNSI). He is still involved in an advisory role.

18. "Anything goes"—I refer here to Feyerabend's *Against Method: Outline of an Anarchistic Theory of Knowledge* in which he defends the idea that there are no methodological rules always used by scientists. In his view, science would benefit most from a "dose" of theoretical anarchism. University of Minnesota Press, 1975

19. "1917—365 days that shook the world," by Adam Tooze / December 13, 2016. *Prospect Magazine,* January 2017. *https://www.prospectmagazine.co.uk/magazine/1917-year-shook-the-world-russian-revolution-united-states*

20. "Self-Organized Criticality and Emergence in Dynamical Systems," James K. Gimzewski, Adam Z. Stieg, Victoria Vesna. *Handbook of Science and Technology Convergence*. Springer International, 2015, pp. 163–180