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Conference theme: "Arts for Society, Education for Creativity"

Keynote speech: ARTS AT THE CENTER

by Robert and Michele Root-Bernstein

INTRO (Michele)

[SLIDE: Title, Arts at the Center]

Good morning… Bob and I are honored to speak to you at this opening of UNESCO's Second World Conference on Arts Education. We have chosen the topic "Arts at the Center" for the theme of our talk. Arts at the center of what, you may ask? The answer, Bob and I will argue, is that arts are at the center of creative imagination and, thus, at the center of any effort to educate for creativity.

Let us begin with the proposition that the 21st century demands renewed attention to creative imagination. As Mitchel Resnick, of MIT's Media Lab, writes: "In today's rapidly changing world, people must continually come up with creative solutions to unexpected problems. Success is based not only on what you know or how much you know, but on your ability to think and act creatively" (1). Solutions to intractable problems such as global warming, hunger, poverty, systemic injustice and eradicable disease will require thinkers and doers who can bring to bear *new* combinations of knowledge and know-how in economic, political and cultural arenas. Traditional expertise, traditional training will not be enough. It follows, then, that we must school our problem-solvers in *new* ways. We must prepare our young to envision as-yet-unheard-of possibilities that vastly improve the lives of more people – and simultaneously reaffirm authentic living. In short, we must educate for imagination and creativity.

[SLIDE: Mitchel Resnick, Creative Society]

[SLIDE: Arts provide the key]

To this educational enterprise, the arts provide the key.

To make the case Bob and I are going to focus on the role of arts in the high-level pursuit of science, invention and business. First we would like to make clear that we recognize the value of arts in and of themselves, but insist that they have an additional utility. That utility makes them indispensable for economic and intellectual, as well as cultural and personal, reasons. Second, we draw our examples from the ranks of famous people, yet we firmly believe that every connection we make between art and science, art and imagination, art and creativity holds for everyone at every level of ability. Third, while many of our examples come from the European-American tradition, we are quite certain that the patterns we describe apply worldwide. The arts have always been and will always be at the center of creative practice in every discipline in every culture.

[SLIDE: 4 theses of talk]

So, here's our argument: the arts are at the center of creative imagination and should be at the center of any attempt to educate for creativity. We will support this by demonstrating four theses that have formed the backbone of much of our research:

1) arts and crafts underpin innovation in science and technology;
2) scientists can invent new arts and artists can discover new sciences

3) arts and crafts correlate with creativity in all disciplines, from literature to business; and
4) they do so because they involve mastery of creative process and its cognitive “tools for thinking.”

I. THESIS 1: ARTS AND CRAFTS FOSTER SCIENTIFIC CREATIVITY (Bob)

[SLIDE: Thesis 1]

Thesis 1: The arts and crafts foster scientific creativity.

[SLIDE: Van’t Hoff on scientific creativity]

This thesis was proposed over a hundred years ago by J. H. van’t Hoff, the first Nobel Prize winner in Chemistry. Van’t Hoff noticed that some of his colleagues were very creative and some hardly creative at all. He wondered why. “Imagination plays a role both in the ability to do scientific research as well as in the urge to exploit this capability…” he observed. “I have been prompted to investigate whether or not this [imaginative] ability also manifests itself in famous scientists in ways other than their researches. A study of more than two hundred biographies showed that this was indeed the case, and in large measure.” Van’t Hoff found that Galileo was an artist and a craftsman; Kepler a musician and composer; Sir Humphrey Davy an excellent poet; and so on.

[SLIDE: the arts and crafts of Van’t Hoff]

As our own research indicates, artistic or craft talent turns out to be typical of Nobel Prize winners and other eminent scientists. Van’t Hoff, himself, had artistic hobbies. He played the flute well, wrote poetry in four languages, made models of many kinds and enjoyed sending out hand-made New Years' cards.

[SLIDE: Alexis Carrel]

The French Nobel laureate Alexis Carrell recalled that the lace-making he learned as a child from his mother, he later adapted to invent the stitching techniques that have made open heart surgery and transplants possible.

[SLIDE: Dorothy Hodgkin]

Dorothy Hodgkin, British Nobel laureate, said that she learned how to think in three dimensions as a crystallographer because of the art lessons given to her by her mother, who as a professional artist and archeologist. While still a teen, Hodgkin illustrated her parents' archeological finds, and she used her skill to illustrate her own crystallographic discoveries as well. The lovely blue shape you see here is an x-ray crystallographic image Hodgkin painted of the insulin molecule.

[SLIDE: Nusslein-Volhard]

Christiane Nusslein-Volhard, a recent German Nobel Prize winner, has a similar history. Nusslein-Volhard grew up in an artistic family and learned to paint and draw. She has insisted on illustrating all of her papers and books with her own drawings. And for a hobby, she makes fiendishly difficult jigsaw puzzles. Solving these puzzles, she has said, is just like trying to solve a scientific puzzle.

[SLIDE: Hideki Yukawa]

Scientific vocation accompanied by artistic avocation can be found around the world. Physicist Hideki Yukawa typifies the Japanese Nobel Prize winners with a wide range of talents that include performing traditional Japanese songs, as he is doing in the photograph on the right, and practicing traditional calligraphy.

[SLIDE: Sin-Itiro Tomonaga]

His fellow physicist and Nobel laureate, Sin-Itiro Tomonaga, was a painter and photographer who also built exquisitely detailed models for pleasure.

[SLIDE: Homi Bhabha]

The Indian physicist Homi Bhabha exhibited the same range of talents. Architect of India's very successful scientific research programs during the 1950s, Bhabha balanced his scientific research with painting, musical composition and playwrighting.

[SLIDE: Robert R. Wilson]

In many cases, these science vocations and artistic avocations intertwine. American physicist Robert R. Wilson, who had a second career as a professional sculptor, is best known for designing both the supercollider at FermiLab and also its architecture. He wrote at length about how the creative process of designing a supercollider is the same as that of designing a sculpture. Indeed, FermiLab looks look like a modern cathedral, because he believed that the best science is as beautiful and awe-inspiring as the best art.

[SLIDE: Eric Heller]

Harvard physicist and chemist Eric Heller agrees. He models complex physicochemical processes with equations and then turns these equations into images using computer graphics. Sometimes the beauty of his models is so breathtaking that he turns them into art. And sometimes the art reveals characteristics of the mathematical models that are not apparent from the equations, so that his art often yields novel scientific breakthroughs.

[SLIDE: Sir Lawrence Bragg]

Scientists have also relied on crafts for imaginative as well as experimental skill. Sir Lawrence Bragg, the youngest Nobel laureate ever, learned from his artist mother to draw and paint, and from his physicist father to work with wood, metals, and other materials. The working scientist has need of hand knowledge, Bragg wrote, for theory is nothing if it cannot be reduced to a new piece of apparatus or a novel experiment. The training of scientists, he believed, was far too academic, lacking in the necessary physical experience of crafting things.

[SLIDE: Luis Alvarez]

Consider, in this light, the story of Luis Alvarez, whose father sent him to a technical high school instead of an academically elite school. You need to realize that in the pre-WWII California, where Alvarez grew up, technical high schools were for young people destined to be car mechanics or electricians or plumbers. But Alvarez's father realized that while his very bright son would be able to learn any academic material he cared to set his mind to, the only way to develop the visual and mechanical skills necessary to be a great experimentalist was to work with one's hands. This craftsmanship amply repaid Alvarez, who became one of the great inventors in modern physics.

[SLIDE: Virginia Apgar]

The case of physician Virginia Apgar demonstrates that the same principle holds true for women in science as well. Likely many, if not most, of us in this audience born since 1952 were given an Apgar score at birth, a measure of 10 fundamental physiological functions that very accurately predict whether an infant is healthy or needs immediate medical support. Apgar was an extraordinary observer and finder of patterns in medicine who learned these skills both as a trained musician and, significantly, as a craftsman who made her own musical instruments.

[SLIDE: Arts Foster Scientific Success]

So, van't Hoff appears to have been right in proposing that arts and crafts foster scientific ability among scientists. Statistical studies back up our examples. We have completed several studies correlating scientific success with arts and crafts training, but will only present the results of one here. In our largest study, we have examined the biographies and autobiographies of all 510 Nobel Prize winners in science (to 2005) and compared them with the biographies of 1634 United Kingdom Royal Society members, 1266 members of the U. S. National Academy of Sciences, and 4406 members of a non-elite scientific organization, Sigma Xi, which is open to membership by any practicing scientist.

[SLIDE: Arts Foster Data]

We found that compared with typical scientists, Nobel laureates are at least 2 times more likely to be photographers; 4 times more likely to be musicians; 17 times more likely to be artists; 15 times more likely to be craftsmen; 25 times more likely to be writers of non-professional writing, such as poetry or fiction; and 22 times more likely to be performers, such as actors, dancers or magicians. An ongoing study of engineers appears to be yielding similar differences between the average and the most successful engineers, with arts, writing, and crafts avocations being the best predictors of professional success. Which begs a question, doesn't it, Michele?

II. THESIS 2: SCIENTISTS INVENT ART; ARTISTS INVENT SCIENCE (Michele)

[SLIDE: Can Scientists Make Artistic Inventions…]

It certainly does. If arts and crafts can foster better scientific and engineering ability, shouldn't the equation work in reverse as well? Can scientists make artistic and musical innovations? Come to think of it, can artists and musicians make scientific discoveries and technological inventions? The answer, once you ask, is "Absolutely YES!

[SLIDE: Thesis 2]

And this leads to our second thesis: Scientists invent new arts and artists discover new sciences and technologies.

[SLIDE: Roger Guillemin]

One scientist who has invented a new form of art is Nobel laureate Roger Guillemin. Armed with a medical degree, Guillemin discovered the first peptide hormones. He also painted in his spare time. When he got a hold of one of the first computer aided design programs to model his molecules, he quickly realized

– and exploited – their aesthetic potential. He is now widely recognized as one of the founders of electronic art.

[SLIDE: Lajaren Hiller]

In similar fashion Lejaren Hiller transformed music. While working towards a Ph. D. in Chemistry; he also studied music composition. Later, in his chemical research for industry he obtained early access to one of the first computers. In short order, he was programming computer-generated compositions, including his famous *ILIAC Suite,* considered the first significant computer music. In fact, Hiller left chemistry in mid-career to compose and teach music full time.

[SLIDE: Jacquard's loom]

Conversely, artists and craftsmen may discover or invent new sciences. In the 19th century, the Frenchman J. M. Jacquard invented the programmed loom for mass producing tapestries. His invention utilized punched cards, which became the technology for programming the first computers. Jacquard also produced the first digital image, a self-portrait out of black and white threads – the ultimate melding of art and technology.

[SLIDE: Abbott Thayer]

Abbott Thayer, an early 20th century American painter, also melded his art with his avocation, which was natural history, and in the process discovered that animals adapt to their environments through camouflage. Both the modern science and the technology of camouflage owe their existence to his application of a trained artistic eye to scientific questions.

[SLIDE: Loie Fuller]

About the same time, American Loie Fuller pioneered a new kind of dance in the music halls of Paris, and did so with a series of patented chemical and physical inventions that helped usher in the modern era of stage effects. These included fluorescent dyes, mechanical wands, special lamps and transparent stage floors – all of which allowed her to manipulate yards and yards of silk in a blaze of colored light.

[SLIDE: Edward Elgar]

The composer Sir Edward Elgar was also a patented chemist and the Elgar Society is at great pains to make sure that he, like his fellow composer-chemist Alexander Borodin, is remembered not only as a great musician, but also as a Renaissance man whose many abilities informed each other.

[SLIDE: Wallace Walker]

More recently, sculptor Wallace Walker has made an even more unusual contribution to the sciences, inventing an entirely new form of geometry with his paper sculpture “IsoAxis” ©.

[SLIDE: Kaleidocycles]

Developed in recent years in collaboration with geometer Doris Schattschneider, this new geometry is popularly available in a book called *M. C. Escher Kaleidocycles*.

[SLIDE: Hedy Lamarr and George Antheil]

The impact that such science-art interactions may have on society are often overlooked, witness the all-but-forgotten example of actress Hedy Lamarr and composer George Antheil, who together invented a way to encode electronic information called “frequency hopping.” First applied to weaponry in World War II, frequency hopping permits each of your cell phones to send messages in encrypted forms that are largely safe from interference. We’ll bet that acting and music are not the backgrounds you would have guessed lie behind such a revolutionary invention!

[SLIDE: Robert Mueller]

All these examples lead to a key point that has been stated well by the MIT-trained engineer, composer, and artist Robert Mueller in his 1967 book, *The Science of Art*: “Art may be a necessary condition for constructing the new consciousness from which future science gets its structural realities to match nature, in which case it is more important than we generally admit.”

III. THESIS 3: ARTS AND CRAFTS CORRELATE WITH CREATIVITY IN ALL DISCIPLINES (Michele)

[SLIDE: Thesis 3]

We come, now, to our third thesis: Arts and Crafts Correlate with Creativity in All Disciplines from Literature to Business.

[Slide: polymathy predicts success]

Since the 1920’s, studies have shown that most people who achieve eminence in one field display more than average ability in one or more other fields as well. These are your Renaissance men and women. Yet the same kind of breadth breeds success for more average people as well. As one Israeli study concluded, the only reliable predictor of professional achievement, no matter the field, is the individual's pursuit of an intellectually demanding avocation over a long period of time. At any level of achievement, polymathy – which is to say, developed skill in more than one discipline – is highly correlated with vocational success.

[SLIDE: Nobels have 3x more avocations…]

Bob and I have been investigating polymathy in a number of ways. Recently, we led a research class of MSU undergraduates in amassing information on the avocational interests of Nobel Prize winners in Economics, Peace and Literature and collating it with our data on Nobel scientists. Overall, Nobel laureates have about 3 times more adult avocations than the general U.S. public, most clearly seen in this graph comparing Nobel Prize winners in the sciences, on the far right, with average scientists and average Americans on the far left.

[SLIDE: Nobel prize interests …]

As you might expect, each Nobel group has a distinct and different pattern of avocational distribution. Here we compare Nobel laureates in the sciences [dark gray bars] and in literature [light gray bars] to make two simple observations: 1) the percentage of science laureates with avocations in the arts is *very nearly identical* to the percentage of literature laureates with arts avocations (arrows on the left) and 2) there are very nearly the same proportions of Nobel scientists with writing pursuits as Nobel writers with science pursuits (arrows to the right).

[SLIDE: Literary Nobels have science avocations]

Bob and I have published preliminary data, collated in this table, indicating the science and engineering training and interests of Nobel laureates in literature.

[SLIDE: Literary Nobels are often artists]

Literature laureates are also unusually likely to have avocational interests in the visual arts, music, dance and drama.

[SLIDE: Rabindranath Tagore, portrait and music]

Some examples would include the various arts of Rabindranath Tagore, the Bengali poet, short-story writer, novelist, dramatist and educator who won the Nobel Prize in the early 20th century. He was also a composer, setting many hundreds of his poems to music.

[SLIDE: Tagore paintings]

Late in life, Tagore took up painting.

[SLIDE: Derek Walcott]

Derek Walcott, Nobel laureate from St. Lucia, began writing at an early age – and began painting, too. He has devoted much of his grown up life to painting – and incorporates many artistic references into his writing.

[SLIDE: Gao Xingjian]

The Chinese Nobel laureate Gao Xingjian is a novelist, short story writer, and dramatist. He pursues a second career in painting -- indeed before winning the Nobel, he made his living from his work as an artist.

[SLIDE: Xingjian's complementary expressions]

Xingjian has written an autobiographical novel called *Soul Mountain*. He has given an ink drawing, shown here, the same title. For Xingjian, painting and writing are distinct yet complementary expressions.

[SLIDE: Artist Writers are Common]

Artist-writers are not limited to Nobel circles, as is made clear by at least two books, *The Writers Brush* and *Doubly Gifted*. The work of the 20th century American poet, Sylvia Plath, graces the book cover on the left; the work of the American writer Henry Miller is featured on the right. The writer-artist combination appears to be particularly common.

[SLIDE: Dag Hammerskold]

Nevertheless, arts play strong avocational roles for professionals of many sorts, not just scientists and literary folk. Nobel Prize winners in other categories have pursued one or other of the arts. Dag Hammarskjold, posthumously awarded the Peace Prize in 1961, was not only a statesman, but a philosopher-writer and amateur photographer.

[SLIDE: Albert Schweitzer]

Albert Schweitzer, a Peace Prize winner for his work as a medical missionary and theologian, was also a concert organist.

[SLIDE: Artist-businessmen]

Similarly, individuals at work in business also place arts at the center of their interests. David Finn and Judith Jedlicka have written an intriguing book called the *Art of Leadership* that highlights the work of a group called the Business Committee for the Arts. This Committee was founded by John D.

Rockefeller IV when he observed that the companies he owned that fostered arts among their employees and communities were much more profitable than those that did not. Finn and Jedlicka's book highlights examples of how arts stimulate creativity and profitability in several dozen companies around the world.

[SLIDE: Suk-Jean Kang: CEO of GE Korea]

Suk-Jean Kang, former CEO of General Electric Korea and now CEO of LG Electronics is a case in point. As CEO of GE Korea, he arranged to take one full month off each year to paint. Not only did this time away from work stimulate new ideas, but it also permitted his coworkers to implement their skills and strategies in his absence, building leadership.

[SLIDE: John Safer: Businessman/Sculptor]

John Safer, a successful entrepreneur in banking, is also a renowned sculptor whose work has been exhibited around the world.

[SLIDE: Charles Ives…]

Similarly, in the early twentieth century, the American composer Charles Ives worked in the insurance industry, even as he pursued the composition of innovative music. The two pursuits were not antithetical in his mind: "You cannot set art off in a corner and hope for it to have vitality, reality and substance," he is reported to have said. "The fabric weaves itself whole. My work in music helped my business and my work in business helped my music."

[SLIDE: Not dilettantes: Integrated Networks of Enterprise…]

Other polymathic individuals have likewise remarked on the fit between vocation and avocation. Skilled in more than one way of thinking and in more than one way of expressing, polymaths link their interests into integrated networks of enterprise, which display “correlative talents” and creative habits.

This tendency to synthesize vocation and avocation appears not only at the high reaches of creative accomplishment, but among all of us.

[SLIDE: We all meld all the time…]

Indeed, we might say that it is the personal genius of every one of us to apply our particular talents to much of what we do… Wearing multiple hats, we all meld all the time – or we have the capacity to do so – and practice helps!

IV. THESIS 4: ARTS AND CRAFTS MASTERY OF CREATIVE IMAGINATION (Michele)

[SLIDE: Thesis FOUR]

This brings us to thesis 4, that what links arts and crafts with other disciplines is mastery of the creative process and the cognitive skills necessary to imagination.

[SLIDE: Sparks and tools…]

Bob and I base this thesis on our work in *Sparks of Genius, The 13 Thinking Tools of the World’s Most Creative People.* Researching what hundreds of successful people in a wide range of professions had to say about their imaginative and creative abilities, we found a common set of 13 thinking tools: *observing, imaging, abstracting, pattern recognizing, pattern forming, analogizing, empathizing, body thinking, dimensional thinking, modeling, playing, transforming* and *synthesizing.*

These are not esoteric skills, available only to the highly talented or trained, however. These are skills available to us all; skills we can exercise and hone. And because they are common to all problem-solving endeavors across the arts and sciences, the humanities and technologies, these imaginative tools for thinking articulate personal networks of enterprise. They articulate the connections between disciplines that foster the synergies of innovation. Bob will explain how.

V. THE ART AND SCIENCE OF IMAGINATIVE THINKING TOOLS (Bob)

[SLIDE: Observing definition]

Let's begin with the most basic of our imaginative thinking tools, which is observing. Observing is the active process of using any or all of your senses to experience the world acutely and accurately, and it takes time and practice to learn to observe.

[SLIDE: Jasper Johns green flag]

The artist Jasper Johns has explored the process of observing in his famous American flag paintings. How, he wondered, could he make people not just look at a flag, but actually *see* it as if for the first time? One way is to paint flags that remind us of something we know, but which are different enough to get our attention, such as this green and black flag patterned on the American flag. We look and look again, engaging our mind as well as our eyes.

[SLIDE: Johns green flag with complementary colors]

What is Johns up to? Stare at the little white dot in the middle of the flag without blinking while I explain. There is a clue in the colors he has used. They are all complementary to the normal colors of the American flag. The white stars and stripes are black; the red ones, green; the blue field for the stars is orange. Johns expects us to realize these complementarities. But he expects something else as well. Now look up at the white space above the flag. What do you see? What you should see is the after-image of the flag in its normal colors! Johns understood enough about how our retina processes images to know that his green and black flag can actually be seen as a normal flag by those sophisticated enough to observe it!

[SLIDE: Francis Seymour Haden]

Sir Francis Seymour Haden, one of the greatest anatomists of the early twentieth century, expected the same sophisticated observing from his medical students, and in order to obtain it, he insisted that they all take drawing and painting lessons. "How much sooner would the eye – accustomed to observe and estimate closely the differences of color, aspect, weight, and symmetry – learn to gauge their aberrations as the signs which make up the *facies* [that is, the clinical signs] of the disease;" he wrote. "[H]ow much better [would] the hand, trained to portray them accurately, be able to direct with precision and safety the course of the knife!" *Observe well and you think and perform well*. This is a very common sentiment among great scientific observers and a reason so many practice arts.

[SLIDE: Abstracting Definition]

Our next tool is abstracting, the process of discovering simplicity in complexity by eliminating all but the most essential characteristics of what is observed.

[SLIDE: Picasso abstracts a bull]

Picasso left us an excellent example of the abstracting process. All abstracting, he said, begins with something real and then proceeds by eliminating more and more elements. At the upper left, he begins with a fairly realistic bull and then, going left to right and then down, he explores which characteristics of a bull are most essential. Is it the mass? The planes? The outlines? The size of the horns, tail, sexual organs? In the end, at the lower right, he decides upon a simple set of lines that "say" or suggest bull without actually depicting one.

[SLIDE: Tinbergen gull experiment]

The work of the Nobel prize winning biologist Niko Tinbergen demonstrates that scientists use exactly the same process of abstracting whenever they perform an experiment. In this instance, Tinbergen studied the behavior of the herring gull and noticed that the chicks pecked at the parent's beak to obtain food. Was the stimulus the smell of the food or perhaps a red dot that is present on the lower beak? Tinbergen made a simple, realistic cardboard model of a gull's head, and presented it to the chicks. They pecked at the beak. He now knew that smell was not the trigger. But was it the red dot? Tinbergen made other models. What happened if he changed the shape of the head, its color, or left off the red dot? What if he moved the red dot elsewhere on the head, or simply presented the chicks with something red like a pencil or a ball? In the end, Tinbergen discovered that all that pecking for food could be elicited by anything that was red. Red was the ultimate abstraction of the signal for "food."

[SLIDE: Imaging definition]

Imaging is another tool related to both observing and abstracting. Imaging is the ability to recall or imagine any set of sensory observations or feelings and to combine them in new ways. In this cartoon, the artist asks us whether we can "hear" the sound of Edward Munch's famous painting "The Scream," as this poor museum guard imagines he can.

[SLIDE: Louis DeBroglie]

Physicist Louis de Broglie clearly could. When Neils Bohr announced that the electrons orbiting an atom appeared to behave like vibrating strings, de Broglie, who was an excellent amateur violinist, immediately realized that if these atomic strings really existed, they should have the same kinds of harmonics and overtones that the strings of musical instruments have. When experiments proved that these atomic "sounds" actually existed a few years later, de Broglie was awarded a Nobel Prize.

[SLIDE: Analogizing definition]

De Broglie's discovery also utilized another of our thinking tools, which is analogizing. Analogizing is finding functional similarities between different processes that may have very different structural characteristics. Bohr's atom obviously does not look like a violin, yet de Broglie was able to ignore the structural differences to note instead the functional equivalence of the strings.

Our concept of “tools for thinking” is also an analogy, based on the idea that the mind has a “toolkit” something like a multi-purpose knife that can be used for any number of jobs once we master its components.

[SLIDE: Kenneth Snelson]

Scientists often find useful analogies in the arts: remember that Alexis Carrell equated surgery with lace making; Nusslein-Volhard links jigsaw puzzles with scientific puzzles. Yet another, extraordinary example involves the sculptural innovations of Kenneth Snelson. Snelson has created towering structures in which inflexible elements such as rods or beams are held together by nothing more than the tension of flexible ropes or strings. In the process, he has also invented the novel physical concept of structural integrity from tension, or tensegrity. Tensegrity has not only been employed in architecture and engineering…

[SLIDE: Ingber and Heidemann]

… but in biology as well. Two of my colleagues in cell biology, fans of Ken Snelson’s sculptures, each enjoyed making simple tensegrity sculptures when they were graduate students. One day, discussing their common passions for cell biology and sculpture, they realized that cell structures might be explained by means of tensegrity. Their cellular tensegrity concept has become a major area of research.

[SLIDE: Dimensional thinking definition]

Now, the application of tensegrity from giant sculptures to tiny cells required a leap of imagination that is significant—and characteristic of another of our thinking tools. Dimensional thinking involves a transformation between dimensions, for instance when we relate the three-dimensional world around us to a two-dimensional map; or it involves transformations within dimensions, for instance when we shrink or enlarge the size of a thing, or speed up or slow down time.

[SLIDE: Origami]

The ancient art of origami, or paper folding, has explored the possibilities of dimensional thinking for many centuries, providing artists and laymen alike the experience of making something three dimensional out of a flat, two dimensional square of paper.

[SLIDE: Origami stents]

Surprisingly, the deep understanding of dimensionality embodied in origami has only recently begun to be appreciated. There is now an entire field of origami engineering, one of whose outcomes has been the invention of origami stents that can be inserted into blood vessels in their folded-up form, and then expanded to keep the blood vessel open after they are placed.

[SLIDE: Origami math]

Mathematicians have also recently discovered that origami embodies an entirely new form of geometry, with rules all of its own – another instance of artists discovering phenomena that make possible new sciences.

[SLIDE: Empathizing definition]

To find both scientists and artists observing and abstracting may not be very surprising, but an unexpected tool shared by artists and scientists is empathizing. Empathizing involves becoming one with the object of study in a Zen-like integration of self and other. It involves, too, the capacity to mirror in our minds the behaviors and processes we see and respond to the emotions they elicit.

[SLIDE: Noguchi's "Core"]

We all know that empathizing allows us to understand each other's emotions and actions, but Isamu Noguchi's sculpture "Core" takes empathizing in new directions: "Go ahead," he says, "put your head into it. Then you will know what the inside of a stone feels like."

[SLIDE: Desmond Morris's "Entomologist"]

Oxford zoologist Desmond Morris, who is also a well-known surrealist painter, confirms Noguchi's message, telling us in his painting "The Entomologist," that we have to become a bug to understand a bug!

[SLIDE: Jacob Shaham]

The late physicist Jacob Shaham argued that we even need to empathize in order to understand physical equations. Learning how to solve these equations is not enough, he told us. Equations are like the script of a play. You have to be able to imagine the stage upon which the equations play out their actions and how the various characters that their symbols represent will behave under various circumstances. He himself had learned the subtleties of this process during drama lessons which had required acting out the single word, "hi!" Uttered loudly when running across the stage waving wildly, "hi" means something totally different than when mumbled quietly, head down, face turned away. Equations, too, have different meanings depending on context and interpretation. Empathizing, just as one does on the stage, can be scientifically useful.

[SLIDE: Body Thinking Definition]

Sometimes empathizing is accompanied by yet another of our tools, body thinking. This means thinking with sensations of muscle, sinew and skin, with sensations of body movement, body tension and body balance; it means thinking, too, with emotional sensations that arise when we wrestle with problems.

[SLIDE: Rodin's "Thinker"]

The importance of body thinking to thinking in general is expressed in Auguste Rodin's famous sculpture, "The Thinker." Rodin said of his "Thinker" that he thinks not only with his mind, but with his knitted brow, his clenched fist, his gripping toes, and indeed his entire posture.

[SLIDE: Sommer Gentry]

MIT-trained engineer Sommer Gentry has used body thinking to try to engineer robots to dance with each other. As an avocational dancer, Gentry recognizes that it is one thing to make a robot that can mimic the individual motions of a human being, as in the center picture. But it is quite another to invent robots that can respond to physical signs and signals as human partners do.

[SLIDE: Playing Definition]

Discovering those signs and signals has surely involved playing, yet another of our imaginative thinking tools. Play is all about doing something – like dancing – for the fun of it, without direct purpose. Yet that same play can incidentally develop new skills and novel understanding; it can court serendipitous discovery.

[SLIDE: Alexander Fleming played at painting]

Sir Alexander Fleming was a great player who combined both art and science in his many of his games. One of those games involved painting…

[SLIDE: Fleming, painting with a twist]

…but with a twist. As it said on this agar plate, "This is not written with ink but with bacteria that develop colors as they grow." In yet another twist, Fleming may have painted with bacteria just for fun…

[SLIDE: Penicillin]

…however, his play resulted in one of the greatest medical discoveries of all time. While collecting colored microbes for his microbiological "palette," he came across the bluish green *Penicillium notatum*, the mold that produces the drug penicillin. Not only did Fleming appreciate the mold's distinctive color, but because of his extensive experience with microbial interactions in his microbe paintings, he immediately recognized its pharmacological potential.

[SLIDE: Synosia Definition]

Observing, imaging, abstracting, dimension thinking, empathizing, body thinking, playing – all these capacities figure together in our final thinking tool, synthesizing, and all figure together in the ultimate goal of imaginative thinking, which Michele and I call "synosia." Synosia comes from two words, *synaesthesia* – a combining of the senses – and *gnosis*, the Greek root for knowledge. Synosia refers, then, to the fusion of feeling and knowing, of subjective with objective understanding.

[SLIDE: Synaesthesia]

In clinical settings, synesthesia specifies an involuntary fusion of two or more senses. Common among children, but rare among adults, clinical or involuntary synesthesia most often involves color-letter or color-number combinations. Some synesthetes, for instance, literally see each letter or phoneme in a particular and invariable hue, coloring their response to words as a whole. Synesthesia can also involve other sensory combinations – colors with tones, for instance, or tastes with shapes. These combinations may seem unusual, but they are really no different from the cross-modal thinking we all share. If I say “apple” or “kimchi,” I have no doubt you will immediately associate either word with particular smells, tastes and colors. Such associations are an essential part of imaginative learning and exploration and are often embodied in aesthetic practice.

[SLIDE: Synosia – iPod]

This iPod advertisement is an excellent example of how a graphic designer has produced a synosic image by using a combination of many tools for thinking. There is only one word, and yet we have no problem knowing what the product is and does. The very abstract design allows us to empathize with the iPod owner, imagining the music being played, the emotional and body feelings he is experiencing that will make us want to express ourselves through dance as he is doing. We know what he feels and feel what he knows. Very effective!

[SLIDE: Synosia – Bob Langridge]

Scientists also search for the synthesis of feeling with knowing that artists aspire to achieve. These are two images created by one of my mentors, Bob Langridge, who was the first scientist to make computer models of DNA. On the right, you see one of his early computer images of DNA looking down its long axis. Langridge compared its aesthetic impact to that of a rose window from a French cathedral. And that aesthetic impact, he taught his students for decades, is how you know when you are doing really great science: it is too beautiful not to be right!

VI: CONCLUSION (Michele)

[SLIDE: Tools for Thinking & Synosic Education]

Bob, I can't imagine a better symbol for the art at the center of science, or the all-purpose cognitive skills at the center of creative imagination in all disciplines, in all walks of life. Tools for thinking make synosia happen. Learn to observe in art class, and you prepare yourself for observing in science class, as Jasper John's flags or Niko Tinbergen's gull experiments must make clear. Learn imaging, abstracting, empathizing or body thinking in the performing arts and you utilize them in science, math, social studies and language arts. Learn through any art or craft to tie feeling with thinking and you make personal understanding a conduit to public knowledge.

[SLIDE: Bronowski on creativity]

Imaginative thinking tools lie at the heart of authentic learning and exploration; they also make creative synthesis and invention possible. In every field of endeavor, creativity means putting together things that haven't been put together before -- and to good effect. The scientist poet Jacob Bronowski made this clear when he referred to the "explosion of likeness" between unlike things as the foundation of creative imagination in both science and art. It is in the nature of disciplines to carve out boundaries that inhibit the cross-fertilization of ideas, data and technique. It is in the nature of imaginative thinking to permeate these boundaries – and pull unlike elements into synthesis.

[SLIDE: 8 Strategies for Trans-disciplinary Education]

So we end where we began. If we are to educate for creativity, as the 21st century challenges us to do, we must educate for imagination and its thinking tools as well. In *Sparks of Genius*, Bob and I suggest eight strategies that can help implement this goal. Given the nature of this conference, we want to draw specific attention to just three of them in concluding here:

1. Teach tools for thinking, so that students learn to develop imaginative skills and conceive their own personal, original ideas.

2. Teach the creative process, so that students learn how conceived ideas are realized and implemented; how poems, experiments, dances, theories, paintings and policies are created and made.

3. Implement a multi-disciplinary education that places the arts on an equal footing with the sciences, so that students learn the imaginative thinking and expression that lead to discovery and invention. Like reading, writing and math, the practice of the arts – and the development of correlative talents -- should be required for all students in all grades through college.

[SLIDE: Take Home Messages]

Let us end with three take home messages.

First, arts and crafts develop skills, tools, concepts, structures, and knowledge that are useful to many other disciplines; indeed, their practice correlates with professional creativity in the sciences and technologies, in literature and business.

Second, the arts particularly exercise the creative imagination and its thinking tools and develop mastery of creative process.

Third, any effort to educate for creativity must therefore include arts at the center.

This role for the arts supposes a utilitarian value and purpose, but so it is for all disciplines at the hub of education. Just as we do not teach mathematics solely or mainly to train new mathematicians, nor teach languages solely or mainly to produce poets and novelists, we cannot teach the arts and crafts simply to educate more artists and craftspeople. Arts and crafts look out upon a much larger horizon.

Arts and crafts—and the thinking tools they exercise—belong at the center of education because they can and will ignite the creative imagination so vital to those cross-disciplinary innovations in science, politics, and culture that must lead us into the future.

[SLIDE: Thank you!]

[SLIDE: Title, with emails]