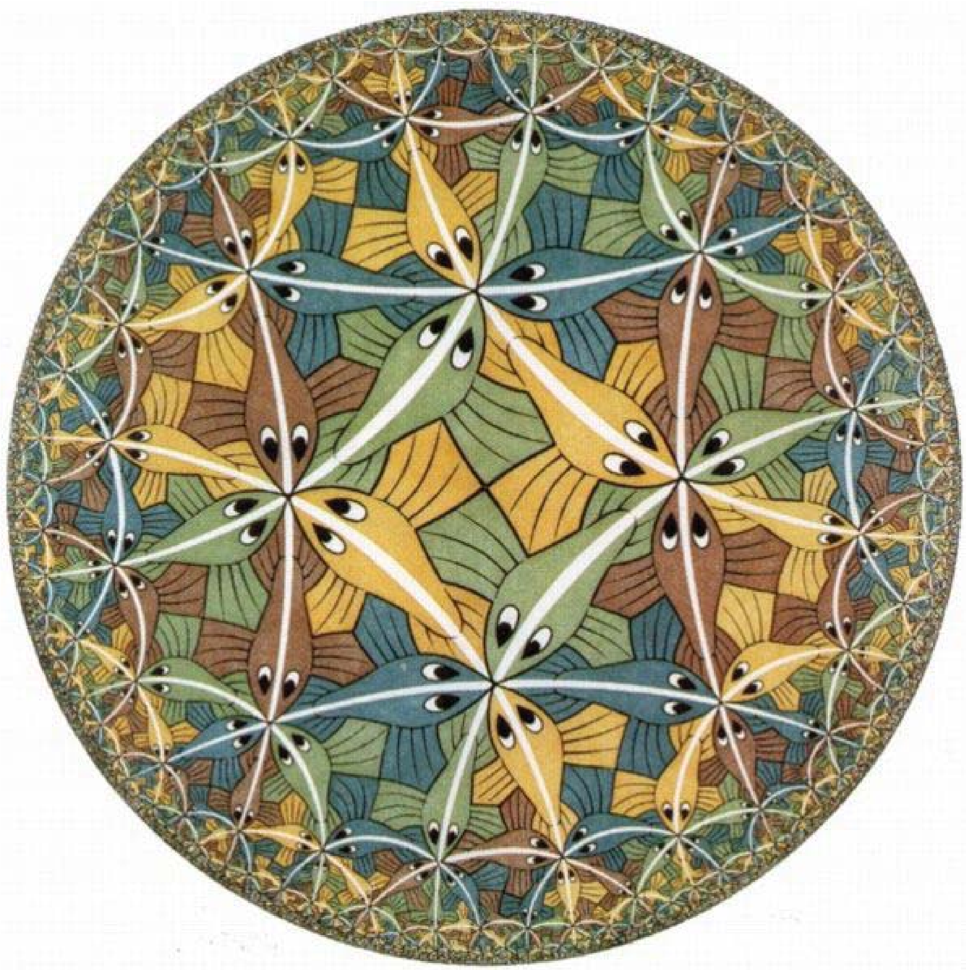
Interplay of Perspectives: History, Art & Culture + Science

Interdisciplinary Crossover and Collaboration



Report prepared for the Office of the Secretary

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Cover image: M.C. Escher, *Circle Limit III*, 1959

Circle Limit III pictorially represents hyperbolic space, a non-Euclidian form of geometry. From a mathematical point of view, it is one of Escher's most important works. Indeed, this image has been used by cosmologists as a visual explanation of what could happen at the boundaries of the universe (Bright, 2000).

Preface

Few would dispute the notion that many of the problems that the world faces today are large and complex. Solving them requires a strong intellectual orientation that draws upon history, art, culture and science. Major universities and a few other institutions have the potential to transcend disciplines, and when they do, much of their interdisciplinary work occurs outside formal channels.

The Smithsonian Institution is well positioned to break down compartmentalization between the social and behavioral sciences and humanities, to assemble a portfolio of influential work, and to positively execute its mission: the increase and diffusion of knowledge. The driving force for mobilization of the staffs' talents and energies is directly related to the four grand challenges presented in the Institution's new *Strategic Plan: Inspiring Generations Through Knowledge and Discovery*. How collaboration and discovery among disciplines occurs and what benefits accrue are the topics of this exploratory study.

Because the Office of Policy and Analysis (OP&A) previously conducted an in depth study of the processes involved in managing interdisciplinary work, this study describes both group and individual activities and discusses promising projects that have yielded returns mainly in the form of innovation, determination, understanding and inspiration. Both studies are available on OP&A's website: www.si.edu/opanda. I encourage you to share them.

There is another point that I wish to emphasize. This study could have been extended because examples of interdisciplinary work abound. The dilemma of when to end the research and stop focusing on compatibilities between science and the humanities taught the staff and I a great deal about visionary people at the Smithsonian who have an abiding interest in interdisciplinary work and the challenges they face. I thank them for their assistance.

I also wish to acknowledge the work of Kathleen M. Ernst, Senior Research Analyst, and Claire Eckert, Research Scholar, for their imaginations, patience, energy and writing skills. They were assisted by several interns including Kristine Sudbeck, who was instrumental in the formation of the study. Whitney Watriss, Senior Research Analyst and external readers Marie Elena Amatangelo, Jeremiah Gallay, Nancy Knowlton and Jane Milosch reviewed the report and offered helpful suggestions. OP&A analyst Lance Costello assisted with the report layout. Thanks are due to all of the contributors.

Carole MP Neves, PhD,
Director, Office of Policy and Analysis

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List of Acronyms

AIB	Arts and Industries Building
CFCH	Center for Folklife and Cultural Heritage
CHNDM	Cooper-Hewitt National Design Museum
CPNAS	Cultural Programs of the National Academies
FSG	Freer Gallery of Art and Arthur M. Sackler Gallery
HAC	History, Art and Culture
HMSG	Hirshhorn Museum and Sculpture Garden
IDR	Interdisciplinary research
IRC	Imaging Research Center
IT	Information technology
JPL	Jet Propulsion Laboratory
MIT	Massachusetts Institute of Technology
MCI	Museum Conservation Institute
MLN	Museum Loan Network
MoMA	Museum of Modern Art
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NMAH	National Museum of American History
NMNH	National Museum of Natural History
NPG	National Portrait Gallery
NSF	National Science Foundation
NZP	National Zoological Park
OIS	Office of Interdisciplinary Studies
OP&A	Office of Policy and Analysis
OUSHAC	Office of the Under Secretary for History, Art and Culture
OUSS	Office of the Under Secretary for Science
SAAM	Smithsonian American Art Museum
SAO	Smithsonian Astrophysical Observatory
SARF	Smithsonian Artist Research Fellowship

SCEMS	Smithsonian Center for Education and Museum Studies
SERC	Smithsonian Environmental Research Center
SI	Smithsonian Institution
SIA	Smithsonian Institution Archives
SIL	Smithsonian Institution Libraries
SITES	Smithsonian Institution Traveling Exhibition Service
SP	Strategic Plan
SPI	Smithsonian Photography Initiative
STRI	Smithsonian Tropical Research Institute
SUNY	State University New York
TSA	The Smithsonian Associates
UMBC	University of Maryland, Baltimore County

Executive Summary

Interplay of Perspectives: History, Art & Culture + Science, Interdisciplinary Crossover and Collaboration is an exploratory report produced by the Smithsonian's (SI) Office of Policy and Analysis (OP&A) at the request of the Office of the Secretary, that examines out-of-the box and ground breaking practices at the nexus of history, art, culture (HAC) and science.

All complex problems facing the world such as poverty, climate change, loss of cultural and bio-diversity and geo-political tensions require multidisciplinary solution-finding, as no one discipline has a magic bullet answer. The Smithsonian's newly formed Consortia for the Institution's Four Grand Challenges, as detailed in the 2010-2015 Strategic Plan, provide ample opportunity to initiate forward-thinking, interdisciplinary activities that tackle pressing issues that the Smithsonian is particularly well suited to address. This effort is already under way as evidenced by the "Idea Fairs," a series of multidisciplinary, cross-unit collaborative proposal presentations followed by question and answer periods and networking.

Interdisciplinary collaboration can be placed on a spectrum: side-by-side (the most convenient; two or more disciplines run something in parallel and information is shared), overlap (disciplines "overlap" to raise common questions they have about an issue) and synthesis (the disciplines collude to try and ask questions that neither could ask alone). This report provides a plethora of examples of all three with particular attention paid to "synthesis" which is arguably the most demanding and innovative level of interdisciplinary collaboration.

Interplay of Perspectives addresses the art/science schism as perceived historically, and presents some intrinsic similarities and differences that are still manifesting today. Shifting its emphasis to examples that are current, appealing, lesser-known and applicable to the Smithsonian, this report details inter-disciplines, such as design, craft, science illustration, materials conservation, photography, technology/new media, history of science and technology, anthropology, archeology and horticulture, that inherently span disciplines and are a part of the lifeblood of the Smithsonian. Next, the report explores interdisciplinary collaboration at the intersection of HAC + Science divided under three foci: stimulating creativity and discovery, social commentary and activism, and communicating science to wide audiences. Interwoven into the examples are testimonials and reflections about the benefits derived from those undertakings. Below is a highlight from each focus section:

Stimulating creativity and discovery

Knowledge and methods from one discipline can stimulate creativity and discovery in another. Scientists and artists generate new ideas, skills and greater creativity from delving into processes from other disciplines and working with each other. Erik Demaine, recipient of the MacArthur Foundation's "genius grant," conducts microbiological research at the Massachusetts Institute of Technology (MIT) that is informed by his fascination with origami and proves that making art can have a profound effect on the way scientists think, problem solve and innovate. By perceiving connections between folding molecules in human bodies and the ancient art of folding paper into elaborate shapes, his research brings us closer to understanding molecule aberrations and the resulting illnesses. His origami is also exhibited and collected by art museums as exquisite works of art.

Social commentary and activism

There are artists who deliberately participate in scientific discourse and use science methods or materials to critically examine society and the ways that technology and science are utilized, which often carry ethical concerns. The Hyperbolic Crochet Coral Reef art project, to be exhibited at the National Museum of Natural History in October 2010, responds to the degradation of the world's oceans and raises awareness of how rising temperatures and pollution are destroying the Great Barrier Reef. The beautiful crocheted coral reefs are artworks that meld hyperbolic geometry – structures naturally found in corals, anemones, sea slugs and other creatures that live in the reef – craft, and community and environmental activism. The Museum has already hosted workshops where the public was invited to join the process and crochet pieces for the exhibit.

Communicating science to wide audiences

There is a strong awareness that the creative arts –plays, music, popular novels or films – have an incredible ability to excite diverse and wide audiences and promote science understanding. The Smithsonian, with its many public platforms, must consider how art can deepen visitors' appreciation, understanding and empathy of science. The works in the National Air and Space Museum's art collection are stellar examples of artists illuminating space exploration for mass audiences and demonstrate how artworks fit seamlessly into the purview of a science museum and can in fact broaden, amplify and humanize the stories it tells.

Mechanisms are presented in a separate section of the report via examples of how interdisciplinary collaboration can be encouraged and facilitated, including: artists and art spaces in science organizations; interdisciplinary laboratories and studios; grant programs; advocacy, funding and networking organizations; think tanks, conferences, colloquia and working groups; PhD programs for artists; teacher training to integrate arts in core curricula; curricula reform; and informal science education. Gleaned from interviews, talks and a literature review, the report also offers “lessons learned” as strategies to facilitate HAC + Science collaborations; they include: have visionary and risk-taking leaders; assure a win-win arrangement; stay small and nimble; keep in mind that interdisciplinary efforts are not ends in themselves but a means to an end; take time to talk, build relationships and establish trust; make use of middle-people to help span boundaries; be cognizant of negative metaphors; use innovative means, such as computer programs, to overcome the language barrier; and ensure structure and incentives for collaboration. Finally, the report concludes with notes on defining success.

Next steps

Examples abound within the Smithsonian of activities led by highly creative people who already integrate science and art into their research, exhibitions and thinking, much of which is emphasized in this report. The OP&A study team had the privilege of speaking with staff who believe that history, art, culture and science are indispensible to each other and that the Smithsonian is very well situated to advance the dialogue between all disciplines, and as a result strengthen its research, collections, exhibitions and education and deepen its relevance. This report is a jumping off point. It is up to the readers to envision and implement their own goals, strategies and indicators of success for their own interdisciplinary projects, as ultimately, these activities are not formulaic but often opportunistic, passion-driven, creative, unstructured and mold-breaking. It is hoped that this report provides greater understanding about why, together, art and science have inspired artists, scientists and the public throughout history; offers a taste of the exciting diversity of the art/science nexus and reasons why it is beneficial; stimulates readers to imagine how their own fields of scholarship incorporate knowledge and methods from other disciplines; and finally, catalyzes thinking about how the readers’ activities can contribute to greater interdisciplinary collaboration in the future.

Introduction

Purpose and context of the study

In 2008, the Office of the Under Secretary for Science requested the Office of Policy and Analysis (OP&A) to conduct a study of interdisciplinarity and collaboration in science research.[1] This follow-on study, requested by the Office of the Secretary, examines innovative research, projects and programming that exist at the intersection of history, art, cultural studies and science (hereinafter HAC + Science). This exploratory report discusses the benefits that accrue from interplay and collaboration and the challenges encountered at the meeting point of disciplinary fields.

Composed of 19 history, art, culture and science museums, nine research centers, the National Zoo, and numerous other programmatic and outreach offices/units, the Smithsonian is an institution with exceptional breadth. The conception of *Interplay of Perspectives: History, Art & Culture + Science, Interdisciplinary Crossover and Collaboration* grows out of an Institutional attentiveness to collaborative and interdisciplinary research, programming and problem solving. Investment in interdisciplinary activities is presented in the Smithsonian's 2010-2015 Strategic Plan, which mobilizes Institutional resources around Four Grand Challenges, listed verbatim below. Each Grand Challenge is of immense and immediate relevance to our world at large and is an area where the Smithsonian is uniquely positioned to make a difference:

Unlocking the Mysteries of the Universe

We will continue to lead in the quest to understand the fundamental nature of the cosmos, using next-generation technologies to explore our own solar system, meteorites, the Earth's geological past and present, and the paleontological record of our planet.

Understanding and Sustaining a Biodiverse Planet

We will use our resources across scientific museums and centers to significantly advance our knowledge and understanding of life on Earth, respond to the growing threat of environmental change, and sustain human well-being.

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1 *See* Office of Policy and Analysis. 2009. *Addressing Complexity: Fostering Collaboration and Interdisciplinary Science Research at the Smithsonian*. Volume II: Detailed Findings. July. http://www.si.edu/opanda/docs/AdmnMgmt/IDRv2.Findings.Final.090717.pdf

Valuing World Cultures

As a steward and ambassador of cultural connections, with a presence in some 100 countries and expertise and collections that encompass the globe, we will build bridges of mutual respect, and present the diversity of world cultures and the joy of creativity with accuracy, insight, and reverence.

Understanding the American Experience

America is an increasingly diverse society that shares a history, ideals, and an indomitable, innovative spirit. We will use our resources across disciplines to explore what it means to be an American and how the disparate experiences of individual groups strengthen the whole, and to share our story with people of all nations.

Each of these grand challenges is best addressed across a wide array of disciplines and professional fields. Take, for example, "understanding and sustaining a biodiverse planet." Tackling this enormous and multifaceted challenge demands the participation of specialists and motivated people from the natural and social sciences and the arts and humanities. Designers, historians, artists and educators, working alongside conservation biologists and other scientists, can and do play informing roles. *Design for a Living World*, a recent exhibition at the Cooper-Hewitt National Design Museum (CHNDM) that was co-developed with The Nature Conservancy, highlighted new uses for sustainably grown and harvested materials. Bill Moggridge, Director of CHNDM, is confident that designers can come up with solutions in the face of environmental change and emphasizes that to be truly effective, designers cannot do it alone; collaboration across disciplines can amplify one's understanding of the underlying complexities and causes.

> *[Designers] can also recommend actions at a pragmatic level, advancing practices of recycling, design for disassembly, sustainable materials and so on. Perhaps we can collaborate with Smithsonian scientists to understand the complexities of the challenge more deeply?* (Bill's Blog, CHNDM Website).

The Smithsonian, with its diverse scholarship across disciplines, remarkable and expansive collections and archives, and special ability to interface with the public through its museums and public programs, is well situated to provide leadership in all four grand challenge areas and impact those core issues that affect humankind and the planet. By addressing these issues head on, the Smithsonian places itself in the center of debate and discovery, reinforcing the Institution's national and international relevance.

Smithsonian organizational structure

The division between the sciences and history, art and culture at the Institution is structural as much as anything else, with all discipline-based centers, museums, and other units and a large portion of its staff and resources reporting to one of two top executives under the Smithsonian Secretary – the Under Secretary for Science and the Under Secretary for History, Art and Culture.[2] Some disciplinary areas are found in both science and HAC units; examples include anthropology, archeology, geography and environmental history. As described in a later section of this report, many fields of study found throughout the Smithsonian and integral to its mission such as conservation, scientific illustration, design, photography and the history of science are inherently interdisciplinary.

Methodology

Data collection by the OP&A study team for the HAC + Science report began September 2009. The data in this report are based on the following sources and methods:

- In-person interviews with 14 Smithsonian staff from history, art, culture and science units who are involved in interdisciplinary work. They included education, exhibition design, curatorial, conservation and executive staff.
- In-person and telephone interviews with 11 individuals from organizations external to the Smithsonian including museums, cultural centers, academia, and interdisciplinary advocacy and granting organizations.[3]
- OP&A staff attendance at artist talks, conference proceedings, lectures and exhibitions.
- Studio and laboratory visits, internal and external.
- A literature review of published and unpublished documents, Smithsonian materials, and websites pertaining to interdisciplinary research and programming. (See Appendix A Bibliography for a comprehensive list).
- A selective review of relevant webcasts, including panel discussions and presentations from the Smithsonian archive and from external sources.

2 Note that at this writing it is contemplated that education and outreach units such as Smithsonian Center for Education and Museum Studies (SCEMS), Affiliations, Smithsonian Institution Traveling Exhibition Service (SITES) and The Smithsonian Associates (TSA), and other units such as Smithsonian Institution Libraries (SIL) and Smithsonian Institution Archives (SIA) that play equally in the science and HAC arenas, will be organized under the new Director of Education and a new Division of Pan-Institutional programs, respectively.

3 OP&A assured interviewees confidentiality; this report does not contain names or references that would identify specific individuals unless their comments were clearly in the public domain or the interviewee granted permission. Any quote that appears without attribution is from an interviewee.

- A selective review of mission-related and program material from advocacy groups, funding agencies and art and science organizations.
- A review of OP&A's *Addressing Complexity* report, with a focus on the interviews and bibliography.
- Reduction of interviews and secondary source materials using NVIVO 8 software.

Definitions

Interdisciplinary

The study defines "interdisciplinary" as an activity involving two or more academic, scientific or artistic disciplines. In this report, we do not make a distinction between interdisciplinary and transdisciplinary or multidisciplinary.

A helpful definition of interdisciplinary is borrowed from the former Smithsonian Office of Interdisciplinary Studies (OIS):

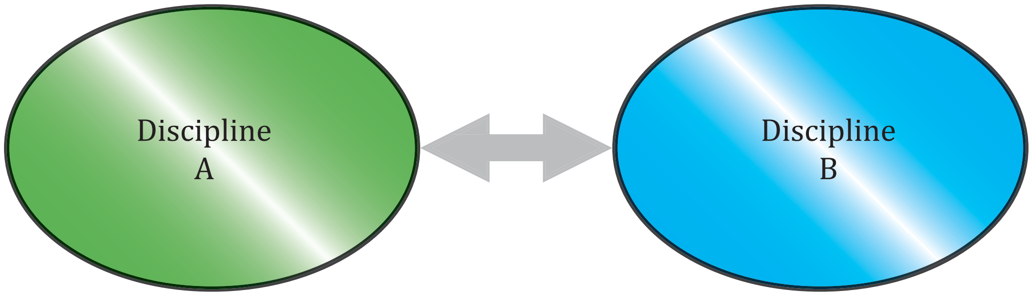
> *A first defining element is the exploration of gaps in existing knowledge – the identification and study of questions that fall between disciplines, and between discipline-based entities. A second is the examination of the interplay between disciplines, noting their distinctiveness and commonalities and the ways in which they can enrich one another's process of inquiry. A third element is the synthesis of data from various disciplines through higher-order conceptual frameworks for understanding and action* (OIS, 1990).

Spectrum of collaboration (side-by-side, overlap and synthesis)

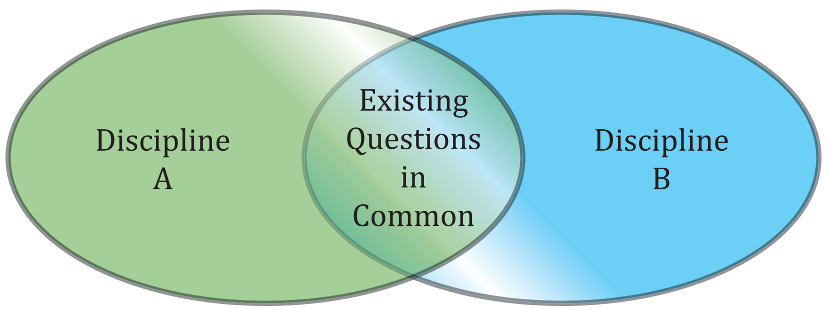
Interdisciplinary collaboration can take a myriad of forms as described by Ed Kerns, an art instructor at Lafayette University. He places interdisciplinary collaboration on three levels: side-by-side, overlap and synthesis. The first level is the most convenient; two or more disciplines run something in parallel and inform each other from the base of their discipline. For example, a symposium where scholars discuss a topic from their own disciplinary perspective and everyone learns something new. The second level is "overlap," when the disciplines come together to expose common questions they have about an issue. The third level is a synthesis; the disciplines collude to try to ask questions that neither could ask alone (Lafayette YouTube, n.d.).

Figure 1. Spectrum of collaboration

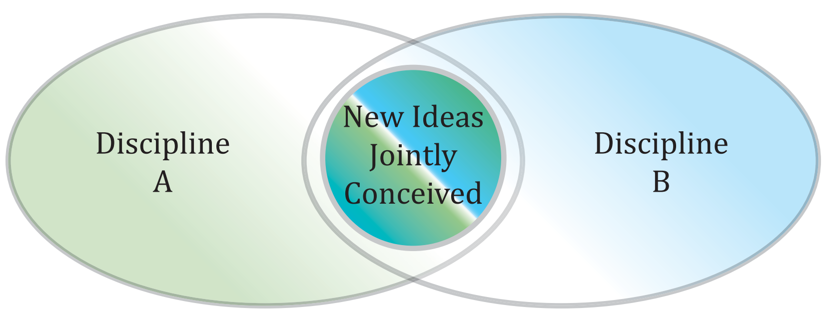
Side-by-Side: Parallel work by two or more specialists informing each other from the base of their discipline



Overlap: Experts from different fields come together to expose common questions they have about an issue



Synthesis: Experts from different fields collude to try to ask question that neither could ask alone



Art and science

As terms, art and science carry different connotations based on history, geography and the culture from which they arise. In this report, “science” refers to the natural and social sciences, technology and activities at the Smithsonian that fall under the Office of the Under Secretary for Science. “Art” includes the humanities, visual and expressive arts, and Smithsonian activities under the auspices of the Office of the Under Secretary for History, Art and Culture.

Art and Science: Similarities and Differences

People tend to gravitate towards disciplines because they have certain ways of organizing knowledge or intuiting information. Artists process information in different ways than scientists…. Artists as a whole tend to be more open-ended and driven less by a desire to come up with an answer or solution (Interview, internal).

Science perceives who can feel blue and other sensations and who cannot feel them, and explains why that difference exists. Art in contrast transmits feelings among persons of the same capacity. In other words, science explains feeling, while art transmits it (Wilson, 1998).

Art and science are epistemologically and necessarily different. Science understands the world through cumulative knowledge that is founded on reproducible outcomes and facts; it strives for objectivity. The humanities, academic disciplines that study the human condition, use methods that are primarily analytic, critical and speculative. The performing, visual and literary arts express the world by privileging idiosyncratic experiences, intuition, motion and metaphors. Artists often draw inspiration from the past, but an artwork's "truth" is not based on systematic inquiry that would lead to cumulative, reproducible facts; it is often subjective and sensorial (see Table 1).

Table 1. Differences between Art and Science[4]

Art	Science
Seeks aesthetic response	Seeks knowledge and understanding
Emotion and intuition	Reason
Idiosyncratic	Normative
Visual or sonic communication	Narrative text communication
Evocative	Explanatory
Values break with tradition	Values systematic building on tradition and adherence to standards

Source: (Wilson, 2002).

However, the disciplines are also deeply connected in that at a basic level all explore phenomena and lived experiences, and attempt to understand reality and the potentialities that may exist below the surface of that reality. In his bood *Art and Physics*, Leonard Shlain reminds us, "Revolutionary art and visionary physics are both investigations into the nature of reality" (Shlain, 1991).

4 Stephen Wilson's chart emphasizes art production and is highly generalized. One interviewee pointed out that art also seeks knowledge and understanding and quite often art includes text communication; in fact, art does not exclude any media.

Even more evident are the fundamental similarities shared by artists and scientists. Artists and scientists are often and equally described as creative, intuitive, disciplined, logical and inspired in their pursuits to understand the world (see Table 2).

Table 2. Similarities between Art and Science

Both value the careful observation of their environments to gather information through the senses.
Both value creativity.
Both propose to introduce change, innovation, or improvement over what exists.
Both use abstract models to understand the world.
Both aspire to create works that have universal relevance.

Source: (Wilson, 2002).

Below are comments from interviewees on the commonalities:

- *One of the inherent similarities between art, science and technology is that we are often dealing with highly creative people who are capable of seeing a step ahead of where society is. They are visionary people.*

- *What is fascinating for me is seeing the people working within the arts, who are not so different from the scientists in that they are very observant and also very analytical and creative. … Art and science together demonstrate that neither are purely empirical or intuitive. In fact they rely on both. And also leaps of faith.*

- *Much of what we're trying to do in science is perceive patterns that we haven't discovered yet, realities beneath our superficial vision of things, trying to get deeper, with instruments sometimes, sometimes with theory. And I think that some artists are also trying to do something very much like that.*

These ideas are echoed by others. Artist Luke Jerram opined: "Scientists and artists start by asking similar questions about the natural world, they just end up with completely different answers" (Boustead, 2009). Lisa Randall, Harvard physicist-cum-composer, pointed out that a similar curiosity pushes artists and scientists alike: "I've met a lot of other people in creative fields, and it is interesting to see how the same things drive them: The sense that there's something missing, that there's more to be done, that there's more to be known" (Cline, 2009). Anne Goodyear, a Smithsonian curator, remarked in her thesis on the intersection of art, science and technology, "The same kind of imagination that allowed Michelangelo to produce the crowning achievement of his era helped NASA's engineers build their moon ships" (Goodyear, 2002). John Latham, a senior researcher at the National Science Foundation (NSF) sponsored National Center for Atmospheric Research and emeritus professor at the University of Manchester, is also an award-winning playwright, novelist and poet. He observed:

> *I have many friends who are creative artists. They are often surprised, at first, if I suggest that scientific research has much in common with writing poetry or painting a picture. Yet on both sides of the divide there is an idea, a goal, and techniques to pursue it. It is often a stuttering journey, with cul-de-sacs and fog. And the goal can change as you approach it* (Hauser, 2010).

Researchers Robert and Michelle Root-Bernstein, for their book *Sparks of Genius*, took an in-depth look at the skills and lifestyles of successful people in the arts, humanities, sciences and technologies to understand what makes individuals think creatively, innovate and succeed within, and even outside, their disciplines. They found that the individuals they studied, be they "artists like Picasso or physicists like Richard Feynman," all exhibited the same set of imaginative skills.

That said, there is always a need to find the right balance of interdisciplinary with deep disciplinary expertise. This report does not argue that there are only superficial differences between the arts and sciences. On the contrary, there are important traits, methodologies and lines of questioning that are intrinsic and unique to each discipline that must be acknowledged, appreciated and respected. However, disciplinary straightjackets, that is to say enforcing rigid thinking about what a discipline is or isn't, can lead to misunderstanding and unnecessary limitations:

> *The worst and deepest stereotypes drive a particularly strong wedge between art (viewed as an ineffably "creative" activity, based on personal idiosyncrasy and subject only to hermeneutical interpretation) and science (viewed as a universal and rational enterprise, based on factual affirmation and analytical coherence)* (Shearer and Gould, 1999).

This report attempts to shift away from a simplistic binary grouping of activities and ideas to present the places where art informs science and science informs art.

A History of Friction and Influence between Art and Science

It is interesting that everyone is now acting like art and science are integral and important to each other, but it has been like that for thousands of years. It is nothing new; it has always been that way (Interview, internal).

History of Friction

There is a rich history of literature and theory about tension, division and coalescence between art and science. What makes this nexus so contentious and so appealing?[5] Within the last half century, a major figure in the art vs. science debate is C.P. Snow, an English novelist and physicist, who famously lamented in his 1959 Rede Lecture titled "Two Cultures" at Cambridge University that there was a formidable and growing cultural friction and divide between scientists and literary intellectuals. The condition that Snow described was one of hostile non-communication between the professions. He alleged that scientists and literary intellectuals felt that they had little in common with each other. He found the root of the problem in the education system, which encouraged field specialization at the exclusion of other disciplines. One result was that the arts and sciences did not have a common language. Snow envisioned a Third Culture, one where scientists and artists could communicate freely and as equals.[6] At the time, Snow's lecture drew both laudatory and

5 At the outset of this section it is important to note that it is difficult to make sweeping trans-cultural and trans-historical statements about the correlation of art and science and people's relationship to these two forms of knowledge. We recognize that contextual factors deeply inform how and why art and science are conceptualized and practiced, both as separate enterprises and together. The historical, geographical and cultural context that underpins scientific and artistic inquiry varies, and therefore the expressions of science and art do also. In some cases it can be argued that the boundaries between art and science are permeable or even non-existent. To illustrate this point, in Native American cultures the notion of science, which is unlike the disciplinary specialization that developed in Western cultures, is tightly linked to other intellectual, artistic and religious expressions. The exhibition *Lama, Patron, Artist: The Great Situ Panchen* at the Freer and Sackler Galleries highlighted the artwork of 18th century Tibetan Buddhist leader Situ Panchen (1700–1774) and his followers, but also his role as a teacher, religious leader and dabbler in medicine and science.

6 C.P. Snow's notion of the "Third Culture" has been appropriated by a present day movement where scientists, such as Richard Dawkins, communicate directly with the broader public. However, as Jonah Lehrer commented in *Proust was a Neuroscientist*, this is not exactly what Snow had called for a half century ago. "On the one hand," Lehrer wrote, "this is an important and necessary development." The general public has an understanding of "black holes, memes, and selfish genes" as a result. "Look deeper, however, and it becomes clear that this third culture has serious limitations. For one thing, it has failed to bridge the divide between our two existing cultures. There is still no dialogue of equals. Scientists and artists continue to describe the world in incommensurate languages" (Lehrer, 2007). Some caution that a "third way" is not possible or necessarily desirable. Ken Arnold commented: "Contrary to some contemporary opinion, there is little evidence for the existence of a unified single visual culture or a new 'third way' straddled between sciences and arts" (Ede, 2000). In the same anthology, Mike Page echoes this sentiment:

scathing feedback. Today, Snow's diagnosis is still relevant, as made clear by the symposium *A Dangerous Divide*, a series of presentations and discussions organized by the New York Academy of Sciences in 2009. Fifty years after Snow's original lecture, the symposium addressed the historical and contemporary manifestations of the divide between art and science.

At *A Dangerous Divide*, Ann Blair, a Harvard University historian, explained that although the term "scientist" was not coined until 1833, the origins of the split between the arts and sciences date to the creation of natural philosophy in 13th century European universities, at which time new disciplines developed that were independent of theological studies. This shift allowed for explanations and research that was not based on religious scriptures. Blair noted that because the new disciplines operated just outside the scrutiny of the church, "scientists" were able to explore the natural world with new found freedom. However, Blair remarked, by Isaac Newton's time in the 17th century, the professionalization of science with its protocols for conducting research had increased, and as a result, limited access to the field for amateurs and created a gap between science and the public. Gradually with time, scientific academies were founded and new specialized scientific disciplines were developed, such as biology and chemistry. Within this environment divisions existed between science research fields as well as between scientists and non-scientists.

Despite the separation and specialization of the disciplines, according to historians of science and technology and others who study creativity, the sciences and technology have never flourished in the absence of a similar flourishing of the arts. Periods of great advancement in human history are characterized as times when both art and science thrived. The Renaissance, beginning in Florence before spreading to the rest of Europe between the 14th and 17th centuries, is an excellent example of art and science – be it painting, sculpture, architecture, engineering, mathematics, manufacturing, trade, civic planning or politics – receiving financial and popular support, which in turn, contributed to the prestige and power of the society of the time. Leonardo da Vinci, the epitome of the Renaissance man, was an extraordinarily talented and revered visual artist, scientist, engineer and philosopher. The Golden Age of Islam, between the 8th and 13th centuries, is another example of a period in history that is remembered for its robust intellectual and cultural activity in all fields: art, science, agriculture, technology, philosophy and religion.

If there is to be any dialogue between art and physics it is important to realize that they show fundamental differences in approach and that a great deal in the study of each is non-transferable. The quest for simplicity on the part of science and the delight in complexity on the part of art are incompatible although each can learn from the other (Ede, 2000).

History of Art Influencing Science and Science Influencing Art

A number of recent books and exhibitions examine how artists were influenced by the scientific advances and discoveries of their day and, conversely, how scientists were influenced by art. One internal interviewee talked about how the new intellectual, scientific complex of the early part of the 20th century – dubbed "science moderne" – influenced everything from music to architecture to education.

Richard Holmes' *The Age of Wonder* offers an alternative to the assessment that disciplinary specialization within academia hampered amateur experimentation and further galvanized a divide between the arts and humanities and science. In his book, Holmes details the remarkable lives of several late 18th century men and women whose passions, multidisciplinary endeavors and scientific contributions characterize the "Romantic Age of Science," the second scientific revolution that took place at the end of the 18th century in Britain (Holmes, 2008). Holmes characterized these historical figures, from botanist and explorer Joseph Banks to novelist Mary Shelley, whose pursuits made contributions to science, art and culture, as curious about the nature of the world, full of wonder and ready for adventure and new experiences. These character attributes and motivations are found in both expressions of art and pursuits of scientific knowledge.

About the perceived split between the arts/humanities and science, Holmes contends:

> *Romanticism as a cultural force is generally regarded as intensely hostile to science, its ideal of subjectivity eternally opposed to that of scientific objectivity. But I do not believe this was always the case, or that the terms are so mutually exclusive. The notion of wonder seems to be something that once united them, and can still do so. In effect there is Romantic science in the same sense that there is Romantic poetry, and often for the same enduring reasons* (Holmes, xvi).

Holmes presents several scientists including William Herschel, a trained musician and self-taught astronomer and telescope maker, as an exemplar of the Romantic scientist. Herschel developed fantastical theories about life on the moon and the existence of other galaxies beyond our own (the latter proved to be true); he was also meticulous and steadfast in his work schedule, astronomical observations and record keeping, for which he received assistance from his sister Caroline. Holmes cites Herschel as holding the view that there must be a balance between speculation (i.e., imagination and wonder) and observation (Holmes, 2008).

While Herschel's imaginative speculations translated into groundbreaking theories that changed modern astronomy, music education contributed greatly to his aptitude as an astronomer. In his correspondences and writings Herschel reflected on the parallels between his stellar observations and his musical techniques. He attributed his ability to build original telescopes of impressive size and viewing capabilities to his understanding of musical instruments, and he credited his capacity to "read" the night sky to his speed and skill in reading sheet music. As Holmes puts it: "the brain that was trained to recognize the highly complex counterpoints and harmonies of Bach or Handel could instinctively recognize analogous stellar patternings" (Holmes, 2008).

Herschel's career-defining discovery of a new planet, Uranus, brought the self-taught astronomer fame, validation and credibility, but his legacy is that his sighting (and accuracy in interpreting its significance) greatly enlarged the size and mystery of the known universe. For Holmes, Uranus was "a symbol of the new, pioneering discoveries of Romantic science." It altered the contemporary perceptions of the world beyond the heavens and man's ability to decipher it, and, connected to this, had a profound effect on art, literature and the popular imagination of the day. Erasmus Darwin's popular poem, *The Botanic Garden* (1791), illustrates some of Herschel's astronomical theories, such as the existence of myriad solar systems (Holmes, 2008).

In a similar vein, Leonard Shlain's book *Art and Physics: Parallel Visions in Space, Time, and Light* noted how in the early 1700s Newton's *Principia* impacted the perception philosophers and theologians had of the universe. The explanatory metaphor shifted from "the image of a white-bearded God on a heavenly throne" controlling the universe to the universe as "a huge, mechanized ticking clock, set in motion by the deity" (Shlain, 1991). Kerfeld, in her review of the book *Tactical Biopolitics*, shares this idea that periods when the public imagination is captivated by science are reflected in works of art. It can be argued that 17th century astronomy influenced Milton's *Paradise Lost*, relativity theory was instrumental in the development of cubist painting, and both relativity and quantum mechanics are seen in the poetry of T.S. Eliot (Kerfeld, 2009).

Robert Farren, *Duria Antiquior (An Earlier Dorset)*, ca. 1850, Sedgwick Museum of Earth Sciences, University of Cambridge

The 2009 traveling exhibition, *Endless Forms: Charles Darwin, Natural Science, and the Visual Arts*, organized by the Yale Center for British Art and the Fitzwilliam Museum in Cambridge, England explores how Darwin's ideas of natural selection and human evolution influenced 19th century artists. The works of art – depicting such themes as the earth's ancient history, the origin of man, kinship with other animals and the struggle for existence – illustrate how Victorian-era artists responded "as academic science began to challenge the subjective nature of romantic art" (Guo, 2009).

Shlain (1991) points out that artists throughout history have used their intense observational skills to hypothesize about how the physical world operates, sometimes predating scientific discovery or contradicting the accepted theory of the day. Images produced by artists are argued to precede and prepare the way for science by first visualizing what is otherwise strange and unknown. In order to learn something radically new says Shlain, "we first have to imagine it."

> *The artist, with little or no awareness of what is going on in the field of physics, manages to conjure up images and metaphors that are strikingly appropriate when superimposed upon the conceptual framework of the physicist's later revisions of our ideas about physical reality. Repeatedly throughout history, the artist introduces symbols and icons that in retrospect prove to have been an avant-garde for the thought patterns of a scientific age not yet born* (Shlain, 1991).

As an example, Newton, Huygens and Young are names associated with the science of optics. However, as early as 1655, the post-Renaissance painter Grimaldi observed a thin layer of "interference fringes" in the shadows surrounding an opaque object, leading him to suggest, in contradiction to the positions of Galileo and Newton, that light was a fluid-like substance that could flow around objects, rather that a stream of particles – predating Huygen's wave theory by thirteen years. In another example, Leonardo DaVinci is rarely credited for his investigation of inertia, which comes "astonishingly close" to the central idea behind the laws of motion elaborated by Newton two centuries later (Shlain, 1991).

An interviewee at the National Air and Space Museum (NASM), in response to the question, "Are there examples where art inspires scientists?" spoke with great enthusiasm: "Art has been the inspiration for technology and technologists, you bet!" The interviewee described how the artwork of Chesley Bonestell, who was trained as an architectural draftsman and had painted Hollywood sets for films like *Citizen Kane* and illustrated space-related books in the late 1940s, '50s and early '60s, offered people extraordinary views of other worlds, such as the surface of Saturn from one of its moons. About visual art's impact, he concluded:

> *You can talk to one engineer after another in the space business or just tons of people that are interested in space and they will ultimately get around to telling you what an impact those paintings of Chesley Bonestell had on them. Just a huge impact … and that's only one case in point.*

In his essay, "For the sake of science, the arts deserve support," Root-Bernstein (1997) provides numerous examples of how the arts stimulate scientific progress as a basis for his argument for greater public support for the arts and collaboration across art and science agencies.

- Turn of the century nature painter Abbot H. Thayer's discovery of the concept of camouflage contributed to the understanding of the co-evolution of animals and had practical application for the protection of soldiers on the battlefield.
- Composer George Antheil and actress Hedy Lamarr's 1942 method of using song melody to send signals in Morse Code is the basis for many of today's secure communications systems.
- Buckminster Fuller's invention of geodesic domes led to the structure being used to describe viruses and a class of chemicals called "buckminsterfullerenes."
- Kenneth Snelson's "tensegrity sculptures" were considered as a method for constructing platforms for use in outer space.
- Conversion of complex data (e.g., gene sequences, economic trends) into musical notation facilitates analysis, making patterns easier to see than with numbers or words. A spinoff is that aural data analysis makes scientific results available to the visually impaired.

Rhonda Roland Shearer and Stephen Jay Gould (1999), the two founders of the Art Science Research Laboratory in New York, reference artist Marcel Duchamp as maintaining a passionate interest in science and making innovations in mathematics, optics and perception. While Italian scientists discovered the form of illusion they named the "stereo-kinetic effect" in 1924, Duchamp had independently found the perceptual phenomenon in the early 1920s and used it in his spinning disc "Rotoreliefs." Shearer and Gould argue for a more deliberate co-creative process:

> *What could be more precious, or more difficult, than conceptual innovation? We need to access all the tools at our command – even when linguistic and sociological convention parcels out these common mental devices among non-communicating disciplinary camps – if we wish to triumph in this hardest, yet most rewarding, of all intellectual pursuits* (Shearer and Gould, 1999).

Similarly, Lehrer (2007) writes that many artists and writers have intuited knowledge about the brain that predated and predicted scientific breakthroughs in neuroscience. For example, Proust's literary observations that smell and taste are the most remembered sensations and that the memory is faulty and always changing foreshadow later scientific explanations of such phenomena. One interviewee described artists as "sensitive instruments" who can perhaps pick up things that the machinery we use for perceiving the world cannot. He referenced the example in Lehrer's book of the artist Cezanne, who anticipated what neuroscientists would eventually find out about the complicated physical process of perception – what images come in, what we see first and how we reassemble the inputs that come into our eyes into the pictures we put together in our brain.

While Lehrer drew criticism for too-broad interpretation and lack of attribution to lesser lights in favor of household names, the point of these writers who seek to link the seemingly disparate disciplines is not to say who did what first but to see the complementarities of art and science – as Shlain says, where the two fields "intimately entwine to form a lattice upon which we all can climb a little higher in order to construct our view of reality… a more synthesized awareness which begins in wonder and ends with wisdom" (Shlain, 1991).

Achieving Synthesis

In *Consilience: the Unity of Knowledge*, the book's author, acclaimed biologist E.O. Wilson, calls for consilience: the unification of all areas of knowledge to address all aspects of culture and the natural world, be that the study of cell biology, religion, or the arts and their interpretation. Wilson confers considerable credit on the Enlightenment, a time in Western philosophy and cultural life in which reason was advocated as the primary source for understanding reality and for creating a framework to join the natural environment to all modes of human experience, enterprise and creativity.

> *The greatest enterprise of the mind has always been and always will be the attempted linkage of the sciences and humanities. The ongoing fragmentation of knowledge and resulting chaos in philosophy are not reflections of the real world but artifacts of scholarship* (Wilson, 1998).

With the aid of science and technology, Wilson contends that our access to "facts" has increased, but the speed with which this information is understood and synthesized has not accelerated equally:

> *We are drowning in information, while starving for wisdom … The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely* (Wilson, 1998).

Synthesizers are interdisciplinary thinkers, people who can make connections between vast amounts of information in multiple, new and breakthrough ways. A foremost example is American artist Todd Siler, the first visual artist to receive a doctorate in Interdisciplinary Studies in Psychology and Art from the Massachusetts Institute of Technology (MIT). Siler's drawings, collages, paintings, sculptures and installations seek out similarities of process across the two domains of knowledge. To convey his insights into the relationships and deep connections between the sciences and the arts Siler uses symbolic languages ("visual metaphors, physical analogies, signs, symbols, stories, allegories, puns, premises, and much more") to create a global "common language" or "metaphorms." By connecting metaphorms, one can increase the meaning and usefulness of all information, ideas, knowledge, experience and wisdom, thus stimulating breakthroughs and discoveries and generating inventions and innovations (Todd Siler website). As art critic Ann Wilson Lloyd described Siler's work:

> *His works drew on his concepts of "metaphorming," or the creation of metaphors that enable us to relate information from one discipline to another, and "processmorphs: things that are alike in process but unlike in form or appearance." He asserts that the brain reflects the universe in function and form and that we become what we think about and create.* (Lloyd, 1991 review in *Art In America* as quoted on Todd Siler website).

Examples of HAC + Science

This section of the report highlights examples of interdisciplinary activities across HAC + Science within and outside the Smithsonian Institution. The amount of interdisciplinary work across the "two cultures" is vast. HAC + Science come together in myriad ways, and examples of each type of interaction are far too numerous to cover in this report. The study team chose examples that it felt were particularly illustrative or innovative – a sampling of best examples to stir thinking about possibilities.

First, this section looks at fields of research and practice that are inherently interdisciplinary in that they combine scientific and artistic training and methods from the outset. It then gives examples of types of interdisciplinary activities, collaboration and discoveries at the intersection of HAC + Science. The aim of this part is not so much to categorize or put too fine of a point on ways of intersecting, but to show the richness, complexity, new insights and potential societal benefits that emerge from those intersections. For example:

- How an overlap of art and science has enhanced creativity in scientists and artists that generated new questions, ideas and discoveries
- Contemporary artists whose work comments on social, cultural and ethical implications of modern science
- Artists who, in collaboration with scientists, use their art to raise awareness and advocate for solutions to societal problems such as global climate change and loss of biodiversity
- How complex scientific ideas and data are expressed through imaging
- How artwork can express science in novel and compelling ways

Inherently interdisciplinary

Before delving into some exciting novel ways that the arts, humanities, sciences and technology are coming together, it is important not to overlook the areas of study and practice that are "inherently interdisciplinary." In other words, they inseparably encompass the camps of both the sciences and arts/humanities and are recognized as distinct academic departments and areas of expertise. Many of these "interdisciplines" exist throughout the Smithsonian and are natural jumping-off points in bridging "siloed" academic departments and units across the four Grand Challenges of the Institution's Strategic Plan. Examples highlighted here are design, craft, science illustration, photography, materials conservation, technology/new media, history of science and technology, anthropology/archeology and horticulture.

Design

> *Design ties into creativity and innovation, which lies at the Smithsonian's core. Design is where art and science meet, and having the Smithsonian in this unique space is a very good thing* (Secretary Clough, interview in *The Torch*, 2010).

> *Design sits at the intersection of science, technology, and the visual arts. More than the traditional arts, the field of design is all encompassing, ranging from small objects like microchips or light bulbs, to architecture, to the infrastructure of our cities, to the internet's unparalleled capacity to disseminate information around the world. Design impacts virtually every aspect of our life, from the clothing we wear to the stewardship of natural resources* (CHNDM pan-Institutional exhibition proposal: Design from the Smithsonian, 2009).

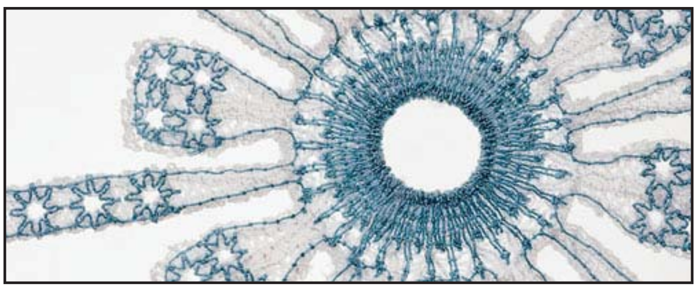


Image from *Extreme Textiles: Designing for High Performance*

Indeed, as Secretary Clough noted, design – from research design to exhibition design to design of education programs to the aesthetic and functional design of collections objects and more – is at the center of the Smithsonian enterprise. The Institution has two primary museum spaces that celebrate design – the Cooper-Hewitt National Design Museum in New York and the Jerome and Dorothy Lemelson Center for the Study of Invention and Innovation at the National Museum of American History (NMAH). Just one example of design merging art and science at the Smithsonian is the CHNDM exhibition *Extreme Textiles: Designing for High Performance*, with incredible (and beautiful) new materials that are revolutionizing architecture, apparel, medicine, transportation, aerospace, and the environment, including the ultimate extreme fabrics used in space suits from NASM.

In the design world, there is increasing emphasis on design with a social purpose of impacting human and environmental problems.[7] One interviewee described a paradigm shift in the past two decades beyond "the indulgent and desirable, to respond to a more genuine need." This shift, as seen through the lens of design and technology, was a response to the United Nations' Millennium goals including eradication of poverty, acceleration of

7 The movement of designers and artists collaborating with scientists to address broad societal concerns is addressed further in the later section on Eco-Arts.

information sharing such as through social media, and the shrinking of the global village – a greater awareness that everyone is sharing one earth (Interview, internal).

Q Drum durable container designed to roll easily and transport seventy-five liters of clean and potable water

The CHNDM traveling exhibition *Design for the Other 90%* explored this movement of like-minded designers, engineers, students, professors, architects and social entrepreneurs, along with organizations and communities, who aim to develop low-cost solutions that address the challenges – such as access to food and water, energy, education, healthcare, revenue-generating activities and affordable transportation – that are faced by the world's poor and marginalized, that is, 90% of the world's total population (CHNDM website).

The Bamboo Treadle Pump allows poor farmers to access groundwater during the dry season. The treadles and support structure are made of inexpensive, locally available materials and the pump can be manufactured locally by metalworking shops. (Designer: Gunnar Barnes of Rangpur/Dinajpur Rural Service and International Development Enterprises [IDE] Nepal)

Another aspect of the design movement is the involvement of citizens as active participants in local design solutions. This has been propelled by programs such as the World Bank's Development Marketplace Global Competition on Climate Change, which awarded $4.8 million to awardees in 2009 for innovative approaches to affect climate change in some of the most adversely affected communities and environments in the developing world (Relief Web, 2010).

External examples of design as the fulcrum on which different areas of expertise are brought to bear to improve the human state are many. At MIT's renowned Media Lab, "human adaptability" initiatives include sociable robots that can monitor the health of children or the elderly and smart prostheses that can mimic—or even exceed—the capabilities of our biological limbs (Media Lab website). The intersection of design and the new frontier of brain science was recently on view at the Mori Art Museum in Japan. A wheelchair designed to help the physically impaired that can be controlled by brainwaves – *Brain-wave-driven Wheelchair* (2009) – was developed by the Japanese team RIKEN BSI-Toyota (Birmingham, 2010).

Craft

The work of many craft artists is inextricably bound up with science – potters have to know their glaze chemistry, glass artists the properties that make up glass and the use of furnaces, and fiber artists their dye properties and materials. An internal interviewee referenced the technical skills of four extraordinary craft artists featured in the upcoming Renwick Craft Invitational 2011 at the Smithsonian American Art Museum's Renwick Gallery who "have fallen in love with the science of their mediums." One, Cliff Lee, a neurosurgeon by training, employs his knowledge of chemistry in recreating the medieval Chinese glazes of his elegant porcelain vessels, described as created "with the exactitude of a doctor" (exhibition website).

Artwork by Joan Lederman

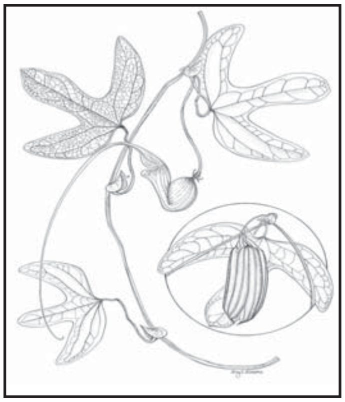
Joan Lederman creates pottery using deep sea mud obtained from the Woods Hole Oceanographic Institution. The core samples of sea mud collected from research vessels on oceanographic cruises have different chemical compositions and behave differently when fired. The colors and patterns made by some sea mud radiate like the dendrites of nerve cells – dendritic patterns are caused by foraminifera, ancient shells of marine organisms, some of which are thirty-five to forty million years old. Woods Hole scientist Marie Tharpe wrote to the artist:

> *Your tireless effort to secure bottom sediments with some tiny fossil animals from the lakes, bays, and seas of our planet is serious scientific stuff. Your next phase of arranging these artistically into a lasting pattern of glazed stoneware is a superb combination of science and art* (The Soft Earth website).

Science illustration

> *That which has not been drawn has not been seen* (Adage quoted in Root Bernstein, 1997).

> *Take the elevator to the sixth floor of the National Museum of Natural History's east wing and you enter another world. In the Department of Entomology, row after row of cases store tiny, often beautiful, six-legged creatures. Step inside the office of Elaine Hodges and Young Sohn, and you will find trays of wasps and bees, microscopes, slides, dissecting tools, and what's this?: carbon pencils, crow quill pens, artist's brushes, scratch board, tracing paper. In many ways, the room looks more like an artist's studio than a scientist's lab. In reality, it's a bit of both* (Henson, 1996).



Aristolochia trilobata (Aristolochiaceae) Collection: H. von Wedel 1404, Panama, Provincia de Bocas del Toro; leafy branch with flowers. Artist: Mary Sue Monsma, Date unknown, pen and ink

Some science illustrators say the tradition goes back over four centuries to "cabinets of curiosity" that were the first natural history collections; others trace their craft to prehistoric cave drawings. The art of science illustration is a true convergence of the two fields, which are both about close observation, where "students are as concerned with the way that light glints off fur as they are with identifying the mammal covered by that fur." Across the country some 20 university programs offer training in science illustration; notable ones include the Rhode Island School of Design and the University of California, Santa Cruz. At the University of Minnesota's entomology department, students exclusively learn to draw insects (Méndez, 2005; Zimmer, 2009). Henson (1996) explains why scientific illustration is better than photography in allowing us to see the shape and anatomical features of a specimen: "The lighting of a photograph may distort shape, emulsions may distort color, and the camera cannot fix crumpled, damaged or discolored parts."

The Smithsonian has long been known as having one of the highest concentrations of scientific illustrators in the US. The Guild of Natural Science Illustrators, now a global entity, was begun at the National Museum of Natural History in 1968 (Hodges, 2006). Today's expanded world of science illustration using modern technology tools such as computer graphics and animation software programs is taken up in a later section of this paper.

Photography

The series of technological developments utilizing chemical processes known as photography has been of equal interest to scientists and artists from its very beginnings. Scientists in the mid-19th century eagerly enlisted the camera to catalogue plant and animal species and document the grandeur of the American landscape and its Native American inhabitants. "Photography brought the faraway near and made visible the previously invisible" (Smithsonian Photography Initiative website). Artists were similarly drawn to the technology's possibilities, and the early 20th century saw the acceptance of art photography and documentary photography into the gallery system (Wikipedia, n.d.). The Smithsonian is an extraordinary repository of more than 13 million images spanning art, history, culture and science located in some seven hundred collections across the Institution's museums and research centers.

Examples of photography as a medium spanning disciplines are infinite. Here we look at just two combinations – the art of photography with biology/natural history and with astrophysics.

Nature photography

> *Part adventurer, part artist, [nature photographers] travel the world to capture the beauty and mystery of its farthest reaches. We spend our days and nights amid the mud and the bugs, searching for those fleeting moments of magic that reveal glimpses of our planet and illustrate the wonders of life.*

Florian Schulz, *Otters*

The above introduction to the National Museum of Natural History's (NMNH) website for its annual *Nature's Best Photography Awards* exhibition, taken from *Celebration of Life by* Patricio Robles Gil, the 2009 Conservation Photographer of the Year, captures the science-art nexus of nature photography.

Amy Lamb, *Emerging clematis*

Washington, D.C. artist/photographer Amy Lamb, trained as a biologist, explains that she has always been intrigued and enthralled by the beauty and precision of the natural world and the elegant and mysterious partnership of form and function found in the structures of fruits and flowers. Her recent exhibition *Patterns in Nature* reveals similarities of form and symmetry – spirals, branches and layers – predictable across nature and natural phenomena (Amy Lamb Studio website). An earlier show, *The Nature of Architecture*, juxtaposed her precise close-ups of fruits and flowers with details of the built environment, suggesting that "in developing an architectural vision for structures that meet needs for shelter, comfort, and security, humans have turned both consciously and subconsciously, to the forms, structures, and proportions found in the natural world" (American Architectural Foundation website).

Justine Cooper's *Saved by Science* series of large-scale photographs taken inside the American Museum of Natural History follows in the artistic tradition of documenting natural history collections but with the twist of focusing on the cultural institutions that contain those collections to capture "the crowded stillness of those halls, the unexpected treasures. The seals in the attic" (Zimmer, 2009).

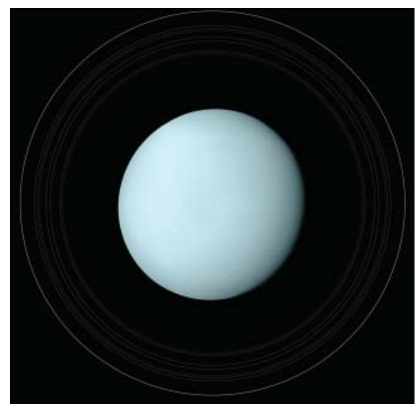
Justine Cooper, *The Waiting Room* (specimens waiting for treatment for carpet beetle infestation)

Joseph Scheer's work explores the inherent human need for nature – what E.O. Wilson named "biophilia" – through the medium of moths. The artist uses digital scanning technology allowing us to see the insects at very high resolution. He explains,

> *There is an incredible reality that we are now able to see that reveals the beauty along with the monstrosity of moths with all their preposterous hair and scales. Their beauty becomes a totally different kind – a sort of repulsive, disquieting beauty* (Joseph Scheer website).

Installation shot of artwork by Joseph Scheer

Space photography



Michael Benson, *Uranus and Its Rings*, Credit: NASA; JPL; Calvin Hamilton

For *Beyond: Visions of Our Solar System*, recently on view in the art gallery of NASM, artist Michael Benson mined the archives of the National Aeronautics and Space Administration (NASA) and the European Space Agency for images taken by unmanned interplanetary missions, which he used to create mesmerizing large-format composite views of planets and moons. Visitors to *Beyond* can experience the frozen plains of Jupiter's moon Europa, volcanoes and lava flows on Venus, a canyon on Mars as big as the continental U.S., and panoramic views of Saturn's rings. The artist's hope is that visitors will "come away with a new awareness of how our Earth belongs to a vast continuity of related landscapes, all of them turning under the Sun. They will see that we are one world within a stunningly variegated archipelago" (Exhibition website).

Materials conservation

Materials conservation and research unite knowledge across the arts and humanities and physical and natural sciences. Internal interviewees described how specialized knowledge from multiple disciplines including engineering is needed to address such problems as storage space that must be climate controlled, chemically inert, anti-corrosive and low movement. Conservators can still take an apprenticeship path but typically now must have a professional degree that requires classes in studio art, art history and chemistry.

While scientific research on art museum collections has been in existence since the 1930s, it is only in the past 30 years that museums have routinely hired conservation scientists as permanent staff (Schulz, 2009). The Smithsonian has long been a bastion of conservation science with the Freer and Sackler Galleries (FSG) Department of Conservation and Scientific Research started as the Technical Laboratory in 1951; the Museum Conservation Institute (MCI) (successor to the Smithsonian Center for Materials Research and Education and before that the Conservation Analytical Laboratory) established in 1963; the more recent Lunder Conservation Center, a shared facility of the American Art Museum (SAAM) and National Portrait Gallery (NPG); and conservation units at the Hirshhorn Museum and Sculpture Garden (HMSG), National Museum of African Art (NMAfA) and other Smithsonian museums. The Smithsonian has a number of talented conservators who have made contributions to their field. In her recent book, *Zinc Sculpture in America: 1850-1950* (2009), Carol Grissom at MCI combines her knowledge of chemistry, art conservation, American history and monument building practices to inventory and conserve zinc monuments and sculptures. The conservation lab at NMAfA produced *Ivory: Identification and Regulation of a Precious Material*, a resource guide written by conservator Stephanie Hornbeck for specialists, art collectors and the public to assist with ivory identification and provenance research; promote the responsible and legal collection of ivory; and enhance appreciation for the animals and habitats that produce it.

Schulz (2009) describes an increasing instance of more discipline-based chemists and other scientists working in cultural settings on studies of archeological objects, cultural heritage properties, fine arts collections, archives, historical buildings, monuments and more. In a 2009 "watershed event," NSF issued its first solicitation for research in cultural heritage through its Chemistry Division. The funding is intended to spur collaborations involving chemists or materials scientists in cultural heritage institutions and those in universities and national laboratories and address grand challenges in the area of fundamental (versus applied) science for cultural heritage (Schulz, 2009).

X-ray fluorescence spectroscopy is used by Metropolitan Museum of Art scientists to investigate the original polychromy of a Roman sculpture (Schulz, 2009)

New technology adds another dimension to the disciplinary mix that is conservation science. In March 2010 the Smithsonian hosted "Collaborations in Conserving Time-Based Art" a colloquium that brought together curators, conservators, technology experts, archivists and other museum staff to address the special challenges that arise when preserving artworks created in moving image and digital media.

Materials conservation research enters the public education realm in the exhibition *Close Examination: Fakes, Mistakes and Discoveries*, on display at the National Gallery, London. Offering visitors the chance to “witness the forensic detective work taking place behind restorers’ closed doors” the exhibition shows how scientific research using such technologies as Raman microscopy and high-performance liquid chromatography (HPLC) has, for example, revealed artwork bearing famous signatures to be collaborative workshop productions and work deemed an early copy to be the unique original (Fara, 2010). *Santos: Substance & Soul*, a traveling exhibition resulting from a collaboration of the Smithsonian Museum Conservation Institute, National Museum of American History, Albuquerque Museum, Museo De Arte de Ponce, Spanish Colonial Arts Society, Millicent Rogers Museum of Northern New Mexico and a private collection, similarly explored the integration of scientific research into the study of cultural expression (MCI website).

Technology / new media

Ken Arnold, in his chapter “Between Explanation and Inspiration: Images in Science” in Sian Ede’s book *Strange and Charmed: Science and the Contemporary Visual Arts*, asserts that the places where the arts and sciences best inform each other are places not monopolized by either discipline. This is especially true in the realm of technology.

> *A particularly rich location for contemporary image-making, and indeed for knowledge creation, and which has provided just such a neutral cultural space, is information technology. Digital media and computer software have provided the perfect point of contact for technologically orientated artists and artistically sympathetic scientists and technicians* (Ede, 2000).

An external interviewee spoke of the emerging area of virtual worlds, gaming theory and areas “that are genuinely so new that we as a society haven’t quite decided whether they are art or science. Some of those people [who work in these technologies] are therefore neither one nor the other.”

There is a wide array of interconnections between contemporary art and science-based technology. In fact, nothing seems outside the purview of contemporary artists, as demonstrated in Stephen Wilson’s book *Information Arts: Intersections of art, science and technology* (2002), which provides a comprehensive survey of artistic practices related to the technological aspects of biology, the physical sciences, mathematics and algorithms, kinetics, telecommunications and digital systems. The many idiosyncratic ways that artists engage with technology, which cover experiments with artificial intelligence to plastic surgery procedures, are beyond the reach of this report. However, some examples are included in later sections, such as bio-art (addressed in the *Contemporary art, science, and social commentary* section of Wilson’s book), which incorporates engineering and technology that are developed in tandem with biological research.

New media – the digital, computerized, or networked information and communication technology that emerged in the late 20th century – has been adopted by artists, scientists and educators and is a fertile area, as new media is neither strictly science nor art, but has attributes of and applications for both. At the Smithsonian there are a number of initiatives and examples where art, science and new media come together in novel formations:

- Smithsonian Web 2.0 responds to the rapidly changing 21st century digital environment and the Smithsonian's growing virtual visitorship. Web 2.0 aims to make accessible through new media technology the Smithsonian's 137 million artifacts, works of art and scientific specimens, along with staff expertise, and to use its resources to generate and support research as well as engage, educate and inspire Americans and digital visitors around the world. The Smithsonian Web 2.0 Fund supports forward-thinking new media projects that work towards those ambitions. One example of a Web 2.0-funded project that spans HAC + Science is the Virtual Watershed project of the Smithsonian Latino Center's Latino Virtual Museum (LVM) in Second Life. The Virtual Watershed is a state-of-the-art, immersive, 3D digital environment for learning about watershed ecosystems and human interaction with that environment. It is an interdisciplinary and inter-Smithsonian unit partnership with NMNH, Smithsonian Environmental Research Center (SERC), Smithsonian Tropical Research Institute (STRI), and National Zoological park (NZP), plus the Grid Institute of Boston College, and is accessible to visitors through the internet.

- The *Smithsonian Connections: Lincoln* project inventively used the web, social media and cell phone technology to link the scores of Smithsonian sites where Abraham Lincoln artifacts, memorabilia and scholarship reside, such as the Smithsonian Castle, National Postal Museum, NASM and SAAM. Young, tech-savvy visitors connected to the history of the past president through cell phone texts, interactive maps and other social media. One interviewee noted that Smithsonian Connections has been examined by other museums that are eager to replicate its success. Importantly, the project highlighted how independent Smithsonian museums, aided by the Institution's outreach units such as SCEMS and for-profit offices such Smithsonian Enterprises' *GO Smithsonian*, can join together to tell a more comprehensive and sophisticated story, one that enriches the visitors' experiences.

The Smithsonian has a significant role to play in understanding how technology, art and society interlink in America's history. For example, SAAM oversees the archive and seminal artworks by Korean-American artist Nam Jun Paik (1932-2006), who was an early adopter of electronic and communication media and is credited with transforming broadcast television, its equipment and electronic moving image into artists' media. Senior Curator for Media Arts John Hanhardt expresses the indelible legacy that Nam Jun Paik left:

> *[Paik treated] film and video as flexible and dynamic multi-textual art forms. Using television, as well as the modalities of single channel videotape and sculptural/installation formats, he imbued the electronic moving image with new meanings. Paik's investigations into video and television and his key role in transforming the electronic moving image into an artist's medium are part of the history of the media arts* (Hanhardt, n.d.).

Nam Jun Paik, *Electronic Superhighway: Continental U.S. Alaska, Hawaii*, 1995

Still from John Gerrard's *Animated Scene (Oil Field)*, 2007

Indebted to pioneers such as Paik, Irish artist John Gerrard appropriates the emerging technology of his generation, in this case videogame software, to create art. Gerrard's visually striking moving images of American landscapes echo the imagery of realist landscape painting of the 20th century. His software-generated artwork was on display in *Directions: John Gerrard* (November 2009–May 2010) at HMSG.

Artists working with technology have the support of international networks and art-science labs that exist to promote collaboration between artists, scientists and technologists and experimentation with new technology. Examples are listed in the Art-Science Labs section of this report.

History of Science and Technology

> *Actorum memores simul affectamus agenda – "mindful of things that have taken place, at the same time we strive after things yet to be done"* (Motto of the Newcomen Society, a British learned society formed to foster the study of the history of engineering and technology).

Another inherently interdisciplinary field, History of Science and Technology, looks at scientific and technological progress through a humanistic and social lens as a measure of the development of human civilization. The field has its roots in national museums founded in the 19th century to celebrate achievements in science, technology and industrial design, such as the Science Museum in London and the Technical Museum of Industry and Trade in Vienna. One interviewee described the shift, around the 1970s, away from the more purely technical approach of "internalists" to more emphasis on social context; for example, where earlier exhibitions on transportation looked at how steam engines in locomotives worked, today's transportation exhibit examines how the arrival of trains impacted the food industry.

The field of the history of science and technology is found throughout the Smithsonian. Curators in the science and technology divisions of NMAH explore the history of computers, electricity, mathematics, photography, industrial machinery, engineering, transportation, medicine, the biological, physical and environmental sciences and more. Likewise, curators at NASM study the history of aeronautics and space exploration. Another focal point of the history of science and technology is the Lemelson Center at NMAH, an interdisciplinary center founded in 1995. As one interviewee explained, "history is a way to understand the forward trajectory of invention. It is also a wonderful portal to engagement with young people." The Smithsonian is also home to the Dibner Library, with some 35,000 rare books and 10,000 manuscripts (some nearly six centuries old) encompassing works on engineering, transportation, chemistry, mathematics, physics, electricity and astronomy. The Institution's rich tradition in the field is exemplified by its Arts and Industries Building (AIB), long a showcase for interdisciplinary exhibitions crossing science, technology, and the arts and humanities.

The international organization *Artefacts*, cosponsored by the Smithsonian, the Science Museum (London) and the Deutsches Museum (Munich), is concerned with the use of objects in scholarly studies of the history of science, technology and medicine. Its annual meetings seed ideas for its publication series – recent meetings have dealt with exploration, icons of achievement in science and technology, and globalization. A meeting in Vienna explored the intersection of science and technology with music and the 2008 meeting in Washington, D.C. looked at the relationship between art, science and technology.

Exhibitions exploring the history of science and technology appear in art as well as science and history museums. For example, *Light! The Industrial Age, 1750-1900 Art & Science, Technology & Society,* a multi-perspective take on the subject of light, human perception, electricity, the culture of the industrial age, inventions and the artwork it inspired and reacted to was a collaboration of the Carnegie Museum of Art in Pittsburgh and the Van Gogh Museum in Amsterdam.

Anthropology and Archeology

Anthropology, the study of humanity, and archeology, which looks at past human societies, encompass the natural and social sciences and humanities. The interdisciplines are found in both Smithsonian culture and science museums. An example of the tight weave of history, art, culture and science involved in anthropology is NMNH's Korea Gallery, which presents Korea's millennia of history and cultural themes of family, weddings, writing system, and natural and built environments, as well as contemporary visual arts, through ceramics, paintings, textiles and sculptures. The archeobiology program at NMNH was explicitly started as an interdisciplinary program that could bring together botany, biology and anthropology to study the interactions of humans, plants and animals.

Horticulture

The merging of botanical, historical, cultural and artistic pursuits is found in the "outdoor museums" surrounding Smithsonian museums. Besides their aesthetic virtues, the National Museum of the American Indian Museum's landscape recalls the natural environment that existed prior to European contact; NMAH's Heirloom Garden features heirloom, open-pollinated plants that preceded today's hybrids and genetically altered varieties; and the Butterfly Habitat Garden at NMAH presents the ecologies of wetlands, meadows and woodland.

New Interdisciplines

Interdisciplines are constantly evolving – examples of inherently interdisciplinary areas of study and practices that are newer to the scene include:

Acoustic ecology

Science and music converge in the research of composer and ecologist David Dunn and physicist Jim Crutchfield, in collaboration with forest ecologist Richard Hofstetter. The use of extensive field recordings in their study of the bioacoustic ecology of bark beetles in relation to deforestation and entomogenic climate change found that "bioacoustic communication plays a role in infestation dynamics and is likely to be a critical link in the feedback loop. These results open the way to novel detection and monitoring strategies and nontoxic control interventions" (Dunn and Crutchfield, 2009).

Microbial art

Some researchers – microbiologists and biochemists, for example – are finding new audiences in their practice of microbial art, manipulating bacteria, yeast, fungi and protists into things of "preternatural beauty." Advances in biotechnology are enabling experimentation with new colors, fluorescence and media. Two microbial artists, evolutionary biologist T. Ryan Gregory and industrial biologist Niall Hamilton, collaborated on the site microbialart.com to document the "growing number

Niall Hamilton, *Apple Tree*

of ephemeral pieces – living works, which ultimately overgrow their desired forms and die" (Boustead, 2010).

Interdisciplinary collaboration at the intersection of HAC + Science

This section of the report organizes HAC + Science examples under three broad categories: stimulation of creativity and discovery; social commentary and activism; and communication of science to wide audiences. The study team recognizes that these three overarching "outcomes" are in fact interwoven and not mutually exclusive. For example, an artist deeply inspired by a scientific concept who collaborates with a scientist in creating an artwork that communicates science to a non-scientific audience has multiple outcomes associated with it. As mentioned at the beginning of this section, the study team distilled a range of benefits derived from the art-science nexus from interviews, the literature review and a number of other primary and secondary sources. Each of the three overarching categories has any number and combination of benefits occurring in the examples included under that rubric. The list, by no means exhaustive, includes:

- Challenges to the dominant structures and assumptions to gain new insights into the history and development of ideas in both the sciences and arts/humanities and the biases inherent in them;
- New knowledge, discovery and invention as a result of enhanced creativity and a wider set of perspectives/skills;
- The wonder and complexity of science inspiring art;
- Exploration of new content areas, e.g., combining art with technology, biology, etc.;
- Personal fulfillment, enrichment and collaborative spirit;
- Influence of policy makers and public opinion; generating discussion on scientific topics and global problems, e.g., climate change;
- Improved public image and social buy-in by humanizing technologies and testing out ideas in the public realm;
- Making scientific discoveries cogent and relevant;
- Increasing science literacy; stimulating excitement about science among people of all ages and backgrounds; and
- Expression of complex data and ideas.

Stimulation of creativity and discovery

Artist Dan Goods, during his talk at the Koshland Science Museum of the National Academy of Sciences in Washington D.C., reflected, "The nexus of art and science is most often seen as art *communicating* science; however, art can *stimulate* science ideas."

Scientists generate new ideas, skills and greater creativity from working with artists, engaging with artistic concepts and creating art. One interviewee described the advantage for scientists of getting a more subjective sense and "filling out of the picture of what they are up to."

> *Scientists must think universally about the objective, factual, theoretical sense of what they are interested in, [and] the world of medicine is sometimes detached from real people. The subjective sense of what it is to be ill and what it is like facing up to a different way of thinking about your body has an influence on the knowledge itself* (Interview, external).

On the other hand, artists gain new insights and deepen their understanding of the way the world works from a scientific perspective when they engage with scientists. Both scientists and artists are exposed to new information and a broader way of doing things when they engage in interdisciplinary activities, both within their work and personal lives. New knowledge and understanding can emerge when one forms fresh and uncommon connections between objects, ideas and experiences that on the surface may seem unrelated.

Charles Darwin is often lauded for his expansive interests and remarkable ability to make connections. As David Sloan Wilson characterized, "Darwin's empire of thought was larger than the British Empire" (Wilson, 2007). Darwin's studies spanned geography, geology, paleontology, zoology, agriculture, anthropology, economics, human morality, the arts and more (Root-Bernstein and Root-Bernstein, 2009). Lithographs and renderings of nature by botanist John Stevens Henslow and ornithologist John Gould left an indelible impression on Darwin, and it is supposed that his thesis on the beak adaptations of Galapagos finches was in part inspired by art, specifically a series of lithographs depicting birds (Guo, 2009).

Possessing a wide overview of subjects, theories and practices is an advantage for evolutionists, but this ability to cut across disciplines is also a character trait pervasive among successful scientists in general. Scientists and authors Michele and Robert Root-Bernstein found in their research that scientists who engage in artistic pursuits are more likely to innovate and excel in their field than their counterparts who do not. The bond distinguished scientists share is a capacity to foster a complementary combination of avocation and vocation within their daily lives. The skills and knowledge acquired through their extra activities, be it playing a musical instrument, writing a short story or folding origami "synergize, rather than compete" with other skills and understanding to give them more opportunity to juxtapose and integrate large amounts of disparate information (Root-Bernstein and Root-Bernstein, 1999). Such skills include being able to look acutely (observation skills); think spatially and kinesthetically (how things look in three dimensions and move in space); identify the essential components of a complex whole; recognize and invent patterns (the "rules" governing a system); and synthesize and communicate the results of one's thinking visually, verbally or mathematically (Root-Bernstein, 1997). In other words, scientists who practice art have a pool of skills to draw from that are not learned through conventional science education, which in turn enhances their potential to be creative and make novel connections:

> *Scientific creativity depends not only on a well-oiled imagination coupled to habits of hard work but, more importantly, on the ability to integrate in functional ways a wider range of ideas, concepts and skills than is usual* (Root-Bernstein and Root-Bernstein, 1999).

The business world has also discerned the benefits of cultivating well-rounded, open-thinking employees by encouraging an appreciation and understanding of history, culture and the arts. In South Korea senior employees of the Pohang Iron and Steel Company (POSCO) attend weekly morning lectures on topics such as Oriental classics and ancient history. It is reported that,

> *Some management professors think that humanities can offer CEOs a broader foundation and keen insight to manage companies in an increasingly complicated, global and fast-moving business world* (Chun, 2010).

Within the medical field there are a number of examples where art, which enhances observation and manipulative skills, can improve a doctor's diagnostic aptitude. Anatomy illustration, historically a common practice for medical doctors, can fine-tune one's ability to discern details and nuance. Cardiologists with musical training have a greater ability to pinpoint aberrations in heartbeats. The medical doctors that make up the membership of the Albert Einstein Symphony, Yeshiva University, derive personal pleasure and professional benefits from their participation. (Albert Einstein, who had a passion for the piano and violin, is purported to have said that he often thought of his life in terms of music.) One doctor reflected that his social interaction with his music community makes him a better communicator:

> *It's a question of communication skills with patients, with other doctors … There are a lot of ways to make people feel better, other than giving a cut-and-dry answer and writing a prescription. That's what I would call the art of medicine, and it's not fluff* (NPR, 2004).

The "art of medicine," which is not learned from a textbook or in a traditional classroom, is the social dimension of practicing medicine. Doctors who are able to listen to patients and attune to their behaviors have more diagnostic clues available to them.

Having the acute observation skills required to see details, find patterns and make connections can help scientists "break through" but they must be open to surprise. As one external interviewee told the study team:

> *Great revolutions in scientific thought take place when you get surprised by something. One of the things they look for in the lab is being open to surprise. Often, the evidence is right there in front of you, but you can't see it. Take the example of DNA – Watson and Crick could see what Rosalind Franklin could not see. It was her image, it was right in front of her face, but she did not see the double helix. They looked at it – instantly they knew it was a double helix. The famous quote that allegedly was said was, "we knew it was right because it was so beautiful." They used a visual reference* (Interview, external).

According to Nat Friedman, a mathematician, sculptor and Professor Emeritus at the University of Albany, SUNY, "Learning to see is fundamental to both art and mathematics. Whole new worlds open up when you can see better" (Rehmeyer, 2009).

Nat Friedman, *Trefoil Knot Minimal Surface*, Limestone, 2006

There are a number of scientists who find overlap between their science and their appreciation of art. In a catalogue essay for *Imagining Science: Art, Science and Social Change*, Francis Collins, a genetics expert, drew a parallel between music and DNA and spoke of his scientific exploration in very spiritual terms:

> *After working with this molecule every day for the last three decades, I am still in awe. And that awe is not just mathematical or coldly scientific, it is numinous. It enters the same mental space that is filled by an exquisite sunset or the playing of Mozart's Piano Concerto No. 23. … DNA's got rhythm, we just haven't been able to learn its time signatures yet* (Caulfield and Caulfield, 2008).

An appreciation of art is believed to improve a scientist's capacity to courageously leap into the unknown and to acknowledge and allow for ambiguity and uncertainty. In the same exhibition catalogue Edna Einsiedel, a professor of communication studies, mused:

> *Art can help; it has the potential to transform our fear of uncertainty into an appreciation of mystery by offering us the opportunity to experience wonder and*

awe, and to 'practice' believing impossible things. … Every major advance in scientific thinking – so-called scientific revolutions – has resulted because someone dared to believe the impossible (Caulfield and Caulfield, 2008).

Art can also promote "a feeling of exploration and playfulness. All great discoveries are a product of creativity and surprise" (Interview, external). Being open to surprise and embracing ambiguity are also linked to risk taking. An independent evaluation of the Wellcome Trust's SciArt grants found that "artists were more likely to be innovative and to take risks than scientists, but that some scientists had become more open to risk-taking through their association with artists" (Glinkowski and Bamford, 2009).

One internal interviewee observed that artists excel at asking questions. Artists bring astuteness and inquisitiveness to their interactions with the science community, and this can lead to fruitful tensions, discussions and consequential discoveries. One finding of the *A Dangerous Divide* symposium was that artists, including literary intellectuals, historians and journalists, tend to pose questions about science that have not even occurred to scientists to ask (Williams, 2009).

Interdisciplinary experimentation and dialogue can shake things up and open participants to new perspectives. The collaboration between Benedict Gross, a Harvard professor and number theorist, and Ryoji Ikeda, an artist and composer known for his immersive synaesthetic installations that incorporate imagery derived from mathematics and sound, is an example of the second level of interdisciplinary collaboration – overlap – where practitioners from different disciplines come together to expose common questions they have about an issue. Gross had this to say about his collaboration with Ikeda:

> *[Ikeda] forced me to think about these questions in a way that I never went about before. In some sense he's exploring as an artist exactly the same questions that we are desperately trying to understand as mathematicians and where he's at the border of his art and we're at the border of our mathematics, there's a lot of intersection … I think we're in a period where there's going to be more interactions between scientists and artists* (Connolly, 2008).

Benedict Gross and Ryoji Ikeda's interdisciplinary collaboration came to fruition through Le Laboratoire, a not-for-profit creative center in Paris, founded in 2007 by Harvard biomedical scientist and writer David Edwards, which promotes the cross-fertilization of ideas and experimentation between art and science. The two cultures converge in what Edwards refers to as "ArtScience," a term he explored at length in his book of the same name. He asks: what lies behind innovative intelligence? Edwards found that knowledge from one field can be a catalyst for innovation in another. Seeing Le Laboratoire as an art and science "idea accelerator" that incubates activity and discussion, Edwards wants to push people outside of their disciplinary comfort zone:

... moving from one lab to another is incredibly refreshing and rejuvenating, and I think on the high-performing level artists and scientists understand each other very well and want to understand each other even better. Of course as you move down the competence scale that readiness is less evident – we all find comfort and security in saying, "I don't need or want to understand something." But at Le Laboratoire we're only interested in doing projects at the cutting edge (Edwards quoted in Connolly, 2008).

Scientists creating artwork

There are multiple cases of influential inventions and scientific breakthroughs made by individuals who are comfortable both in the science lab and art studio. Looking historically, Louis-Jacques Daguerre (1787–1851), a French artist and chemist, invented the daguerreotype, one of the first forms of photography. Samuel F.B. Morse (1791–1872), the inventor of the telegraph, was a painter. It is believed that Morse's first telegraph was ingeniously fashioned out of a canvas stretcher (Root-Bernstein, 1997).

More recent examples inform us that when an individual extends his or her perspective by moving from one area of knowledge into another, the opportunities to make novel connections increase. Such was the case for composer Diana Dabby who was trained as a concert pianist. Driven by curiosity, she took a risk and changed her career path, ultimately acquiring a PhD in engineering from MIT. She made an innovative leap in the field of music when she discovered how to apply chaos theory to musical compositions (Edwards, 2008).

Marilyn Emerson-Holtzer, a chemist at the University of Washington and a talented weaver, combined her two passions by applying her understanding of fiber folding in weaving to processes of protein folding. Equally, her chemistry training translated back to weaving, for which she has won awards for her innovative designs (Root-Bernstein, 1997).

Erik Demaine, associate professor at MIT and recipient of the MacArthur Foundation "genius grant," applies the ancient art of origami directly to his microbiological research, which may have real scientific and medical applications. He is researching how the principles that govern origami might also dictate how protein molecules fold in human bodies, and this could have implications for understanding illnesses such as Alzheimer's and Parkinson's diseases. The art world has also paid attention; his computational origami, created in collaboration with his father, visual artist Martin Demaine, was included in the *Design and the Elastic Mind* exhibition

Erik Demaine and Martin Demaine, *Computational Origami*, 2008, MoMA at the Museum of Modern Art (MoMA) in New York. The MoMA acquired three paper sculptures by the Demaines for its permanent collection (Saslow, 2010).

Arguably, all of these creative endeavors – inventing photography, building a telegraph, composing original music, and understanding the way that protein folds through weaving and origami – happened because of curiosity and a willingness to allow knowledge boundaries between disciplines to be permeable. David Edwards would call this "idea translation" the movement of ideas across areas of expertise despite risk of failure (Edwards, 2008).

Personal Satisfaction and Fulfillment

Personal satisfaction is often expressed by scientists and artists involved in interdisciplinary activities. MCI research chemist Lynn Brostoff explains the lure for her of conservation science:

> *I've had times in my life where my training was pulling me away, either because I was doing my material science work or because I was in a job that was more suited to a traditional chemist in a laboratory. For me, the passion wasn't there. It was like having the bloodline cut; for me it's like an umbilical cord. And so, I always have to have that connection to art and to museums. It gives life to what I'm doing* (Video clip on Lunder Conservation Center website).

Edward Bronikowski, a curator at NZP, spoke about his experience as a sponsor to Rachel Berwick, a Smithsonian Artist Research Fellow (SARF) in 2008. He recounted his initial hesitation upon being asked to sponsor an artist and how his early concern was quickly overcome. He had a rich, "fun" experience and felt that the SARF program "really does open the mind for exploration and discovery." Bronikowski observed that the SARF program helped in "breaking down the barriers between our own inter-agency silos," and that "making those types of connections, I'm sure, is going to pay dividends in the years to come" (Smithsonian Forum on Material Culture, 2009).

One interviewee made an astute observation about the excitement, re-engagement and enriching experience that scientists have when they associate with artists and art projects:

> *For quite a lot of the scientists [engaging with art] is a way of expanding their own philosophical take on what science is. Science now is so driven by a sense of needing to be extremely focused on specific questions and specific publications and specific experiments. You have to be ruthlessly concerned with what you're studying in order to get your paper out there to make headway in a very competitive field. But a lot of them feel that they got into science for broader concerns about the nature of the world or the state of being conscious, or how genes transfer down families, or*

whatever else. Some of them feel that they are not able to pursue this broader interest within their science. Therefore, holding onto their science but dealing with it in a different domain, such as talking to artists about it or appearing live on stage in a public venue, allows them to reengage with some of the bigger questions about the very nature of science – all of those rather big and fascinating questions which I sense a lot of scientists still hold but aren't able to deal with in their day-to-day professional lives. If they get out into the public once a month or whatever, it just re-engages them with their broader fascination, what they forget on an hour-to-hour basis being pure scientists in the lab (Interview, external).

Wellcome Trust, a leading charitable organization funding biomedical research in the UK, originated and administrated SciArt, a grant-giving program that supported science and art collaborations. The program ran from 1996 to 2006 before it was transformed by Wellcome Trust into its current "Arts Awards" scheme. In an independent evaluation of the SciArt program, scientists interviewed reported that working with an artist enabled them to rediscover a creative dimension that to some extent had been "sacrificed" due to the professional conventions of being a scientist. Some scientists said their participation had had a "profound and positive effect" on either their career development or personal and professional sense of self. Artist interviewees said they were stimulated and challenged by their interaction with scientists and emerged feeling more confident about their professional capabilities. Relationships forged through the SciArt projects continued on after the funded project ended (Glinkowski and Bamford, 2009).

Social commentary and activism

Contemporary artists often challenge the boundaries between science, art, history and culture. Like the 19th century artists who grappled with Darwin's revelations, many of today's contemporary artists use their art to investigate the moral, ethical and social issues arising from scientific developments. One external interviewee described the phenomenon of contemporary art's fascination with science:

There were lots of artists out there who were already interested in science, particularly genetics and neuroscience, as wonderful and audacious topics that ask us to rethink the origins of life and what it is to be human, and all those other big questions that biomedical science has thrown into a tailspin over the last couple of decades (Interview, external).

The evaluation of the Wellcome Trust SciArt program found that, among many other things, artists acted as the public's representative or "independent scrutinizers." In this capacity the artist could ask probing questions on the public's behalf "that might not otherwise be possible, either from the perspective of the general public or from within the scientific community itself." Artists "open[ed] up scientific practices to a wider gaze" (Glinkowski and Bamford, 2009).

In those scenarios, the artists had special access to experts, spaces, information and experiences that were restricted, inaccessible or intimidating to the average person. The artist acted as a stand-in for the public, experiencing things and asking questions on behalf of the public about what the scientists were doing and how science and technology have repercussions for society. The artwork was a portal through which the public could indirectly access images and experiences from the science world as well.

The artist is also a provocateur, who in his or her questioning challenges the public to examine its own relationship with technology and science. In the introductory essay of the catalogue for the exhibition *Imagining Science: Art, Science, and Social Change*, co-editor Timothy Caulfield addresses the complex legal, ethical and social concerns surrounding advances in biotechnology such as stem cell research, cloning and genetic testing, and the vital role of artists as commentators:

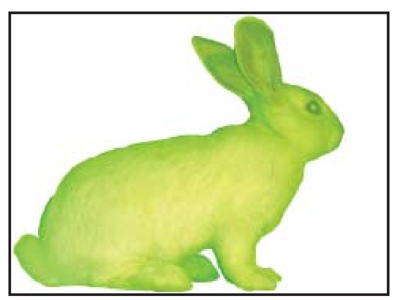
> *Some artists play the role of provocateur, presenting works inspired by the imagined (or unimaginable) possibilities of biotechnology and some of these works bring the public face-to-face with challenging and troublesome issues in a direct visceral way* (Caulfield and Caulfield, 2008).

A recent show at the Mori Art Museum in Tokyo, *Medicine and Art: Imagining a Future for Life and Love*, delves into questions about humanity and life raised by – and about – bio-artists featured in the exhibition. A reviewer draws out some of the intriguing questions:

> *Half a century after Crick and Watson's discovery, some of the most visually charged and important current work in the field is being done by bio-artists exploring the possibilities and ethics of genetic engineering. We now have the incredible power to create life forms, but how do we use it? Are bio-artists the watchdogs of scientists or are they wannabe Dr. Frankensteins without a lab coat?* (Birmingham, 2010)

Social commentary examples

The contemporary art movement referred to as BioArt uses living matter as the medium and explores the possibilities and ethics of biotechnology, including genetic engineering, tissue culturing and cloning. One of the pioneers of BioArt, Eduardo Kac, coined the new art form "transgenic art," for its use of genetic engineering to transfer natural or synthetic genes to an organism. According to the artist, "this must be done with great care, with acknowledgment of the complex



Eduardo Kac, *GFP Bunny*

issues thus raised and, above all, with a commitment to respect, nurture, and love the life thus created." For his most famous work, *GFP Bunny*, he commissioned a French laboratory to implant a rabbit – "Alba" – with green fluorescent protein from a type of jellyfish that caused the rabbit to glow green under a blue light. The installation, where Kac and Alba "lived" in a gallery, was intended to raise questions about how society constructs the idea of difference.

Artist Damien Hirst's website describes his work as using unconventional and unexpected media to recast fundamental questions concerning the meaning of life and the fragility of biological existence. His best-known Natural History series presents animals in vitrines suspended in formaldehyde, including the 1991 iconic work *The Physical Impossibility of Death in the Mind of Someone Living*.

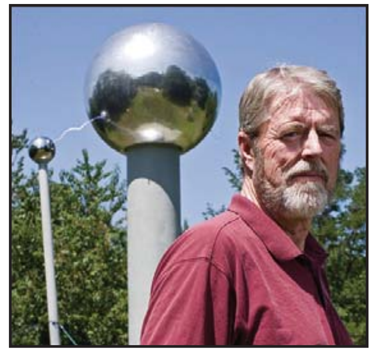
Damien Hirst, *The Physical Impossibility of Death in the Mind of Someone Living*

Alexis Rockman, *The Farm*, 2000, Courtesy of JGS, Inc.

Alexis Rockman's visual vocabulary nods to scientific illustration, museum dioramas, 19th century landscape painting and science fiction films. As well, his images of distorted flora and fauna in strange and sometimes scandalous environments rely on firsthand field studies. SAAM, which has organized a mid-career survey exhibition of Rockman's work to open November 2010, states that the artist's work has attracted attention from both the science and art worlds because of its "ability to straddle the boundary between empirical fact and plausible fiction" (SAAM website). In many of his works, the artist seems to acknowledge the exploitative power relations that often typify society's attitudes toward other life forms and play into society's fear of genetic pollution and unbridled science. For example, *The Farm*, with its bloated vegetables and farm animals, comments on the role culture plays in manipulating the direction of natural history, specifically the biotech industry's hand in the manufacture of food. Rockman explains, "The flora and fauna of the farm are easily recognizable; they are, at the same time, in danger of losing their ancestral identities" (Alexis Rockman website).

Washington, D.C. artist Jim Sanborn's works have always blurred the line between history, art and science. For over two decades he has created installations that explore the Manhattan Project and the U.S. nuclear weapons program. As the introduction to his installation at the Corcoran Gallery (2003-4) described, "*Critical Assembly* stimulates a dialogue about the allure of pure science and the ethical dilemmas researchers have faced for decades." His latest work, *Terrestrial Physics*, was described by art critic Blake Gopnik as “a real, honest-to-God, no-holds-barred, fully operational electrostatic particle accelerator.” Gopnik quotes MoMA Art curator Barbara London in the article, who captures the powerful impact art can have when addressing science:

> *We talk about nuclear this and nuclear that – the arms race – but Jim is taking us into the lab … to the "eurekas" that someone like Einstein achieved. To that moment, and the beauty of that moment* (Gopnik, 2009).



Jim Sanborn

Eco-arts: activist artists collaborating with scientists to solve world dilemmas

A growing number of artists, using empirical data and science research, explore critical environmental and social problems in their artworks – especially ones where human activities play a contributing role, such as climate change, world hunger and biodiversity loss – with the express purpose of generating discussion, raising public awareness and encouraging social change.

In his installation remarks, Secretary Clough explored why it is essential to communicate scientific information generated by the Smithsonian community in a clear and broad manner:

> *Through the long-standing efforts of our scientists, the Smithsonian has been among the leaders in understanding climate change and biodiversity issues. Now we need to take two more steps. The first recognizes that these problems are not simple, and that communicating the complex science behind the dynamic processes is difficult, but necessary. Now is the time for the Smithsonian to extend its reach by communicating the research in such a way so that our political leaders and the public can understand it, so that global action can be mobilized to help our planet become more sustainable. This will position the Smithsonian to increase the impact of the remarkable efforts of our scientists* (Clough, 2009b).

Clearly, it is not enough for Smithsonian staff to amass scientific data and generate knowledge for a closed scientific community. The Smithsonian has a responsibility to share information and communicate its importance to a wide, general audience that includes policy makers. A lot is at stake, to paraphrase Secretary Clough: our planet is in need of help. Strengthening people's sensitivity to – and their understanding of the science behind – such concerns as environmental degradation and biodiversity loss can influence how society chooses to confront these issues. E.O. Wilson put it simply and succinctly: "I realized that it's only when you can engage a larger part of the population that we'll ever get any action on global conservation" (Roberts, 2006). In his lecture, *Humanizing the Science of Climate Change: The Role of the Arts in Driving Sustainable Lifestyles*, Dr. Ben Todd, Director of the UK's Arcola Theater, outlined the critical role of cultural institutions in bringing about such large-scale involvement:

> *While scientists tell us that we already have the technologies required to avert catastrophic climate change, policy makers and businesses continue to seek new technological "solutions." I believe that to change the lifestyles of entire populations, a cultural shift is required, and thus it is cultural agents which must take the lead* (Todd, 2010).

The role of artists in engaging with such global problems is to inspire, to communicate, to bear witness and to engage politically. It can be transformative; some feel that the arts and the sciences need to use [climate change] "as the enobling issue of our generation" (Carter, 2008).

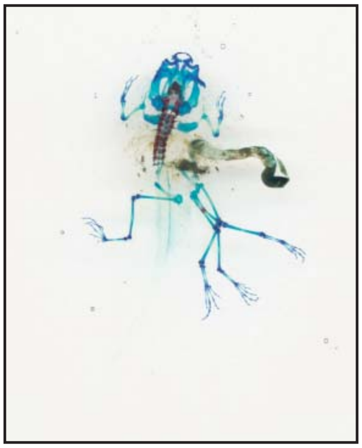
Qualities of the arts that make them uniquely well-positioned to effect social change include creative vision and a collaborative, action-oriented approach. Indeed, the popularity of this theme in the literature and emerging practice suggests that focused real-world problem solving across the traditional boundaries of art and science, and with concerted efforts across professional backgrounds such as artists, engineers, climatologists, biologists and politicians, is the only way through such intractable human and planetary conditions as climate change, environmental degradation, world hunger and disease, civil war and terrorism (Burke, 2008).

Eco-Art: Examples

Cape Farewell was founded by UK artist David Buckland under the conviction that climate change is a cultural, social and economic problem caused by all of us and must move beyond scientific debate. He believes "one salient image, sculpture or event can speak louder than volumes of scientific data and engage the public's imagination in an immediate way" (Cape Farewell website). Since 2003, the program has invited artists, scientists, writers, teachers and film crews on seven expeditions to the High Arctic. Scientific organizations such as the University College London's National Oceanography Centre, British Geological Survey and Scottish Association of Marine Science are partners on the expeditions and the artwork and ideas that develop are grounded in scientific research. British novelist Ian McEwan's book Solar was inspired by his arctic expedition with Cape Farewell in 2005.

A multitude of artwork, educational projects and collaborations has resulted from Cape Farewell expeditions, including a major traveling exhibition, *Art and Climate Change*, co-curated with the Natural History Museum, London. *Art and Climate Change* has been shown at venues such as the Cranbrook Art Museum in Michigan, where it was seen as part of *Artology: The Fusion of Art and Science,* a year-long series of programs co-organized by the

Cranbrook Art Museum and the Cranbrook Institute of Science. The exhibition is now on a world tour with Barbican Touring Arts, London.



Brandon Ballengée, *DFA 25, Promethéus*, Scanner print of cleared and stained multi-limbed Pacific Treefrog

New York artist Brandon Ballengée's work spans art and biology. Notably, the artist is interested in raising awareness of amphibian decline and abnormalities and how these changes are an early warning sign of environmental change. Over a two-year period before his March 2010 exhibition, *The Case of the Deviant Toad* at The Royal Institution of Great Britain, Ballengée collaborated with scientists to study the population of toads with a high incidence of deformity at Yorkshire Sculpture Park. He collected and observed thousands of specimens, established an open laboratory and conducted experiments to determine what the cause might be. For the art exhibition he used a process of clearing and staining specimens of deformed toads, which in gallery context "resemble translucent gems – enchanting, terrible, and other-worldly" (The Arts Catalyst, 2010).

"We can save two birds with one tree." Such is the slogan of world-renowned artist and architect Maya Lin, designer of the Vietnam Veterans Memorial in Washington, D.C., for what she says is her last memorial project. *What is Missing?* is a collective growing memorial that will bear witness to what we are losing in terms of biodiversity, species and habitats. The project aims to "create, through science-based artworks, an awareness about the present sixth mass extinction of species, connect this loss of species to habitat degradation and loss, and emphasize that by preventing deforestation, we can both reduce carbon emissions and protect species and habitats." It will exist in multiple forms and at multiple sites, including permanent Listening Cones at select science institutions (the first in 2009 at the California Academy of Sciences), a traveling Empty Room exhibit, and other multi-media works.

For Lin, art can distill and communicate essential information about extinction in a manner that evokes in the viewer an emotional and contemplative response rooted in his or her personal experiences, effectively drawing the viewer in as opposed to potentially boring the viewer with tedious facts. She explained in an interview on CNN why the project is a real collaboration between art and science, and why art is so powerful at communicating science.

> *I think art gives you an opportunity to maybe re-think it in a way that is simpler at times. One could say that art can reduce things to almost a bare essence at times. And if I can use surprise and wonder as a way, it might not come at you with fact; it might approach it more viscerally. It might say that the sounds of these songbirds that as a*

child I used to listen to are in a 70 percent to 40 percent decline and wake you up to it (Amanpour, 2009).

© Jason deCaires Taylor

Mexico's Subaquatic Sculpture Museum will eventually have 400 sculptures underwater off the coast of the Yucatan Peninsula that will hopefully attract snorkelers away from the damaged coral reefs in the West Coast National Park and, in time, encourage coral reefs and marine life to grow on the PH neutral concrete figures. Underwater artist Jason deCaires Taylor, who designed a first underwater sculpture park in Grenada, West Indies and oversees the project, orchestrates the convergence of science and art in the works, which are based on contemporary and Mayan narratives and use live propagated coral within the structures (Gordon, 2009).

Another example of an artwork equally concerned with the degradation of the world's coral reefs is the Hyperbolic Crochet Coral Reef, an "environmental version of the AIDS quilt" that intends to raise awareness of how rising temperatures and pollution are destroying the Great Barrier Reef. Margaret and Christine Wertheim, sisters who instigated the idea, were familiar with the hyperbolic geometric structures of the corals, anemones, kelps, sponges, sea slugs and other creatures that live in the reef. The sisters were inspired by the work of Dr. Daina Taimina, a mathematics researcher and skilled crocheter, who discovered in the 1990s – by combining her craft and science – that she could create three-dimensional models of hyperbolic geometry by continually adding stitches in a repeating pattern. The Coral Reef project, which intersects science, mathematics, art, handicrafts and social activism, has attracted participants from across those spectrums (Cohen, 2008).

Image from the Hyperbolic Crochet Coral Reef project

The Hyperbolic Crochet Coral Reef will open at the Smithsonian in the Sant Ocean Hall, NMNH, October 2010 – April 2011. In a lead-up to the exhibition at NMNH, Margaret Wertheim delivered a lecture about the project and led a crocheting workshop for the public, which proved very popular with over 400 participants. Future workshops are being planned in a larger room within NMNH as there is a clear public appetite. Components of the "coral" created by local participants will be incorporated into the exhibition. Wertheim mentioned that through overwhelming international participation, most often women working unprompted and unaffiliated with funding sources or institutions, this project may be the "biggest art and science project in the world." Wertheim mused that hyperbolic geometry was once mysterious to mathematicians and now it is being applied to spatially understand the universe. There is a tenacious connection between "sea slugs, feminine handicraft and the structure of the universe … the boundaries of disciplines, of human practice, are superficial" (Wertheim, 2010). The Hyperbolic Crochet Coral Reef project exemplifies the third and highest level of interdisciplinarity – synthesis – where disciplines collude to ask questions that neither could ask alone.

Impact by Degrees: Australian perspectives on Art and Climate Change brought together eight Australian and Australian-American media artists whose works address the question "what is to be done?" about the causes and impacts of climate change. The artworks document a crisis in Australia, the driest inhabited continent, where the combination of global warming and drought has meant spiraling fire conditions, disappearing habitats and species such as the Tasmanian Tiger, and once mighty rivers drained and poisoned by agricultural fertilizers. And yet, curator Antoanetta Ivanova observes,

> *… living in the age of climate change, we ought to have great faith in the capacity and ingenuity of the creative mind, in the new possibilities that arise from shared knowledge and collaborations across disciplines and borders, and in our resolve to work together to meet the challenge* (Ivanova, 2009).

Natalie Jeremijenko, one of the *Impact by Degrees* artists, maintains that if we can understand and relate to climate change on a personal level, we are more likely to take ownership of the solutions at the local level. The designer, whose background includes studies in biochemistry, physics, neuroscience and precision engineering, is director of the Environmental Health Clinic at New York University, which offers individuals and communities low-cost, immediate and practical eco-solutions that combine art, design, science and engineering. For example, the NoPARK project returns no parking zones associated with fire hydrants to grass and moss micro-engineered green spaces that continue to provide emergency parking space, but the other 99.9% of the time prevent storm water runoff (xClinic website, 2008).

Resonating Bodies – Bumble Domicile is a series of art installations that focus on bee biodiversity, especially bees indigenous to the Greater Toronto Area, Canada. A team of artists led by Sarah Peebles worked collaboratively with Canadian and American biologists to observe and research bee biology, pathogen transmission and pollination ecology, and this research informed the creation of multi-media art installations (Resonating Bodies Website).

The Smithsonian Center for Education and Museum Studies (SCEMS) addressed climate change with its Smithsonian Online Education Conference: Climate Change, in which

Smithsonian scientists and curators discussed the environment from the perspectives of science, history and art. Charles Duncan, a collections specialist at the Smithsonian's Archives of American Art (AAA), illuminated the link between how artists' portray and society understands the natural world, and its implications for the climate change debate. Duncan spotlighted American video artist Paul Ryan (b. 1943) who was a video art pioneer and champion of the environment. Ryan, who is known for his videotapes of the natural environment in New York City and "Earth Scores," which overlap natural scenes such as water with music, proposed an "eco-channel" for public access television that would play footage of the natural world at all times. Interestingly, this proposal received public endorsement from politician and fellow environmental activist Al Gore. This artist's archive, including a letter from Al Gore, is housed in AAA.

Communication of science to wide audiences

Within the wider science community there is growing awareness of the need for engagement and dialogue with all facets of the public. For Kevin Finneran, Editor-in-Chief of *Issues in Science and Technology*, the problem is complex, and the solution includes contributions from non-science disciplines: "There is no doubt that the science community is far more engaged in reaching the public and policymakers than it was 50 years ago." However, he writes in his blog, there must be a collaborative element to it:

> *The danger for scientists is to believe that communication means teaching the public more about science. It must also include listening to the insights of other intellectual disciplines in the humanities and social sciences, respecting journalists' efforts to translate science for a broad audience, appreciating the insights of artists, and engaging in real conversations. Science has much to contribute, but it is not the only way to view the world, and it does not have all the answers to the world's questions and needs* (Finneran, 2009).

Collaboration between disciplines for the purpose of communicating science requires a willingness to learn from one another, that is, to accept that biases and limitations exist within one's discipline and that individuals from other disciplines have fresh questions to ask and new perspectives and insights to offer. Mutual respect and trust between art and science professionals are needed to effectively collaborate, and this is true in the case of engaging with the public through both science and non-science languages and tools. For the scientific community, gaining social trust and buy-in is "not an optional extra," as one external interviewee put it: "It has to be seen as part of what science is about. [Science] can't be done in a vacuum." This interviewee had an interesting recommendation for generating social trust and support for science, without which he believed "our society is in quite a bit of trouble":

> *In many big cities there is a 1% scheme: when you put [up] the new building of a certain scale, you have to devote 1% of your project to the public good. It almost feels as though science is beginning to work in the same direction. I don't know what the percentage would be* (Interview, external).

This urge to communicate with the public may be connected to what artist Suzanne Anker describes as the scientists' image problem: they are seen as "seeped in hubris, the image of the 'mad' scientist is still pervasive within popular culture and mass media" (Anker, 2007). Indeed, debates are waged on the ethics of animal and organ cloning, genetically modified food and the resulting "genetic pollution" of our food sources, and how satellite and internet technology jeopardizes the privacy of individuals. Science fiction literature and movie plots engage in these debates with films like David Cronenberg's *The Fly* and post-apocalyptic blockbusters like James Cameron's *The Terminator*.

Recognizing that television and film can involve the public in the latest advances in science, medicine and technology, and to facilitate filmmakers' access to scientific truth, the National Academy of Sciences in 2008 created The Science and Entertainment Exchange. The initiative seeks to connect top scientists and engineers with the creative minds of Hollywood and the entertainment industry and "bring the reality of cutting-edge science to creative and engaging storylines." An example is Dr. James Kakalios, a physicist at the University of Minnesota who consulted on the movie *Watchmen*, detailed in his Emmy award-winning video *Science of Watchmen* (NAS, 2008 and Science and Entertainment Exchange website).

Given that the public often approaches science and technology with a dose of suspicion and puzzlement, art can make science more human. In the report *BRIDGES I: Interdisciplinary Collaboration as Practice* the authors observe that, "Both technical and creative expertise, as well as humanism, have come to be recognized as essential to the successful integration of technology into culture" (Pearce, et al., 2003). Art helps people cope with rapid change, particularly advancements in science, and its "psychic and social consequences" by humanizing science, that is to say, making it comprehensible and less foreign (Shlain, 1991). Marshall McLuhan, a pioneer in media theory, suggests that art is a guide on how to transform oneself to handle change, technology and their ramifications:

> *If men were able to be convinced that art is precise advance knowledge of how to cope with the psychic and social consequences of the next technology, would they all become artists? Or would they begin a careful translation of new art forms into social navigation charts? I am curious to know what would happen if art were suddenly seen for what it is, namely, exact information of how to rearrange one's psyche in order to anticipate the next blow from our own extended faculties* (As quoted in Shlain, 1991).

In her study of NASA's Artists' Cooperation Program from the 1960s, Goodyear found that art was perceived to be a counter-balance to science; art helped, at least in people's minds, "to ensure that scientific advancement did not result in human devastation":

> *… Despite an increased emphasis placed on scientific education, the general public continued to believe that exclusive pursuit of scientific research lacked a "human" dimension… In a society bent upon supporting scientific study, art was seen as an antidote to the potentially inhumane tendencies of science* (Goodyear, 2002).

Randy Olson, a marine biology professor turned filmmaker, argues is his book *Don't Be Such a Scientist* that the film industry can teach scientists a thing or two about how to speak to the public, especially on issues of pressing social importance such as climate change. For him, there is a tremendous distinction between academic science communication and communicating science to a popular audience. The former has a very narrow audience that will make the effort required to understand the material and stay engaged, while the latter must involve compelling, non-esoteric storytelling, because popular audiences are not "ready to hang on every single word you have to say" (Olson, 2009). According to Olson, scientists who want to disseminate scientific information to mainstream audiences must be creative and learn to tell stories that audiences find relatable, intriguing and entertaining. Olson has achieved this balance in his two feature films, *Flock of the Dodos: the Evolution-Intelligent Design Circus* and *Sizzle: A Global Warming Comedy*, which break from the usual science documentary mold to present scientific debate in a humorous and story filled manner that is accessible to wide audiences.

For others, the communication gap is not so acute. John Brockman, a literary agent, author and founder of the Edge Foundation,[8] entices wide audiences to science through popular literature, his own and the works of others, such as scientist Richard Dawkins. About the C.P. Snow "Two Cultures" divide and his conception of a "Third Culture," i.e., synergy between science and the literary arts, Brockman states:

> *Literary intellectuals are not communicating with scientists… Scientists are communicating directly with the general public. Traditional intellectual media played a vertical game; journalists wrote up and professors wrote down. Today, Third Culture thinkers tend to avoid the middleman and endeavor to express their deepest thoughts in a manner accessible to the intelligent reading public* (As quoted in Adams, 2007).

Despite the efforts of some scientists to communicate with wide audiences (and many do so with immense success), presenters at the New York Academy of Sciences symposium *A Dangerous Divide* believed that scientists on the whole lack the ability to explain to the

8 Edge is a forum for leading intellectuals from the science world and other disciplines to debate and discuss intellectual, philosophical, artistic and literary issues.

public what they do and why it is important, and that it is imperative that they be able to do so.

> *Today more scientists than ever are sitting in front of cameras and writing for the public, but many still have trouble communicating their research effectively to laymen. "You shouldn't be able to get a PhD without knowing how to write a news column," Flatow [a panelist] argued. "You have to be able to explain what you do." The need is very great for scientists and journalists to reach out across the gap by making science more accessible and more human* (Williams, 2009).

The 2009 external evaluation of the Wellcome Trust SciArt grant program found a widespread view among interviewees that "artists' communicative abilities had helped to demystify and make more intelligible aspects of contemporary science." The evaluation also found that the education components of the SciArt funded projects had improved public perceptions of both artists and scientists as communicators and educators – "In this sense the 'two cultures' were shown to have the potential to coexist in a fruitful symbiotic relationship." A benefit of such artistic collaborations to scientists pointed out in the Wellcome Trust evaluation was that it gave scientists a chance to test out their ideas in the public realm. Scientists had access to audiences from which they could gauge human reactions and observe other qualities of the world outside the lab (Glinkowski and Bamford, 2009). A variation of this finding was shared by the authors of *BRIDGES I: Interdisciplinary Collaboration as Practice*, who noted that "Putting on a show allows researchers to test new ideas in a simulation of the real world" (Pearce, et al., 2003).

Expressing Science through Art: Examples

One of the chief benefits of incorporating artists' perspectives in science is for educational purposes. Whether institutionalized as with artist-in-residence programs or on an ad hoc basis, the OP&A study team encountered many examples of the arts being used as a communication tool to stimulate curiosity and excitement about science and advance science literacy,[9] or just to get viewers jazzed about science. And as much as scientists get from the exchange in terms of meeting critical education goals, artists in turn benefit from the opportunity to expand their conceptual horizons and techniques.

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9 "Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately." National Science Education Standards. Copyright 1996 by the National Academy of Sciences. Courtesy of the National Academy Press, Washington, D.C.

Here we examine two activities that are related in that they both communicate science, but are distinguishable in their primary objectives: 1. Visualizations, which use artistic language, principals and tool for the main purpose of communicating science;[10] and 2. Interpretations – artwork that expresses scientific concepts and data for artistic purposes, and as a corollary result, communicates science to audiences in innovative, thought-provoking and interdisciplinary ways.

Visualizations

> *… the modeling of scientific information is an interdisciplinary activity which combines a knowledge of the modeled phenomena, the computer science methodology for creating the simulations, and the craft of visualizing the models for validation purposes. In its highest form, this craft becomes an art, fulfilling the role phrased by Pablo Picasso: Art is the lie that helps us see the truth* (Prusinkiewicz, 1998).

Artistic training, sensibilities and materials can be utilized to show what cannot be observed with the naked eye or with microscopes alone. Luke Jerram, an artist fascinated by science, spoke about the intuitive leaps that scientists must make when there are limits to what they can see:

> *When I ask virologists how exactly RNA is packed into a virus, well, the answer is that they just don't know. Most viruses are right at the edges of microscopy capabilities ... So scientists have to take a leap – from what they can see to what they know about chemical interactions* (As quoted in Boustead, 2009).

It is common for scientists analyzing complex data to collaborate with artists to determine how to display important parts of the data without sacrificing equally important nuance. This was the experience of Milton Halem from the NASA Jet Propulsion Laboratory (JPL), who analyzed data from the Landsat satellite program. He collaborated with artist Sarah Tweedy of the Corcoran School of Art to translate the data into meaningful visualizations (Root-Bernstein, 1997).

Representing scientific information is a human endeavor and therefore involves aesthetic choices. Whether it is representing viruses seen through a microscope or the death of a star captured by a telescope in space, aesthetic decisions are made about color, tone, scale and much more. For example, a Smithsonian scholar mentioned that the colors red, white and blue are often used in the coloring of deep space images for patriotic effect.

David Aguilar, a space artist and Director of Public Affairs and Science Information at the Harvard-Smithsonian Center for Astrophysics, combines his astronomy training and astute

10 Scientific illustration is omitted from this section, as it is treated within the rubric of "inherently interdisciplinary" discussed earlier in the report.

artistic ingenuity to turn raw science data transmitted through specialized equipment such as radio and gamma-ray telescopes, into didactic and awe-inspiring renderings of outer space. Aguilar has worked with National Geographic to create popular illustrated books that communicate the wonders of space to young audiences and he is often enlisted by scientists to illustrate new discoveries and theories, which he remarked puts him in a unique position: "I am giving you that first look at your future" (Lambert, 2004).

David Aguilar's hypothetical rendering shows how a distant world inhabited by intelligent aliens might look

The Imaging Research Center (IRC), University of Maryland-Baltimore County (UMBC), specializes in visual imaging – what an interviewee described as taking complex material and finding the "engagement point" – primarily through the use of digital and computer technology. Visual imaging is not purely visual: IRC's state-of-the-art facilities enable research in immersive technologies, interactivity, installation, animation, high definition video and sound. Projects include a mix of interdisciplinary collaborators, among them artists, researchers, industry partners and students, and are rooted in art and design that incorporates describing science and technology ideas in ways that resonate with the public. IRC has produced visualizations of satellite missions for NASA/Goddard, a feature film titled *Euphoria* that examines the pursuit of happiness and neuroscience, and three-dimensional imaging of the casting processes used by the artist Matisse, which allowed museum visitors and scholars to better understand Matisse's artwork. In collaboration with architectural historians, cartographers, engineers and ecologists, IRC researchers visualized early Washington, D.C. ca. 1814 using computer technology (Interview, external, and IRC website).

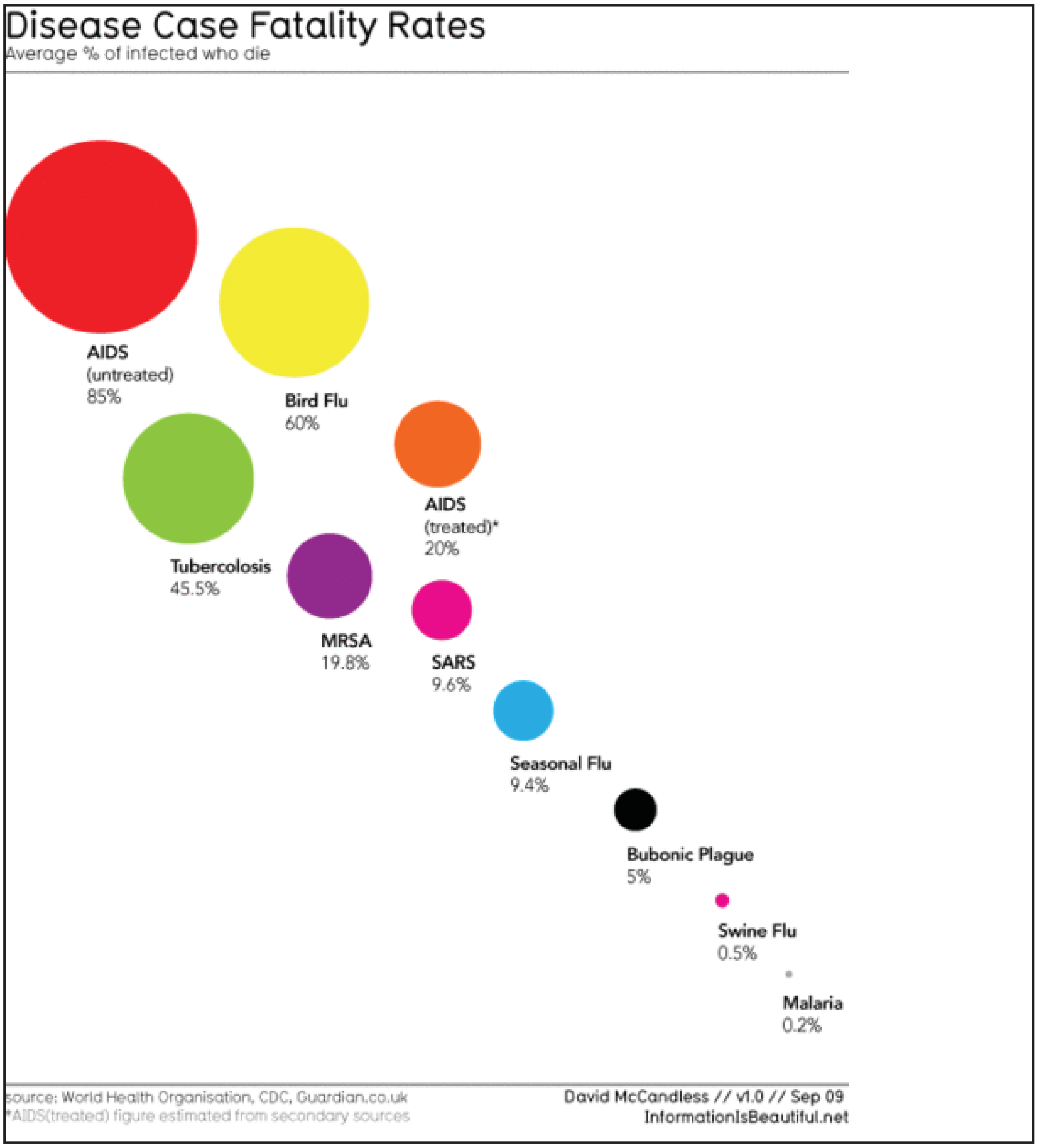
Art can find simpler, more direct ways of communicating complex ideas, which John Seely Brown refers to as the power of simplicity:

> *Simplicity prior to complexity doesn't mean much. But simplicity, after you pass through the wall of complexity, after you have marinated in a fully nuanced reading of the situation and then rendering it in very simple ways is extraordinarily powerful* (As quoted in Naiman, 2003).

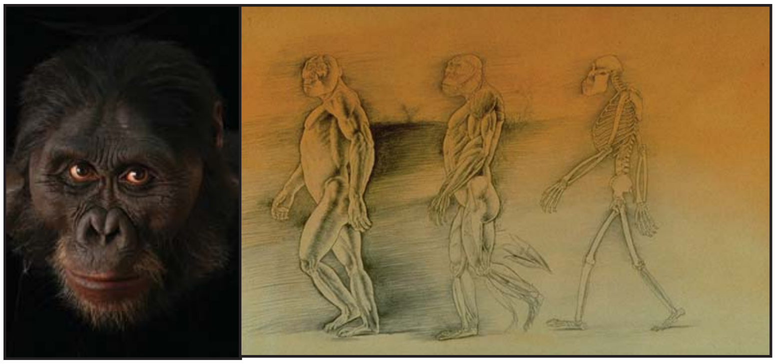
This principle is echoed by Yale emeritus professor of political science and guru of information design, Edward Tufte, who espouses showing as much data as possible with as little ornamentation as possible – where every data point has value and trends and patterns can emerge when seen overall. Famously allergic to PowerPoint, which he deems overly simplistic, Tufte's design ideas are captured in such texts as: *The Visual Display of Quantitative Information*, *Envisioning Information*, *Visual Explanations*, and *Beautiful Evidence* (Edward Tufte and Wikipedia websites).

David McCandless likewise creatively visualizes statistics and random facts in visually appealing graphs, charts and illustrations in his book *The Visual Miscellaneum: A Colorful Guide to the World's Most Consequential Trivia*. A reviewer of McCandless' book commented on the efficiency with which information is communicated:

> *[T]he visuals will draw you in, and the sharpness of the questions some of them attempt to answer – and the efficiency with which they can communicate complex comparisons in a single page – will keep you hooked* (Nissley, 2009).



John Gurche is an award-winning artist who specializes in visualizing prehistoric life. His attention to scientific accuracy and exceptional artistic skills place him at the art and science nexus. His work has appeared on the covers of *National Geographic*, in the



Reconstruction and renderings of *Australopithecus afarensis*, gurche.com

film *Jurassic Park*, and at the Smithsonian; currently his reconstructions of human ancestors are on display in *Human Origins*, an exhibition at NMNH. Visitors to *Human Origins* can use a "morphing station" to see what they would look like as early humans – features are based on fossils and scientific evidence that is visualized by Gurche. The popularity of the stations spawned the MEanderthal App (a combination of "me" and "Neanderthal") for the iPhone or Android. A user uploads his or her picture, and it is merged with the features of early ancestors. Briana Pobiner, an education specialist at the Smithsonian Human Origins Program, explained why this is significant:

Photo of a visitor to the *Human Origins* exhibition who was "transformed" into a Homo floresiensis, a human ancestor that has been extinct for 17,000 years

> *We think it's really important for people to make emotional connections to our ancestors … It's an important way to break down that barrier between things we think are so different or so "other."* (As quoted in Bryner, 2010).

But not everyone the study team interviewed felt that science visualizations are always an equal marriage of art and science; instead, there are degrees of collaboration and interdisciplinarity:

> *… the scientists are really just interested in, "I have this work, I need to understand how to illustrate it." That's well and good, but a very shallow, surface discussion when you're talking about interdisciplinary… there's a lot more that can be exchanged on many different levels. … I've attended a lot of these conferences, and I think that where they seem to fall apart for me is when, like one organized by MIT – Imaging Science – it positioned [interdisciplinary collaboration] like, okay now we need the artists because our understanding is beyond what we can technically photograph or represent, so now we need the artists as basically science's handmaiden* (Interview, external).

Interpretations

Here we list examples of artworks that cut across art and science, involve interdisciplinary collaboration, are inspired by scientific knowledge, and creatively interpret science in ways that resonate with diverse audiences, all the while exploring innovative artistic techniques and concepts.

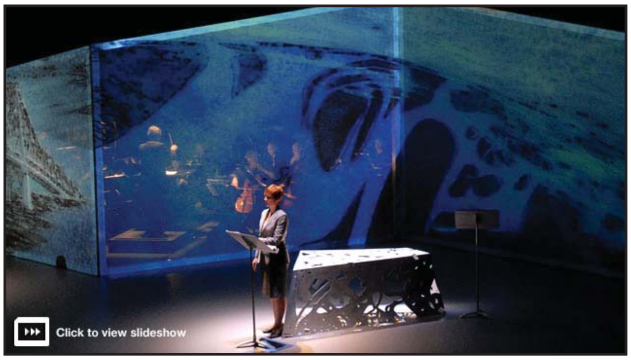


Image from *Hypermusic Prologue: A Projective Opera in Seven Planes*

In *Hypermusic Prologue: A Projective Opera in Seven Planes*,[11] Harvard physicist Lisa Randall re-imagined her complex extra-dimensional theory of the universe as opera. Spanish composer Hèctor Parra, the son of a physicist and whose prior works have been influenced by particle physics, approached Randall about writing the libretto after reading her book, *Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions*. Parra's score "uses an array of intricately thought-out sounds and instrumentations to communicate warped space-time, as well as to signal changes in energy, mass, time, and gravity." Artist Matthew Ritchie, known to reference inflationary universe theory in his sculptures, designed the sets of video projections. Industrial imagery projected behind the baritone was used to represent the lower four-dimensional universe and projections of wildly colored celestial shapes around the soprano to suggest the expanded reality of a fifth dimension. *Hypermusic Prologue* illustrates well the mutual benefits that can come from such interdisciplinary projects – "it doesn't simply make art out of hard-to-grasp scientific theory, it inverts and renovates the genre of opera with an experimental score, a two-person cast, and minimalist and abstract stage design." The opera has been praised for its ability to be enjoyed by both a specialized and general audience:

> *... it manages to translate the impenetrable world of theoretical physics into something that not only appeals to scientists, but to anyone willing to look beyond the obvious for clues about the nature of reality* (Cline, 2009).

Another aspect of the Hyperbolic Crochet Coral Reef Project, mentioned earlier, is how the crocheted geometrical forms literally allow you to "hold the theorems in [your] hands" – it has tremendous tactile, educational and communicative value (Cohen, 2008). The artwork can stir in the viewers and those involved in the crocheting a tangible, physical and visual connection to mathematical thinking, artistic sensibilities and environmental concerns.

11 The project was done with the support of the Institute for Research and Coordination Acoustic/Music, a public research center dedicated to musical experimentation and scientific research affiliated with the Centre Pompidou in Paris.

Multimedia artist Deborah Wing-Spoul creates sculptures and performance artworks as part of her ongoing series titled *Tidal Culture*. One component of this project is her one-hour seated performances where she is alone and silent in front of the ocean, which she videotapes for later viewing. Another component is her sculptures – utensils, cups and bowls – that are made from ocean materials such as algae and seaweed and evoke contemplation about the preciousness and fragility of life, both on land and in the sea. About the role ocean ecology plays in her art practice she writes:

> *I'm interested in using the ocean and algae as metaphor and investigatory tool for asking questions pertaining to identity, influence and isolation. Seaweed, which does not honor human-established boundaries, is my primary medium both for making what the nomadic existence requires (food, clothing, utensils) and also as a means of referencing the ways in which cultures influence one another* (the artist's website).

Rebecca Kamen, *Divining Nature: An Elemental Garden*, installation shot

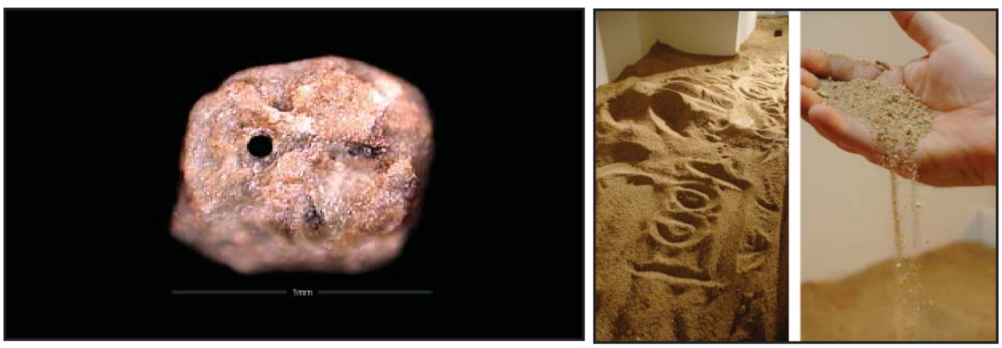
Washington, D.C. sculptor Rebecca Kamen's recent installation, *Divining Nature: An Elemental Garden*, used the periodic table as a vehicle and metaphor to get people excited about what it represents. Flat orbital patterns are transformed into three-dimensional flowers, providing people with a unique way of seeing and knowing the chemical elements. Collaborating architect Alick Dearie integrated the Fibonacci spiral, long associated with nature's most beautiful proportions, in the garden plan. Accompanying the installation is a soundscape by composer Susan Alexander that is similarly science-based – "derived by mapping the frequencies of a magnetic-field-induced oscillation of atomic nuclei (Larmor frequencies) to audible frequencies played through a synthesizer." By turning something rigid such as the traditional periodic table into something of beauty to experience by walking through it, Kamen hopes people will come away feeling a little more in awe of the world around them (Amato, 2009).

External interviewees referenced writing and performance art that draw from neuroscience, termed "neuroaesthetics." For example, *Replica*, a dance performance choreographed by Jonah Bokaer in collaboration with Daniel Arsham and Judith Sanchez Ruiz, examines memory loss, pattern recognition and perceptual faculties as they apply to the human body. *Replica* was co-sponsored by

Image from *Replica* brochure, CPNAS

the Cultural Programs of the National Academy of Sciences and the Shakespeare Theatre Company.

Closer to home, Smithsonian Under Secretary Richard Kurin recently brought together three Smithsonian scientists/scholars – astrophysicist Margaret Geller from the Smithsonian Astrophysical Observatory (SAO), science historian David DeVorkin from NASM and ethnomusicologist Atesh Sonneborn from the Center for Folklife and Cultural Heritage (CFCH) – for a conversation with Mickey Hart, the drummer of the iconic rock band The Grateful Dead, who was interested in how he might perceive and record the "music of the universe." As Clough mused, "can lightwaves reaching Earth after traveling hundreds of millions of light-years speak to our creative, as well as our scientific, selves?" A collaboration may be in the offing with the help of a computer savvy musician who can help Hart convert strings of numbers representing star formation, gamma ray bursts, black hole binaries and other astrophysical phenomena into music (Clough, 2009b).


(Dan Goods, http://directedplay.com/bigplayground.html)

Many artists are concerned with what is unseen and finding ways to "see" it. Dan Goods, visual strategist at NASA's JPL, noted in his artist talk that he is intrigued by the concept of "seeing what is unseen." He has created visual metaphors to communicate facts that are "mind-blowing" in their magnitude. For example, Goods drilled a tiny hole, representing our galaxy the Milky Way, into a grain of sand and placed the grain in a very large sandbox, representing the rest of the known universe.


Dan Goods, setup of *Hidden Light*

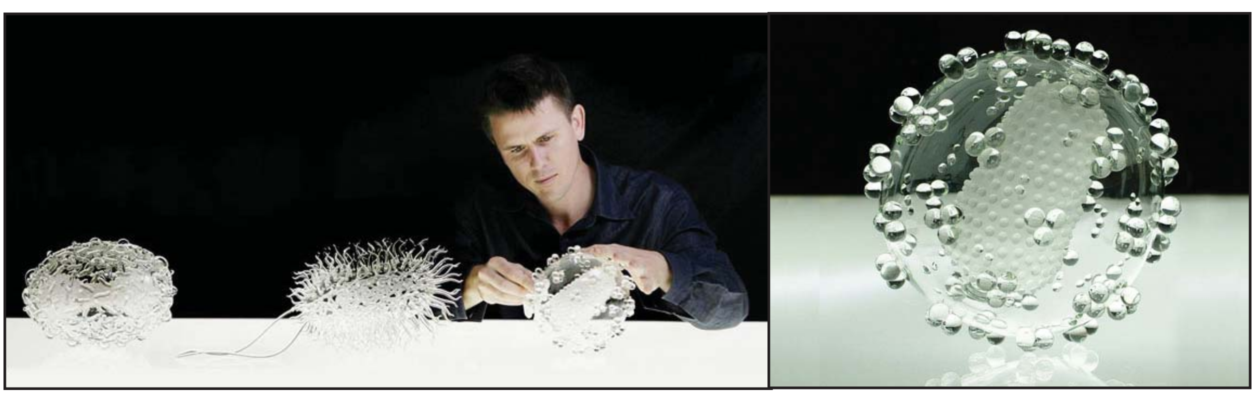
In another artwork, to communicate the technological limitations of discovering earth-like planets around other stars, where the stars are billions of times bigger and brighter than the planets believed to be there, Goods projected a movie onto a large wall surface, while at the same time projecting a brighter "sunlike" light that washes out the movie. As more people enter the space, they block the brighter light, and the movie is revealed inside their shadows.

Artist Luke Jerram borrows from science research in biology, acoustic science, sleep research, ecology and neural pathways in constructing his sculptures, installations, soundscapes and live art projects to explore the process by which we construct inner worlds from objective reality. A common theme is animation of otherwise hidden phenomena. For Glass Microbiology, Jerram worked with a virologist, using high-resolution electron microscopic images as inspiration for his large and accurately rendered glass sculptures of notorious bacteria and viruses such as HIV, SARS, E.coli and H1N1 (Boustead, 2009). Jerram's glass artworks are reminiscent of Leopold Blaschka and his son Randolph Blaschka's famous glass plant sculptures that were commissioned and used as botany teaching aids by Harvard University in the late 19th and early 20th century. The exquisite glass representations are remarkably accurate, attracting the attention of visitors to the Harvard Museum of Natural History where the collection of over 3,000 glass objects is housed, as well as being studied by scientists, students and art enthusiasts.

Detail of a glass sculpture by the Blaschkas

David Ng, of the Advanced Molecular Biology Laboratory, blogged about his reaction to Luke Jerram's virus sculptures. Believing that viewing art is a very subjective experience, he highlighted how the sculptures presented him with a new way of looking at viruses and how art has a special ability to transmit information in ways that are attractive:

> *Not only is it intriguing to view these structures, but there is a new appreciation for the subject. They appear intricate, venerated, and yes, even pretty. Best of all, these sculptures make viruses feel strangely more real. This, I'll warrant, is a form of beauty that will register better to certain beholders, more so than genetic sequences and infection processes* (Ng, 2009).



Luke Jerram with his glass sculptures of notorious viruses (smallpox, E. coli, HIV)

Peter Michelson of Stanford University, the principal investigator of the Large Area Telescope instrument on NASA's GLAST mission, first conceived the idea of using a musical score to illuminate the science of the complex space telescope, the first imaging gamma-ray observatory designed to survey the entire sky every day and with high sensitivity. The idea was taken up by his friend Pierre Schwob, Chief Executive Officer of the Classical Archives website, who provided funding for the project and chose musicologist and composer Nolan Gasser to compose the work. Gasser's finished piece, entitled "GLAST Prelude for Brass Quintet, Op. 12," is performed by the American Brass Quintet. Gasser's full vision was realized in collaboration with Goddard Space Center TV producer Rich Melnick and Goddard's Conceptual Image Lab animation group. (The Glast Prelude music video is easily found with a Google search of that name.)

Looking at a more playful example, Baba Brinkman, a Canadian musician and comedian, merged art and science into a rap song with popular appeal in honor of Charles Darwin's bicentenary. His "Rap Guide to Evolution" is a historically and scientifically accurate and entertaining introduction to the theory of evolution and the science that underpins it.[12] Brinkman's rap, which can be viewed on YouTube, has been used in classrooms to engage students and teach evolution.

Cautions

Inasmuch as interviewees nodded to the potential benefits of HAC + Science collaboration, a common observation was that interdisciplinary collaboration is not an end in itself but a means to an end. There is always the need to balance interdisciplinary collaboration with deep disciplinary specialization. In the same vein, interviewees stressed the need to differentiate between innovative and status quo collaboration. As one interviewee in the *Addressing Complexity* study observed:

> *The current political mantra is that somehow interdisciplinary research has some virtue just because it's interdisciplinary. I would question that. The question that one is [asking] should govern whether there are interdisciplinary approaches or not. It's nice to be able to have those approaches, and there are questions that are best approached that way. But then the converse is that some questions aren't interdisciplinary.*

In the contemporary art movement known as bioart, warnings were sounded about artists undertaking naive, dangerous or opportunist collaborations; or sidestepping social and

12 The story goes that Brinkman was approached by Dr. Mark Pallen, a microbiologist from Birmingham University, who asked him if he would like to create a work for Darwin's bicentenary. Pallen reviewed the lyrics for accuracy, and Brinkman joked that it was the first peer-reviewed rap in rap music history. It was featured at the Cambridge Darwin Festival and the Edinburgh Fringe Festival, where it won a Scotsman Fringe First Award, and appeared on various stages in the UK and US.

humanist analysis. At the same time, there was a sense that artists are capable of deep intervention into actual invention as well as critique of technology or science.

Some cautions had to do with the dangers of stereotyping or narrow thinking, for example ascribing aesthetics strictly to the province of artists. Sherrie Rabinowitz reminds us that scientists have aesthetics, too: "They'll tell you that this is a really beautiful equation, and you'll understand their enthusiasm about the beauty of the way these numbers work together" (Pearce, Diamond & Beam, 2003). Conversely, others worried about definitions being too broad. For example, one interviewee balked at scientific imaging being put in the same class as "art":

> *[There are] also people in the world of science whose job it is to make images. MRI, visualizations, there is quite a lot of artistic license and artist inclinations that encourage them to set up the form of their visual images in one way or another. That is all interesting, but I don't think that is quite the same as being an artist* (Interview, external).

Some expressed concern that interdisciplinary projects will result in too much generalization or dilution of information. However, the predominant view was that cross-disciplinary interplay can actually result in a keener understanding of the issues at hand. As one external interviewee explained:

> *We champion the notion of expertise, but we also champion the notion that one expert is not enough. We are not about dumbing down what someone who has worked on heart transplants for all of their life knows about micro valve repair. That is fascinating and crucial, but we also want to talk to somebody that's an expert in Catholic iconography to find out how the heart has been used in liturgical visual material. This is a place that champions a range of experts, all contributing a bit to a project, so that it can be more than the sum of its parts.*

Mechanisms That Encourage Art-Science Interface

This section reviews various mechanisms used by organizations to bring disparate disciplines together. The study team observed various kinds of arrangements whereby artists/arts and humanities scholars and scientists are physically immersed in the same environment, thus increasing the chance of shared perspectives and synergies to occur. Some science organizations have artist-in-residence programs with visiting artists or even artist(s) on permanent staff. There are art-science laboratories and studios in universities and research institutes internationally as well as not-for-profit laboratory settings designed to spur interdisciplinary creativity. Other mechanisms include art-science symposia and workshops that promote interdisciplinary collaboration and grant programs such as the Smithsonian Artist Research Fellowship grants that enable artists to interact with science curators and collections.

Artists and art spaces in science organizations

Bringing artists into the laboratory to work with scientists, engineers and technologists has many precedents. John Seely Brown, former chief scientist at Xerox and the founder of the Xerox PARC Artist-in-Residence (PAIR) program, explained in an interview that artists who participated in the PARC program were predominately new media artists who were paired with researchers who were often using similar media. Through engagement with the arts and humanities, scientists have the opportunity to gain new insights into the history and development of both ideas in their fields of research and the biases inherent in them. According to Seely Brown, underlying the program was "the notion that engaging in these types of activities evokes deeper responses, deeper emotions. It brings forth many of the tacitly held beliefs and assumptions that you have." He noted that "both interesting art and new scientific innovation" emerged from these alliances. He also identified a less tangible benefit:

> *The artists revitalize the atmosphere by bringing in new ideas, new ways of thinking, new modes of seeing, and new contexts for doing. This is radically different from most corporate support of the arts, where there is little intersection between the disciplines. It takes a bit of faith on both sides, and a belief that both science and art can use a little shaking up, to engage in such a partnership* (As quoted in Naiman, 2003).

Perhaps the best known arts program within a science organization is the NASA Artists' Cooperation Program, begun by NASA Administrator James Webb in the early 1960s to complete the visual record of the U.S. space program. Artists were commissioned by the agency and given behind-the-scenes access to NASA missions, including suit-ups,

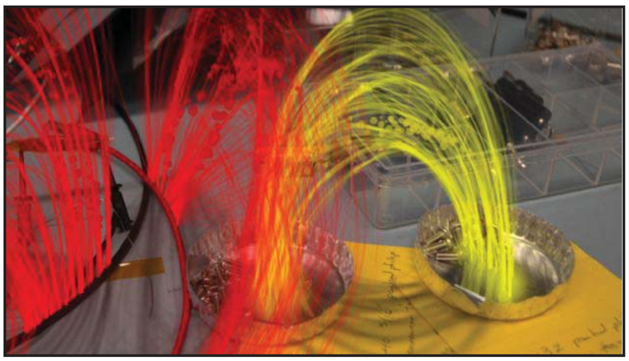
James Browning “Jamie” Wyeth, *Firing Room, Apollo 11*, 1969. Credit: National Air and Space Museum, Smithsonian Institution

launches, landings and meetings with scientists and astronauts. As former director of the arts program James Dean observed, “Machinery can duplicate and preserve the cold facts but the emotional impact of what was going on is within the province of the artist” (James Dean website). The program waned with the close of the Apollo mission in the 1970s, and the artworks were transferred to NASM. NASA commissions gained momentum again with the space shuttle and today include new art forms such as video art, poetry and music. Over the years, such diverse artists as Annie Leibovitz, Nam June Paik, Robert Rauschenberg, Norman Rockwell, Doug and Mike Starn, Andy Warhol, William Wegman and Jamie Wyeth participated – many of the works are currently touring the country through 2012 in the SITES traveling exhibition, *NASA | ART: 50 Years of Exploration* (Ulrich, n.d.).

Goodyear examined NASA’s motivations for creating and maintaining its Artists’ Cooperation Program in the 1960s. The program commissioned artists to create works of fine art based on what they saw and experienced at NASA. The benefits perceived by the program founders included cultivating public goodwill by humanizing technology and scientific advancements, interpreting NASA’s significance for the public for posterity, and granting public access to NASA activities through artists, who became de facto stand-ins for the public:

> *Artists served in effect as surrogates for the American public who could witness only selected events. Artists could render visible what might otherwise be overlooked, and could also respond to major occurrences with an insider’s insight* (Goodyear, 2002).

British artists Ruth Jarman and Joseph Gerhardt, the duo behind the art collaborative Semiconductor, interviewed, observed and worked with scientists and their equipment as artists-in-residence at the NASA Space Sciences Laboratory, University of California at Berkeley. The resulting artwork, titled *Magnetic Movie*, 2007, is a video that mixes dialogue with scientists, high quality recordings of the laboratory and animations of scientific research, such as visualizations of magnetic fields. For example, NASA researcher “Janet Lhumann describes the [magnetic] fields as a ‘hairy ball,’ Ruth and Joe attempted to manifest this visually, placing it within the laboratory itself rather than on the sun from where it was born” (Selby, 2009). *Magnetic Movie* received critical acclaim internationally, and garnered the attention of HMSG, which exhibited the piece in its Black Box series in 2008. It is interesting to note that the artists did not have a plan at the outset; instead, they allowed their experiences at NASA to guide the project, *We arrived fairly naive about the particular fields [NASA scientists] studied but hoped we could use this to our advantage, starting with a blank canvas. It was an experiment on ourselves in many ways and felt quite risky. We were familiar with these feelings of arriving in a new place through previous residency experiences but we couldn't anticipate quite what it would be like in a NASA space sciences lab. We arrived with no preconceived ideas about the art works we might make. Rather we hoped to be guided by the things we would come across and absorb. Of course we have particular interests but we had no idea if these were relevant to the situation or would come out in the work. Through a process of investigation we started to follow varying lines of discovery, being quite freeform about it* (Artist Ruth Jarman in an interview, Selby, 2009).



Ruth Jarman and Joseph Gerhardt, Still from *Magnetic Movie*

Semiconductor is participating in the 2010 Smithsonian Artists Research Fellowship, and will conduct research in the Department of Mineral Sciences within the NMNH, as well as work with HMSG staff.

Housed in the National Academy of Sciences (NAS), the nation's august science institution, is the Cultural Programs of the National Academies (CPNAS), which organizes rotating art exhibitions, lectures and other programs at NAS's headquarters building and Keck Center. Exhibitions feature well-known contemporary artists and photographers and have addressed such diverse subjects as Alzheimer's disease, anatomy, bio-codes, coexistence, evolution, icebergs, insects, monkeys, stories behind natural history collections, proteomics, images of Saturn, taxa, tornadoes, weather and occupied wilderness. The NAS publication *Issues in Science and Technology*, in collaboration with CPNAS, features the work of creative and thought-provoking artists who "provide an essential perspective on the cultural and personal dimensions of science's role in society" (CPNAS website).

The Wellcome Trust, established in 1936 with an endowment from American pharmaceutical tycoon Sir Henry Wellcome, is the UK's largest non-governmental funder of biomedical research. The Trust began its Science and Arts grants in 1996, recognizing that the arts are an effective way of stimulating debate and engaging people with biomedical science. Today, the Trust spends around one million dollars annually on public projects that span artistic genres including film making, sculpture, dance, installation, poetry, music and creative writing. An interviewee explained the genesis of the funding program:

Artists were using their art to investigate some of the moral, ethical and social issues that come about from all the scientific developments. It seemed to us that there was an interesting formula to be played with: could we supply artists and scientists who wanted to work together on public projects money to allow them to get themselves – for a brief while at least – out of their professional mainstream callings to work together to produce projects that we insisted had to have some sort of public outcome (Interview, external).

In 2007, the Trust opened the £30 million Wellcome Collection – a museum-like space with permanent historical and contemporary galleries, traveling exhibitions, events and other amenities – that draws from the quixotic material culture collection of founder Henry Wellcome, along with the Trust's experience in getting scientists and artists to work together on contemporary projects that explore the connections between medicine, life and art. An interviewee said that a crucial aspect of the program is not to disseminate established ideas – "spreading the word to the uninitiated" – in the traditional science museum sense, but to focus on things we know slightly less about:

… things where what we know in the sciences is arguably only half of what there is to know about the topic. Take the heart. Of course you want to know about circulation and surgery, but you also have to think about what religion, art and the writing world has told us about what, in a metaphorical sense, the heart is (Interview, external).

The new venue for age 14 and above, described as "the most inquisitive space in London," has had over double its estimated visitor figures, attracting 70,000 visitors in its first three months. Interdisciplinary exhibitions and programs attract a mix of people, such as the recent event focusing on hair that brought together the Handlebar Mustache Club of Great Britain, dog groomers and a chemist who explained why hair continues to grow after you die (Wellcome Collection introductory video).

Dan Goods (highlighted in previous section), a graphic designer by training, holds the job title "Visual Strategist" at NASA's JPL at the California Institute of Technology and is tasked with devising creative ways of communicating. Goods related in an Artist Talk that part of his appeal to the personnel at JPL is that he can help them see more holistically. Scientists and engineers are typically focused on a narrow disciplinary area of a "humongous" project. His artwork lets scientists "step back" and reminds them of the bigger picture (Goods, 2009).

Fermilab, the US Department of Energy's premier laboratory exploring the frontiers of high energy physics, has an art gallery where, according to its website, art and science converge daily. The Fermilab Art Gallery hosts a combination of art exhibitions, chamber music concerts and science lectures intended to open the door between Fermilab and its neighboring communities and enrich the cultural life of the surrounding suburbs.

The Congressional legislation creating the Smithsonian National Air and Space Museum stipulated that the museum always have an art gallery and a curator of art.

Interdisciplinary Laboratories and Studios

Following is a small sampling of the kinds of spaces where artists work alongside scientists in laboratories, and scientists and technologists work alongside artists in open studios. Many of the arrangements that exist today go back decades; some founded in earlier times are now defunct, while new interdisciplinary laboratories and studios are springing up every day as the arts and sciences grow closer by necessity of bringing diverse perspectives to bear on complex problems.

E.A.T. (Experiments in Art and Technology) was launched in New York in the late 1960s by engineers Billy Klüver and Fred Waldhauer and artists Robert Rauschenberg and Robert Whitman to promote and facilitate collaboration between artists and engineers resulting in projects that explored and incorporated new technologies. E.A.T., a non-profit, was operational through the 1980s and had "chapters" throughout the US and in Canada.

"Video" was the common denominator between the disparate endeavors in the 1960s of physicists in California studying the unconventional field of chaos theory and New York artists experimenting with new forms of digital art. Scientists were exploring video feedback as a chaotic, dynamical system, and artists were experimenting with video technology as artistic medium. This common interest brought the four founders of the Art and Science Laboratory (ASL) to Santa Fe, New Mexico, under different auspices. Through study and conversations with each other, "they came to see how their respective inquiries revealed common patterns in natural, biological phenomena – patterns that spoke of a unifying reality to life that was of interest to artist and scientist alike" (Middlebrooks, 2001). ASL's mission today is to redefine the social role of art and the artist in the context of applied collaboration with focused scientific research. Its integrative research and education areas include electronic arts history and practice, robotics and haptics, sound art, chaos and nonlinear dynamics, bioacoustics, human and machine interface, complex and adaptive systems, and environmental media construction and protocols, among others.

The Center for Advanced Visual Studies (CAVS) at MIT was conceived in 1967 as a fellowship program for artists. Its founder's vision included:

> *… absorption of the new technology as an artistic medium; the interaction of artists, scientists, engineers, and industry; the raising of the scale of work to the scale of the urban setting; media geared to all sensory modalities; incorporation of natural processes, such as cloud play, water flow, and the cyclical variations of light and weather; [and] acceptance of the participation of "spectators" in such a way that art becomes a confluence* (CAVS website: History).

Also in MIT's School of Architecture and Planning is the renowned Media Lab, now in its 25th year, where traditional disciplines are "checked at the door" as designers, engineers, artists and scientists work "atelier-style" (Media Lab website).

The pioneering Exploratorium, founded in San Francisco in 1969 by noted physicist and educator Frank Oppenheimer is a kind of laboratory consisting of a "collage of hundreds of science, art, and human perception exhibits." The Exploratorium is a leader in the movement to promote museums as informal education centers (Exploratorium website).

ArtScience Labs, the brainchild of Harvard biomedical engineering professor David Edwards, is a network of international innovation centers that promote socially beneficial innovations by engaging the creative minds of artists, designers, scientists and students in art and design experiments at the frontiers of contemporary science. Edwards describes an "idea funnel" process where dreams in the minds of passionate high school and university students are cultivated in Idea Translation Programs at Cloud Place in Boston and at Harvard. Those ideas may continue as works of art or exhibitions developed in collaboration with renowned artists and leading scientists at The Laboratory @ Harvard and the most publicly visible place, Le Laboratoire in Paris, France. Experiments may also be realized as commercial and humanitarian products such as Le Whif (breathable low-calorie chocolate), Andrea (living plant air purifier) and Pumpkin (new way of transporting water in Africa).

The Art Science Research Laboratory in New York, founded in 1998 by scholar-artist Rhonda Roland Shearer and the late Harvard Professor Stephen Jay Gould, provides an intellectual environment for interdisciplinary research, collections and publishing among art historians, scientists, artists, designers and programmers. A major project in art-science education focused on the artworks of French-American artist Marcel Duchamp, in which he incorporated mathematics, optics and perceptual theory.

The Imaging Research Center at the University of Maryland, Baltimore County draws together interdisciplinary teams of artists, researchers, industry partners and students to investigate new imaging /digital art /media technologies and their use for interpreting and presenting content in ways that engage the general public.

The Artists in Labs (AIL) program in Switzerland, a collaboration between the Zurich University of the Arts, Institute for Cultural Studies in the Arts, the Bundesamt für Kultur, and Swiss Science laboratories aims to develop the primary creative forces shared by the art and science disciplines by providing a research environment where experiments can take place. AIL sets out clear objectives:

- *Bridge* – to act as a go-between and offer Swiss laboratories as a place of liaison between artists and scientists in order to create new levels of creativity, innovation and communication.

- *Production* – to encourage production of new works, material applications, prototypes, and conceptual processes. To allow artists to know about scientific information and scientists to experience interpretations of their own discoveries and to collaborate in unorthodox ways with artists.

- *Learning* – to recognize the importance of cultural exchange, the nature of physical and psychological space, the working methods and processes involved in making experiments and the nature of interaction between disciplines.

In 1999, husband and wife Oron Catts and Ionat Zurr were the first artists-in-residence at Harvard Medical School under the tutelage of surgeon and pioneer tissue engineer Joseph Vacanti. In 2000, they began running SymbioticA, the cutting-edge artistic laboratory located within the School of Anatomy and Human Biology at The University of Western Australia. SymbioticA, which includes tissue and neuroscience labs, a surgical training facility and sleep labs, is known as the "unofficial mother lode of the bio-art movement." Catts explains that art helps culture come to terms with what science produces, and that it serves a crucial role in science:

> *Art is becoming one of the last privileged professions that ... has a license to fail and to open the issues rather than bring closure to them. This voice is extremely important in science at the moment* (As quoted in Birmingham, 2010).

ZKM (*Zentrum für Kunst und Medientechnologie* or Center for Art and Media) in Karlsruhe, Germany is a government-sponsored cultural institution that supports experimentation and discussion around emerging technology and its development, use and impact on society. Projects incorporate science, art, politics and finance and include production and research, exhibitions and events, and coordination and documentation.

Laboratoria Art and Science Space is the first nonprofit research center in Russia focused on creating platforms for interdisciplinary collaboration at the intersection of contemporary art, science and social psychology.

Grant programs

The Smithsonian's SARF program awards stipends to approximately 10 established artists each year to conduct research without the pressure of producing works of art, with a two-month residency period at Smithsonian museums and research facilities. To date, over 40 artists from various countries have participated. The twelve SARF fellowships awarded for 2010 evidence the exciting new areas of interdisciplinary scholarship/art production that the program engenders; for example, a sound artist will work with NMNH's collection of 19th century acoustic apparatuses, and an installation artist will work with NMNH zoologists to explore the correlation of human and frog skin to show the dangers of environmental change. According to a senior program officer, the intention is for SARF to expand to include poets, musicians, performers and others in the creative arts. Two former SARF fellows that particularly illustrate the melding of science and the arts/humanities are highlighted here.

Connecticut artist Rachel Berwick calls attention to the disappearance of languages and cultural heritage with her evolving installation "may-por-e'." For the original artwork, Berwick trained Amazon parrots to speak the lost language of Maypure'. The parrots, seen only in shadow though translucent walls of a sculptural aviary, have now transmitted the language to four younger parrots. Berwick pursued her interest in ornithology and migration at SIL (writings of 17th to 19th century explorers and naturalists); NMNH (ornithology specimens); and NZP (new migratory bird facility).

Rachel Berwick, *may-por-e'*

Shih Chieh Huang, *Counterillumination (C-2010)* installation

During his 2007 fellowship, New York artist Shih Chieh Huang investigated the evolutionary biology of bioluminescence in sea creatures and insects, working for three months with NMNH scientists. Knowledge gained from the experience is evident in Huang's recent work, which he describes as analogous ecosystems populated with organic living things made from common everyday objects – household appliances, zip ties, water tubes, lights, computer parts and cheap motorized toys. NMNH has commissioned an installation by Shih Chieh Huang that will go on display in 2011.

The artist residency and exhibition project *Human/Nature: Artists Respond to a Changing Planet* was premised on the concept that conservation can inspire contemporary art and vice-versa. The University of California, Berkeley Art Museum and Pacific Film Archive, and the Museum of Contemporary Art San Diego, partnered with the international conservation organization Rare to send eight world artists to eight UNESCO-designated World Heritage sites around the globe for two mini-residencies. The artworks produced formed an exhibition shown at the two sponsoring museums in 2008-2009 and addressed such themes as the relationship between the natural environment and human culture; assumptions about the value of preserving biological and cultural diversity; and global exploration and exchange.

At this writing, the feasibility of a similar project is being explored whereby a diverse set of six artists working in different media and nominated by Smithsonian museums would be selected through a competitive process to accompany NMNH scientists and work with them side-by side as part of the ongoing biodiversity survey and bio-coding of Moorea, an island in French Polynesia.[13] It is anticipated that artists would blog about their experiences and that art pieces generated from the project would be included in a group exhibition at NMNH in the future.

Advocacy, funding and networking organizations

Herewith is another small sampling, this time of organizations that promote and support interdisciplinary collaboration across the arts and sciences through grant-making and other funding schemes, holding workshops and symposia, maintaining websites for information dissemination and networking, and other means.

According to the website for Leonardo/ISAST (International Society for the Arts, Sciences and Technology), "The critical global challenges of the 21st century require the mobilization and cross-fertilization of practitioners in the fields of the arts, sciences and technology." For forty years Leonardo/ISAST has served as a communication channel for artists, scientists and others interested in the integration of contemporary science and technology with art and music. Its legacy includes founder Frank Malina, an astronautical pioneer and kinetic artist who was the second director of JPL; his son, Roger Malina, an astronomer by training; and founding board members Frank Oppenheimer and Robert Maxwell. Leonardo/ISAST advances scholarship and collaboration in art/science/technology through a variety of activities including publishing print journals, book series, and electronic publications, sponsoring educational and awards programs, and hosting symposia, conferences and workshops.

Digi-arts is UNESCO's digital arts portal that serves as a networking tool for digital artists and scientists interested in collaboration, and an information source about creations that are not well-known to the general public. The website offers an overview including prominent artists and scientists working in the fields of virtual reality, robotics, artificial intelligence, internet and biotechnology.

13 Moorea was one of five ecosystems selected as part of a recent National Geographic project that commissioned a photographer to record all of the creatures that lived in or moved through "One Cubic Foot" of habitat from each site.

The eponymous Buckminster Fuller Institute facilitates convergence across art, science, design and technology in order to catalyze the collective intelligence needed to develop and deploy solutions that advance human well being and healthy ecosystems. The Institute aims to empower "design-science pioneers" who will apply "whole systems thinking, Nature's fundamental principles, and an ethically driven worldview" to conceive and apply transformative strategies. It does so through a variety of programs, including its annual $100,000 design challenge and Design Science interdisciplinary immersive lab.

The Arts Catalyst is an arts and education charity based in London that commissions contemporary art that engages with science experimentally and critically – "We produce provocative, playful, risk-taking artists' projects to spark dynamic conversations about our changing world" (Arts Catalyst website).

Art & Science Collaborations, Inc. (ASCI) is a member organization founded in 1988 as a networking place for artists who use or are inspired by science and technology, and scientists and technologists looking to collaborate. ASCI produces exhibitions, holds international symposia, and maintains ArtSci Index, an online matching tool for potential collaborations.

Similarly, the Society for Literature, Science, and the Arts is a member organization for those with an interest in the problems of science and representation, and in the cultural and social dimensions of science, technology and medicine.

Think tanks, conferences, colloquia, working groups and the like

J.D. Talasek, director of Cultural Programs of the National Academies, and Kevin Finneran, editor of NAS's *Issues in Science and Technology,* appear frequently in connection with forums and symposia that delve into the relationships among art, culture and the sciences. In April 2010, 3,500 visitors from 55 countries watched the online discussion by 30 international experts on *Visual Culture and Evolution*, co-sponsored by CPNAS, the Center for Art, Design and Visual Culture at UMBC, and Johns Hopkins University's Master of Arts in Museum Studies Program. Similarly, the *Virtual Symposium on Visual Culture and Bioscience,* co-sponsored by CPNAS and UMBC in March 2007, drew participation from artists, scientists, historians, ethicists, curators, sociologists and writers. Visual artist and theorist Suzanne Anker moderated the virtual symposium and opened it, saying,

> *The ubiquitous employment of digital technologies within the practices of research science and medicine, architecture and design, filmmaking and video production, as well as the visual and performing arts, has set ajar a multiplex of communication networks which crisscross traditional boundaries* (Anker and Talasek, 2007).

In November 2009, the Ontario College of Art and Design (OCAD) in Toronto, Canada hosted *Cultural Knowledge and the Healthy Society: A Research & Innovation Summit*. The summit drew members of the arts/design, social sciences, engineering, technology, medical and rehabilitation communities and industries, policymakers and funders to consider how design and technology can advance health research and direct that research towards better outcomes. Presenters and participants discussed collaborative possibilities in medical visualization as well as how to institute change, fund art/science projects and get people and partners together. The summit was

> *born of the belief that adding the knowledge and insights from design, cultural industries and creative/artistic research to health research will lead to a more effective system of health care and prevention as well as foster technological innovation* (OCAD website).

TED (Technology Entertainment and Design) began as a set of global conferences to disseminate "ideas worth spreading." Since 2006, a growing number of "TED Talks" on a wide range of topics within the research and practice of science and culture are available for free viewing online. The riveting ideas more often than not integrate disciplinary thinking. A number of TED Talks– from Margaret Wertheim expounding on the math of coral duplicated in crochet work to Sir Ken Robinson eloquently appealing for greater openness to the arts, creativity and different learning styles in the education system – were reviewed as part of this study.

The BRIDGES Consortium was initiated in 1991 by the Annenberg Center for Communication of the University of Southern California and the Banff Centre New Media Institute in Banff, Canada as an international think tank and forum to study and enhance the process of interdisciplinary collaboration in the arts, sciences and technology. BRIDGES recognizes that the greatest challenge in interdisciplinary work involves communication between people to overcome differences in work and communication styles, priorities, educational principles, institutional frameworks, funding models, temperaments and even fundamental values. It therefore acts as a network for dissemination of strategies for including collaboration as a vital component in education, creation and research (Pearce, et al., 2003).

TippingPoint, hosted by Oxford University's Environmental Change Institute, is an annual series of meetings involving intense dialogue between artists, scientists and others around the challenging subject of climate change. Recognizing that "the arts have consistently played a role in society in helping thinking shift from reflection to action," Tipping Point seeks to be a catalyst in facilitating debate and increasing artists' engagement in the complex issue. The Oxford scientist who wrote the 2008 meeting report noted:

I am a true scientist in my heart and never really thought about the important role in this issue for the artists in this world. There are many who can and will learn critical things from this group of those who are different from me and who express themselves differently (Carter, 2008).

Ithaca College's School of Humanities and Sciences has, since 1964, had a C.P. Snow Lecture Series to stimulate dialogue and thought and recognize individuals who bridge the gap between the two areas of study. In his talk titled "Beauty and the Scientific Method," 2009 speaker Spencer Finch related how art and science intertwine in his own contemporary artwork, and examined ways in which the scientific method and strategies of art-making are analogous. The artist set up four installations to demonstrate how principles of art and science are brought together, such as his *Bee Purple*, which recreates the luring color purple that bees can see but humans cannot. For *Sky*, the artist dyed water to match the color of the sky over a glacier in New Zealand and froze it, piling the cubes in a glacier-like structure that melted to create a liquid painting of the sky (Ithaca College website).

Spencer Finch, *Sky*

The Aspen Institute, a think tank founded in 1950, brings artists, scientists, scholars, statesmen and corporate and civic leaders together to discuss the world's pressing challenges. Its Global Initiative on Culture and Society promotes

the increasing recognition of artistic and cultural expression to enrich human lives by provoking reflection, stimulating creative solutions to societal challenges, sustaining livelihoods and illuminating the conditions necessary for social change (Aspen Institute website).[14]

Beginning in 2000, the Museum Loan Network gathered a group of leaders in the fields of art history, dance, theater, philanthropy, art, public television, science, history, education, libraries and museums for three "think tank" meetings around the topic "Museum as Catalyst for Interdisciplinary Collaboration." The group came away with the realization that "It takes many languages to describe reality," and interdisciplinary collaboration

14 According to an internal interviewee, a collaboration between the Aspen Institute and SI for a bi-annual, global "Culture & Society Summit" is in the exploratory stages. The summit would focus on creativity and innovation in the cultural sector, the arts and humanities, science and technology, governance and public policy, business and socioeconomic development, environment, and education, with awards for achievements in culture and innovation across art and science.

provides an opportunity to tap a variety of different "languages," i.e., the varying perspectives from fields of special knowledge and ways of knowing. A salient finding with respect to museums was that audience members are very much collaborative partners that bring their own beliefs, experiences and understandings (Museum Loan Network, 2002).

PhD in Art

One of the barriers mentioned to an "equal" collaboration between scientists and artists is the perception that artists are not as credentialed as scientists. One interviewee described a new PhD program for art in some academic institutions that casts the artist as developing knowledge, not just creating objects. The idea that artists can be producers of knowledge and new ways of thinking may be helpful when considering the role that artists play in an interdisciplinary collaboration.

Teacher training to integrate arts in core curricula

The Kennedy Center's Changing Education Through the Arts (CETA) program seeks to "develop teachers', schools', and school districts' knowledge and skills in the arts and arts integration so that they include the arts as a critical component in every child's education." Through CETA courses and workshops hundreds of teachers in the Washington, D.C. metro have learned about the arts and how to integrate the arts with other subject areas from the perspective of creators, performing artists, directors, designers and critics (CETA website).

The Clarice Smith National Teacher Institutes program at SAAM trains high-school, middle-school and upper-grade elementary school teachers to use technology to integrate the visual arts into core curriculum classes such as English, history, social studies, math and science. The program focuses on the value of artwork not so much as a subject of study in and of itself, but as a flexible teaching resource that can promote visual learning and critical thinking skills across a wide range of subjects. In its first two years, the program has helped approximately 50 teachers master concepts and technology tools that will enable them to use the visual arts in this way.

Curriculum reform

"Creativity guru" Sir Ken Robinson argues that national education systems, set up to meet the needs of the industrial age and based on a model that advantages academic skills over expressive skills, are "educating people out of their creative capacities." He explains that the brain is not divided into unrelated compartments; instead, intelligence is interactive. Creativity – "the process of having original ideas that have value" – more often than not

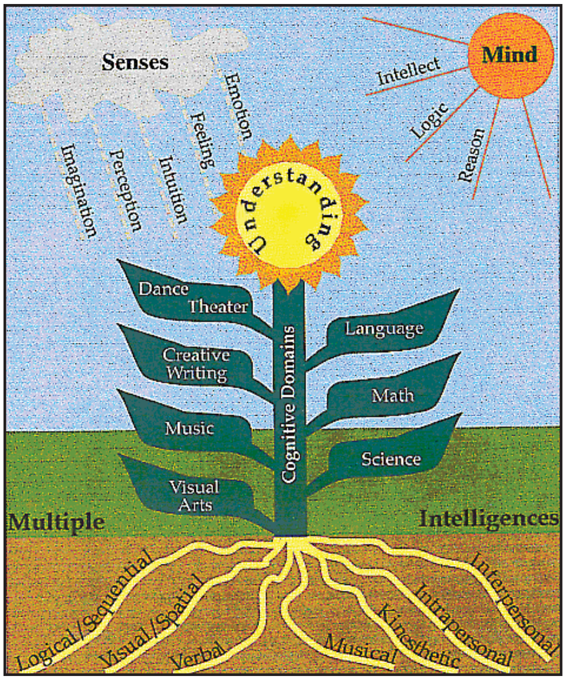


Figure taken from Oddleifson, 1995

happens through the integration of different disciplinary ways of seeing things. Robinson maintains that preparing our children for the future requires educating their whole being. Nurturing the creative capacities of children will require a fundamental rethinking of the principles of the education system (Robinson, 2006).

Education reform to break down disciplinary silos is a vast topic and beyond the scope of this paper. Here, we include just a few examples of education practice at the forefront of the integration of science and the arts and humanities.

A notable local example of integration at the high-school level is the Thomas Jefferson High School for Science and Technology (TJHSST), a public magnet school in Fairfax County, Virginia. It begins each freshman class with its integrated Biology, English and Design and Technology program (IBET), which concurrently instructs students how to conduct primary research, use technologies to solve problems, develop writing and presentation skills in various media, and communicate research findings to different audiences. Another TJHSST program, nicknamed "CHUM," integrates chemistry into 10th grade humanities. Conservators from the Smithsonian's Lunder Conservation Center have worked directly with CHUM students to demonstrate the diverse skills and knowledge needed to be a conservator, i.e., conservators do more than "fix art"; they must possess a comprehensive understanding of materials science, chemistry and art history.

At Lafayette University, professors of biology/neuroscience, art, and computer science are collaborating on a program that explores the connections between art and science "using visualization as a way of modeling in science and science as a way of suggesting creative avenues in art" (Lafayette University website).

The Art/Science Fusion Program, housed in the College of Agricultural and Environmental Sciences, Science and Society Program at the University of California, Davis has as the centerpiece course Entomology 1, Art, Science and the World of Insects (the result of seven years of experimentation). Other courses in the series are Art, Science and the World of Plants; Photography: Bridging Art and Science; and Earth, Water, Science and Song (University of California, Davis website).

One of the more ambitious attempts to overhaul disciplinary division is the campus-wide evolutionary studies program (EvoS) at Binghamton University in New York. Its proponents explain:

> *Unifying the humanities and sciences is not a matter of making the humanities more "scientific." It is genuinely a two-way street, in which subject areas currently associated with the humanities occupy center stage as part of the study of what it means to be human from a scientific perspective, and where the humanities are instrumental in articulating the transformative power of the imagination, a concept that, for the first time in a very long time, is again taken seriously by science* (Wilson and Heywood, 2008).

EvoS's premise is that virtually every human-related subject can be approached from an evolutionary perspective – not only those typically associated with science such as psychology and economics, but also philosophy, literature, art, history and religion. As one external interviewee explained, "There is the apartheid between the biological side of science and the human side of science before even getting into the humanities. It is another barrier that needs to be broken down." By integrating evolutionary theory in all departmental offerings, EvoS seeks to broaden understanding of its consequences for human affairs – "understanding people from an evolutionary perspective is essential to solving problems that are basically problems of human social interactions." EVoS is developing into a worldwide consortium of evolutionary studies programs with some 40 member colleges and universities across the US and internationally (EvoS website).

Critics of interdisciplinary curriculum approaches say that such important aspects as depth of subject matter, coverage of crucial areas and sequencing of important skills are inevitably shortchanged in interdisciplinary efforts (Ellis and Fouts, 2001). One of the more vocal critics, Thomas Sowell, refers to interdisciplinary as "non-disciplinary" in that it ignores the boundaries between academic disciplines, which "exist precisely because the human mind is inadequate to grasp things whole and spontaneously or to judge 'the whole person'" (Sowell, 1995 as quoted in Ellis and Fouts, 2001).

Informal science education (ISE)

Science, history, art and culture intertwine in the environments where informal science education (ISE) takes place: film and broadcast media, science centers and museums, zoos and aquariums, botanical gardens and nature centers, digital media and gaming, science journalism, and youth, community and after-school programs. ISE is another vast topic and the subject of much study and research. The NSF Division of Research on Learning in Formal and Informal Environments supports several centers such as the Center for Advancement of Informal Science Education (CAISE), which seeks to strengthen interdisciplinary collaborations across the field of ISE, improve practice and document evidence of impact. The Smithsonian is a ideal laboratory of ISE, as noted by Secretary Clough in his installation remarks in January 2009:

> *Technology is not our only new opportunity to shape the future of education. There have been recent studies demonstrating the power of informal education programs as well as of systemic education reform, and we have strengths in both areas at the Smithsonian. Taken together, our resources can help inspire young men and women to be the citizens who will sustain our nation's promise* (Clough, 2009b).

Interdisciplinary mechanisms at the Smithsonian[15]

Over the years, the Smithsonian has had many different offices, committees and other formal and informal organizational mechanisms to facilitate dialogue across science, history, art and culture. A notable example is the Office of Interdisciplinary Studies (OIS, 1987-92), which succeeded the earlier Office of Symposia and Seminars and was designed to create opportunities for diverse audiences to discuss global concerns and debate significant issues in contemporary life. In the course of its work it produced international symposia, seminars, books and educational materials. A promotional brochure describes the ways in which the office extended "cross-fertilization": bridging academic disciplines in the sciences and humanities; bringing together practitioners, patrons and users of research; linking the Smithsonian with its partners in higher learning; improving citizens' understanding of other societies and cultures; providing a forum at the Smithsonian for the flow of ideas across organizational boundaries; and joining scholars with public officials, business and industry leaders, educators and students, philanthropists, the media and other interested publics. OIS founding director Wilton Dillon addressed those scholars who would discredit interdisciplinary activities:

> *… Knowledge would not grow without taking some risks at offending the peer review system that basically rewards those who stick to publishing within a single discipline* (Smithsonian Institution, 1989).

Interviewees cited the Smithsonian Folklife Festival, a two-week outdoor international exposition staged annually by the Center for Follklife and Cultural Heritage, as an example of a forum where the interplay of diverse disciplines is inherent in the event itself due to the scope of folklife and the research that comes to bear on it. An interviewee described how the Festival, which is dedicated to understanding and continuity of contemporary diverse grassroots cultures, looks beyond dance, music and crafts at the nexus with a number of issues including social justice and environmental issues. For example, the 2009

15 This section does not discuss interdisciplinary mechanisms at the Smithsonian treated in earlier sections, e.g., SARF, SI Web 2.0 and SI Connections.

Wales program demonstrated how the people are harnessing their traditions, including architectural building techniques and craft traditions, in the service of green technology, with the intent of becoming the first zero-carbon society. The 2010 Mexico program took a comprehensive look – "from traditional remedies to religion to environmental preservation" – at smaller regional groups, many indigenous, that are struggling to carve out a place for their culture in the larger Mexican society. The 2011 partnership with Colombia will examine the relationship between human culture and biodiversity (Interview, internal).

A number of people interviewed internally at the Smithsonian praised the Forum on Material Culture for creating a vital environment for the Smithsonian scholarly community to come together around a specific topic to be addressed from a variety of disciplinary vantage points. The Forum's quarterly programs, which are each followed by a reception and dinner, are open to all Smithsonian staff and interested external scholars and specialists. Program ideas – generated by a pan-Institutional steering committee – aim to be topical, coinciding with an exhibition, book launch, new scholarship or pressing issue. The Forum recognizes that there are similarities and differences in the ways that different disciplines and units academically and culturally approach material objects. Thus, it functions at the first level of interdisciplinary collaboration – side-by-side – where two or more specialists run something in parallel and inform each other from the base of their discipline. For example, the June 2002 program *Silk: Material and Meaning* echoed the Silk Road theme of that year's Folklife Festival and included such diverse interpretations as "Silk - the Fragrant Lord - in Malagasy Textile Production"; "Spiders and Silk"; "The Qualities of Silk"; and "Southeast Asian Silk: Some Puzzles and Questions."

The Smithsonian Congress of Scholars, and in particular the Research Tent it sponsors at staff picnics, was also mentioned as an important mechanism for enhancing communication among researchers and highlighting the diversity of research at the Institution.

The recently established advisory committee for contemporary art at NMNH grew out of the need for greater rigor in the selection of art shows for the museum. The committee includes members from Smithsonian science and art museums and an external member from the Cultural Programs of the National Academies. As one interviewee explained, natural history museums have a long tradition of science illustration, documentary photography and wildlife art shows for which there are established standards, but science museums are generally not equipped with similar standards in the realm of contemporary art.

A few interviewees emphasized how young scholars can shake things up and breathe new life into the dominant culture of an institution. Good ideas percolate up, down and sideways and one interviewee mentioned that the Smithsonian's partnerships with universities, such as the Masters Program in the History of Decorative Arts, which is a partnership between the Smithsonian Associates and the Corcoran College of Art + Design, and its post-doctoral, fellowship and internship programs not only provide significant opportunities for young people to study with SI staff, but also for staff to learn from students who are often less risk-adverse and have skills that differ from their supervisors.

As described in the introduction of this report, the new Smithsonian Strategic Plan (2010-2015) signals a very deliberate move toward more interdisciplinary and cross-institutional collaboration, in particular with the development of the four Consortia around the SI's Four Grand Challenges, which are in areas where the Institution has great longevity of experience, collections and other resources, and deep expertise. The process of team-building across disciplines and units, and advancing interdisciplinary activities under each Grand Challenge has begun, as demonstrated at the "Idea Fairs," a series of proposal presentations followed by question and answer periods and networking. The Idea Fairs solicited multidisciplinary, collaborative proposals that tackle pressing issues that the Smithsonian is particularly well suited to address. For example, at the Understanding the American Experience Idea Fair, one proposal integrated scholarship from the natural and social sciences – linguistics, geology, ethnography etc. – to study indigenous languages, which can lead to the understanding of cultural diversity. Another proposal championed the in-depth study of the various facets of food, food being of pivotal importance to the survival of life, but also to culture and customs, the care of the earth, health sciences, agriculture and religion. It is anticipated that the team approach and interdisciplinary efforts exhibited at the Idea Fairs will bubble into full fledged projects backed by the Smithsonian and supported by a variety of funding sources.

Strategies to Facilitate HAC + Science Interplay

The OP&A report preceding this study, *Addressing Complexity: Fostering Collaboration and Interdisciplinary Science Research at the Smithsonian*, took a comprehensive look at managing interdisciplinary collaborations in science research and distilled a list of best practices offered by interviewees and found in the literature on how to bring about change in organizational culture and operations that support interdisciplinary research. Those sections are included as Appendix C to this report. The study team for this report encountered much similar advice. However, the general sense was that crossing the art/science disciplinary divide required even greater motivation and attention given the more pronounced differences in the "languages" and communication styles of the "two cultures." As one writer (describing the challenge of writing a musical score that would illuminate the science of a complex space telescope) mused:

> *Ask anyone who has tried: oil and water don't mix. So it seemed with art and science. How was he to use the emotion of music to represent the cold technical precision required for a sophisticated scientific investigation? What, if anything, do art and science have in common?* (Steigerwald, 2008)

The following strategies and observations that focus specifically on facilitating collaboration across the arts and sciences were gleaned from interviews for this study.

Look to visionary people as leaders

Interviewees said that a visionary leader is a must for any truly exploratory and innovative enterprise, and one of the hallmarks of such forward thinkers is the willingness to take risks. One director of an interdisciplinary space acclaimed for its innovation said,

> *My primary role among my team is to be a sponge for ideas. My main purpose is to flirt with anybody who seems to have an interesting idea. We end up not being able to work with 95% of the ideas, because they are unsuitable, because we have done them before, or whatever. We would die on our feet if we were not open to ideas, both coming from within and coming from the outside.*

Assure a win-win arrangement

An internal interviewee, when asked what makes a good collaboration, stated:

> *It all boils down to this main thing – it has to work for all the parties involved. And it is a bit more complicated than that. Each one has to bring a resource, each one has to benefit. That is why when I sit down to talk to some of my collaborators, my first questions is, "what is in it for you?" I want to know what they want out of this. So then I know what is going to work for us.*

An external interviewee described what made for a satisfying collaboration between the Carnegie Museum of Art and Carnegie Museum of Natural History on the exhibition *Fierce Friends: Artists and Animals*, which looked at the era of 1750 – 1900 and evolution – how certain scientific discoveries influenced artists and how what artists were doing influenced science:

> *It was not the Art Museum coming to Natural History Museum staff asking for specimen x, y and z. It was the Art Museum coming and saying: this is our concept, what do you think? How do you fit in? The perspective of the Natural History Museum staff was of interest and was integrally included in the development of the exhibition ... Our staff felt that they had a voice. And it wasn't their voices through the art curator; it was their voices with the art museum. That was a major shift.*

Stay small and nimble

One external interviewee who was familiar with the Smithsonian said the Institution is in an enviable position because of its public spaces and "tentacles" of great size and reach: "you cover all that is known about the physical world – from space through to natural history, from local history through to international projects." This interviewee said the key to success for interdisciplinary collaboration is lots of small projects – "if you hang onto just one big project, the risk is that it's not going to quite come off, and then you'll think the whole methodology has gone bad."

> *The real trick with an institution the size and scale of the Smithsonian is to make sure its smallish scale projects can carry the energy. Because some of these things start strategically there can be a danger that it is set up as a formula, i.e., "Here's the formula for how we get interdisciplinary projects." So often that is where all the energy gets dissipated. People are just running around ticking boxes, making sure that what they're doing is interdisciplinary. For us, the fact that these projects draw on different disciplines is actually the most boring part; it is almost ubiquitous. The energy comes from people being so interested in the topic … so it is important to find a way to let lots of little projects flourish, knowing that some will fall to the wayside because they don't work for various reasons. Whereas setting up a formula, having people go through the motions seems disingenuous. So it is about setting*

up a structure that is loose enough to encourage lots of activities to happen while championing a strategic plan.

Suggestions for starting small included types of testing and experimentation, such as floor versions, small projects, small gatherings and works in progress that then inform the way the large-scale productions happen.

Keep in mind that interdisciplinarity is not an end in itself but a means to an end

Related to the above, some interviewees felt that "interdisciplinary" has become a buzzword and a mantra without emphasis on the result of bringing things together in interesting ways. As one said,

> *The aim is that when the project comes out into the public domain it still fizzes with the excitement of the experts, without just looking like one bit from art, one bit from science, and one bit from natural history all thrown together in a jumble that doesn't quite add up to the sum of its parts.*

This interviewee offered a "how to" – what he described as a journalistic approach to curation:

> *I think championing the nature of curation, and we all bandy the term around, some of us think that means a bearded man who knows everything about some fossil, or will go to the grave knowing slightly more than everyone else about it. But I'm more interested in the form of curation that is almost like a form of journalism, the judicious selection of the most exciting examples of different ways of thinking about the subject and then bringing it together with grace and production values to really turn it into an exciting show.*

Another interviewee said that interdisciplinary collaboration can stimulate new ways of thinking and organizing information, but stressed that such collaboration should not be imposed on anybody who is not stimulated by it – "Some people are excited by the difference, and for other people it will drive them crazy."

Take time to talk, build relationships and establish trust

> *At the heart of interdisciplinarity is communication—the conversations, connections and combinations that bring new insights to virtually every kind of scientist and engineer* (National Academy of Science, 2004).

In a recent interview, artist Katie Paterson talked about her work with Caltech astronomers at the WM Keck Observatory in Hawaii, studying the "cosmic dawn" of galaxies 12 billion years back in time. Asked about the process of initiating conversations with scientists and their receptivity to her ideas, she said that sometimes she's been directed to a particular person, but often she sends an email and hopes for the best. She has been fortunate in working with scientists willing to listen to her ideas:

> *The relationships built up are as important to me as the work taking place – and much of the work comes about from many conversations. Conversations about everything from the quality of moonlight, figuring out how to harness lightning, send silence into space, and isotope a grain of sand. Lately, staying up 'til 6am with eminent astronomers at base station, bombarding them with strange questions ... learning about lyman alpha lines, the early universe pictured as distant fog and candle light, expanding dusty space and the possible end of the universe* (Paterson interviewed by Moss, 2010).

Several interviewees emphasized forums as a place for relationship building. Smithsonian staff expressed a desire for greater exchange of ideas through both informal and formal networking opportunities, mentioning idea clinics, symposia and wine tasting get-togethers. A few interviewees recommended more structured sabbatical, advanced research or professional enrichment programs that encouraged interdisciplinary exchange. The Center for Advanced Studies in the Visual Arts (CASVA), National Gallery of Art, was given as one example. An internal interviewee ruminated on the need for a structured program and space to be creative and work creatively with others:

> *I think a center would really thrive if it provided people with a way to get away from their day-to-day responsibilities and to get to know one another and to actually be creative – not just report on creativity, or on the creative things they did elsewhere. To be creative one has to have the ability to synthesize ideas and be sequestered from their day-to-day responsibilities. What would be really nifty about setting this up is if staff could interact as fellows with external people. It would be a way of cultivating excellence among curators who have already been hired for their skills. In turn, you allow your museums to be enriched by the experience that these people have had getting to know folks from around the world potentially and people in other disciplines.*

Similarly, an external interviewee said that one of the struggles in culture change is providing interaction and the opportunity to get to know each other in a not high-stakes environment. One interviewee from an external museum reinforced the importance of having trust and reliability in place to forge a successful partnership. Due to limits on time and resources, people want to collaborate with people they trust to have intellectual integrity and a similar work ethic. Otherwise, the collaboration is deemed too risky. Developing trust and mutual respect also contributes to communication across different disciplinary "languages":

> *When you are with someone from a completely different discipline whom you respect, you're forced to explain your own ideas in a more fundamental, simple way that you are not often encouraged to do when you're in your own disciplinary environment with peers who use the same jargon as you. [Experts] have to explain what they often take for granted. Therefore, both artists and scientists who work with us often find it frightening and refreshing.*

Use boundary spanners

An external interviewee explained that if you are pulling people together who don't naturally spend a lot of time together, you need a bit of glue in the middle:

> *One needs someone with enough vocabulary of one group of experts to put them at ease, but enough jargon from the other group of experts. Just knowing the different needs of the artists and scientists involved in the project, be it work habits, language or facilities, is helpful. Sometimes it's very simple pragmatic things that seem to get in the way of collaborative work because they're just different cultures of how to work. So you need somebody to think about the human-to-human interaction of these projects and how to make it clear that there are some rewards that make sense within the world of science but also within the world of art. That takes genuine work.*

Be cognizant of negative metaphors

It is possible to challenge disciplinary epistemology while being respectful of boundaries, disciplines and areas of expertise. The phrase "breaking down divisions between disciplines" and the dismantling that it implies is not necessarily helpful, advised one interviewee. Instead, the following metaphoric phrases were suggested for consideration as alternatives:

- Making the borders between disciplinary cultures more porous
- Transcending divides
- Gliding across separations
- Stretching to embrace other perspectives

Use innovative means to overcome the language barrier

The study team visited a media imaging laboratory that specializes in making complex scientific information intelligible to the public. Its clients come from different disciplines and industry sectors, e.g., medicine. The staff discussed how different disciplines have different cognitive styles and methods. To overcome the challenges of communicating across disciplinary languages and comfort levels they use computerized “mind-mapping” visualization techniques to determine subject matter, “who cares” about it, how it intersects with the American cultural landscape, and then, where the strong story areas are.

Several interviewees in the previous study that looked at interdisciplinary science research spoke of the criticality of devoting enough time and resources to “translational work” – bridging the differences in communications, methodologies, standards, philosophical context, etc. of different disciplines. The University of Washington’s Urban Ecology IGERT[16] program uses a variety of methods for interdisciplinary training and skill building, which it describes as the “mental effort necessary to rigorously explore interdisciplinary topics while also addressing the interpersonal dynamics intrinsic in groups.” One method it uses is to hire a professional group dynamics facilitator to conduct workshops – attended simultaneously by faculty, students and staff – on group management skills, interpersonal communication strategies and creative problem solving. Three key attributes are identified that greatly increase the chances of a successful interdisciplinary collaboration:

- *Appreciative inquiry* that counteracts academia’s culture of cross-disciplinary criticism
- A *commitment to curiosity* about different disciplines’ contributions to an interdisciplinary endeavor that is a prerequisite to understanding and appreciating different world views; and
- *Flexibility* regarding logistical issues such as short- and long-term structural arrangements, group dynamics, and variable schedules (Graybill, et al., 2006).

Ensure structure and incentive for collaboration

Several people mentioned the need for a structure to be in place so that curators, scientists and other staff know what each other is doing. An internal interviewee suggested the creation of pan-Institutional advisory committees to advise curators and

16 Integrative Graduate Education and Research Traineeship, National Science Foundation’s flagship interdisciplinary training program for U.S. PhD science and engineering candidates. http://www.igert.org/

researchers in the formative stages of exhibition and program research in order to draw out links across the units.

A common concern was that reward systems do not match up with collaborative goals. An external museum interviewee emphasized that collaboration must be supported as part of people's daily work and not an additional responsibility: "We are having to structure [collaboration] into people's job descriptions so that it is not 'having to do everything you did before plus collaborate with another discipline.'"

It takes visionary leaders, said an internal interviewee, who see the potential of HAC + Science interplay and who nourish a culture of curiosity, creativity and sharing. They lead from the top and allow growth from the bottom.

External interviewees talked about engendering an environment where it is okay to take risks and make mistakes:

> *With any language you have to get over the fear of looking stupid when you do these things."Right, you are going to make advances in physics by painting? Sure you are! Get back in the lab where you belong"... I do think that's a big fear in crossing over – that you are going to look ridiculous. But scientists also know that you have to make mistakes to succeed, that you have to be willing to look silly. As artists know, you've got to take chances and you're going to get things wrong… it's self indulgent, nobody gets it… or it's brilliant.*
>
> *You could look silly sending an artist to STRI… why are you doing that? And you say, "We don't know, it might be a bust, but if we get the right person, the potential for payoff is terrific."Every now and then you've got to try these high-risk experiments. But, you are a big institution; the tendency is to be cautious, why stick your neck out….*

Defining Success

How does one define a successful interdisciplinary collaboration? Based on the interviews and review of the literature for this report, and as illustrated in the wide-ranging list of potential benefits listed above, success comes in many different shapes and forms and there is no one formula for testing what is successful. As one external interviewee elaborated:

> *Sometimes success is a big public understanding of scientific issues for the first time because of the interpretation of a work of an artist. If that is what the project set out to do and that is what the artists and scientists involved are comfortable with, then that seems to me to be a success. But, equally, sometimes it will be a work of art that the scientist finds completely baffling or even disingenuous and that the public isn't quite sure about but that actually feels as though it's really touching on something important, which takes you off in a completely different direction … Then there's the kind of X factor. There's something about the project that you can't quite pin down, but there is something that feels as though it's genuinely extraordinary. Sometimes it has to do with the process, the journey of the people involved.*

An internal interviewee struck a similar note: "This question of how we evaluate success must be carefully considered. Are the people who are participating in the program enjoying it? Do they find it rewarding? I think that is very valuable." One external interviewee pointed to three ingredients that go into success: artistic significance and integrity; scientific validity and a way of stretching what science knows or the questions that science asks; and some sort of public impact or public involvement.

On the third point, another external interviewee noted that, theoretically, interdisciplinary research and projects across HAC + Science are very interesting and can be very exciting to work on, but if one's mandate is serving a public audience, it is necessary to have some research or evaluation piece built in to determine "what this means for the people who walk through the door." Certainly determining the benefits or outcomes for museum visitors of interdisciplinary collaboration across HAC + Science is a challenging new ground for research and testing.

External interviewees suggested that the extent to which museums are willing to tackle the big "socio-scientific" issues in society today – not as one way transmitters of ideas but as places of dialogue and discussion – will determine their relevance and value and hence success. To that end, the Smithsonian has signaled its commitment to engage around the Four Grand Challenges of its new Strategic Plan, focusing on collaboration across HAC + Science. External interviewees for this study felt that the Smithsonian can help catalyze the movement of artists and scientists working together. With its unparalleled combination of diverse disciplinary expertise, store of data in its legacy collections, and platforms to engage the public, the Institution is uniquely situated to bring the two domains of knowledge together, uncovering connections and relationships not yet imagined.

As artist Todd Siler describes,

> *... to see beyond the categorization and compartmentalization of our acts of creating and our creations … to continually transform the meanings and uses of things and ideas by connecting and applying them in new contexts and situations (Todd Siler website).*

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Appendix B Interviewees' Organizations

Smithsonian Units and Forums

Center for Folklife and Cultural Heritage

Cooper-Hewitt, National Design Museum

Jerome and Dorothy Lemelson Center for the Study of Invention and Innovation

Lunder Conservation Center

National Air and Space Museum

National Museum of African Art

National Museum of American History

National Museum of Natural History

National Portrait Gallery

Office of the Under Secretary for History, Art and Culture

Smithsonian American Art Museum and Renwick Gallery

Smithsonian Forum on Material Culture

External Organizations

Carnegie Museum of Art

Carnegie Museum of Natural History

Embassy of Australia

National Academy of Sciences, Cultural Programs

National Aeronautics and Space Administration, Jet Propulsion Laboratory

Ontario College of Art and Design

University of Maryland Baltimore County, Imaging Research Center

State University of New York at Binghamton

Wellcome Collection, Wellcome Trust, UK

Lectures, presentations, artist talks, tours, conferences and studio visits

Congress of Scholars, lecture

Forum on Material Culture, panel presentations

National Museum of Natural History, lecture

National Academy of Sciences, Cultural Programs, artist talk

National Gallery of Art, conservation tour

Ontario College of Art and Design, conference

Science Conservation Biology Institute, tour

Smithsonian Idea Fairs, presentations

University of Maryland Baltimore County, Imaging Research Center, studio visit

Appendix C: Management Strategies for Facilitating Interdisciplinary Collaboration

(Abridged excerpts from *Addressing Complexity: Fostering Collaboration and Interdisciplinary Science Research at the Smithsonian*. Volume II: Detailed Findings. July 2009. http://www.si.edu/opanda/docs/AdmnMgmt/IDRv2.Findings.Final.090717.pdf)

Management

While management issues did not come up often, some interviewees, principally external ones who had run or participated in organizational change involving collaborative and interdisciplinary research (IDR), were very conscious of the critical role that managers play, and they shared their experiences. As one interviewee said, "part of it is just a decision about why you have the program in the first place, then deciding how to manage it so that you achieve that." Key themes to emerge from the interviews were treating management as a distinct function requiring special abilities and skills, the importance of investing in qualified managers, choosing the right strategies to accomplish organizational change involving scientists, emphasizing boundary spanning, creating a positive work climate that promotes and sustains this type of research, and holding the organization accountable for desired results.

Investing in Qualified Managers

A number of interviewees commented that management at the Smithsonian was sometimes treated as a collateral duty and did not take into account the distinctive features of collaboration and IDR. In contrast, strong management has to be a specific focus of any effort to move forward with a major initiative that emphasizes collaboration and IDR. That managing collaboration and IDR is different from traditional management was a clear refrain. Often the organization didn't recognize that and assigned people to be managers who were destined to fail. Said one interviewee,—"that unique kind of talent, it is rare. And the effort at IDR can fail very, very easily when they just pick the senior scholar [to manage it]." In recognition of this fact, one interviewee's university was developing a Collaborative Leadership Series—

> *assuming that we need to prepare people for competencies they weren't prepared for in the past. Those [competencies] include conflict resolution, team building, knowing intellectual property law in terms of how collaboration works, and a host of other things that are not what is ordinarily taught … Often there is a mentoring committee set up that is interdisciplinary, again because somebody comes in in one field, but their appointment is in another department. You can't just stick them*

somewhere. The junior faculty really have to be followed and mentored. There has to be a kind of sophistication and commitment on the part of the senior faculty.

An interviewee recommended looking for scientists to be managers who had made their mark and were toward the end of their research careers. They don't have conflicts of interest between building their reputation as a researcher and spending time on management, and they are better able to cope with the time-consuming paperwork, meetings, marketing, etc.

It's not hiring that big guy in the field, although you might want him on your team. It's hiring the senior, a little bit past prime in the sense of having to prove him or herself, eager to mentor more junior colleagues, to coalesce a set of talents, as opposed to "three big tenors," and each of them sings really well. [That] doesn't work because the work of team building, of building a collaborative organization, is fundamentally unlike most academic careers, which are solo or which are strongly hierarchical in a lab setting.

Saxberg and Newell (n.d.) similarly pointed out the continuous internal conflict between the demands of management and of research in IDR. Whereas scientists focus on retaining credibility and respect in their disciplines and staying abreast of progress in their fields, managers must move more toward being a generalist than a specialist and being more oriented toward application. They "can lead by stepping down from the top and being a facilitator to enable the team to realize its potential."

Bozeman and Boardman (2003), in describing management of multipurpose, multidiscipline university research centers (MMURC), reported that the smoothest running ones were those that clearly delineated between the managerial tasks of the center director and an administrative director. The center director focused on issues related to research direction, linkages, and procurement of funds, while the administrative director saw to tasks that did not require scientific knowledge and expertise, such as budgets, NSF reporting requirements, and logistics for events like workshops and conferences. In addition, hiring a research general manager with, for example, a MBA or comparable degree, can facilitate interdisciplinary research activity by overseeing coordination and accountability of researchers, said the authors. If an administrator is dedicated to coordinating scientists from disparate fields, he or she is more likely to recognize emergent problems and quickly take remedial steps.

Advisors can also be helpful—said a Smithsonian scientist, "When you've got everything set up, you can pull these guys in with great expertise for targeted, focused episodes, and take advantage of their skills and interest."

Other points made by interviewees included:

- “[H]ire the best people you can, you do everything you can to support them, then you just get out of the way if you are an administrator. If those researchers are good and productive and well-regarded in their field, they will do collaborative kinds of things.”

- “The glue people. You need the people who can see across and reinterpret” and who are able to speak with both scientists and stakeholders. Another type of glue person is the boundary spanner or broker, discussed below.

- Management is a full-time job, not a collateral duty—or, as one interviewee put it, “100 percent managing the center. It’s not the leadership, not the vision, but making sure that everybody gets together to do what’s right.” Said another, “We have learned that you need a dedicated position to make it easier for everybody to do things and to make sure they do what they are supposed to, rather than having scientists manage, because most of the time they can’t manage well.” Bozeman and Boardman (2003) also spoke to this issue, recommending that organizations should strive to “minimize double duty.”

Decision Making

A number of interviewees commented on the nature of decision making at the Smithsonian. A major driver of decisions is the need for consensus and equity, which can also be interpreted as avoidance of conflict. For example, when new funds become available, they tend to be divided across the units, with the resulting amounts too small to have much impact. Committees are often set up to recommend decisions, and the goal of consensus leads to results that are “lowest common denominator.” Interviewees also noted a lack of decision-making guidance in the form of priorities or cost-benefit analysis. In their study of MMURCs, Bozeman and Boardman (2003) found a variety of approaches to decision making, but found the description by one center director to be fairly typical—

> *We make decisions by our executive committee, setting out with our strategic plan. I try not to do this [strategic planning and decision making] all myself. The executive committee sets out criteria that suggest contributions and potential contributions not only in research, but also education and outreach. Then we solicit proposals for not only research but also education and outreach.*

One MMURC director talked about how he allocates research funds:

> *I want to empower the people that run the programmatic areas and trust them in terms of making intellectual decisions … we have an all-day meeting to see what will be funded … projects [using center funds] are funded to be in line with the strategic plan that is devised by the leaders of the programmatic areas. So we try to*

create some integration with center research goals, even if an individual project is just a professor with a student.

Another director described a slightly different process:

> *[With this input] we develop a final executive proposal. This is top down. We decide what problems we need to resolve … Once the road map is defined, the research proposals must adhere to the road map. If a proposal deviates too far from the road map, I turn it down. I feel strongly that we have to do this. … The road map is decided on by all … we do not accept a dictatorial approach. That is one reason we have an annual retreat.*

IDR Skill Building

> *Graduate schools and centers are still looking for the right ways to train a new generation of interdisciplinary scientists who can both speak the language of multiple fields and maintain enough expertise to take on cutting-edge problems (Vastag, 2008).*

> *As a result of cognitive, subject matter and normative differences, scientists of different disciplines may have difficulty agreeing upon appropriate sets of goals, an appropriate framework for pursuing those goals, and an appropriate evaluative framework (Epton, et al., 1983).*

An issue raised by some interviewees was how to bridge the differences in communications, methodologies, standards, philosophical context, etc. of different disciplines. "How to work together, that's huge, because the [traditional] model for training a scientist is self-sufficiency," said one person. A university IDR center director explained,

> *[It is] like learning to speak each other's language or even developing the self-awareness to know what you don't know—I am the outsider and how do they behave here. And not personalizing it, but seeing it as a sociological problem, and so on—developing greater facility with doing the translational work, but also in terms of setting methodological standards or units of analysis or all kinds of things like that.*

Interviewees provided some very concrete examples of the communication and cultural problems that can arise in interdisciplinary projects. An interviewee spoke of one project where they made a very conscious effort to eliminate disciplinary niches and use very broad labels that would encompass scientists in many fields, using terms like "global connections," "frontiers of science," and "discoveries." The project team soon learned that even broad terms fell short. The social scientists said of the word "discovery,"

> *No, it doesn't apply to us. We do not operate this way; we do not operate with the term "discovery." Someone's discovery is another person's daily life. I go to the communities, I stay with them, I talk to people. What is my discovery? The discovery that they do something this way, or talk about something another way? That's not a discovery. The very idea of new or unknown or original, in this context, is very different from when you go, say, under the ice or to the highest mountain. We don't discover new species, we don't discover new languages or new practices—we are trying to understand people's lives; this is really different.*

Another interviewee described her experience with crossing disciplines:

> *We have one engineer, and sometimes we [natural scientists] just look at each other and say, "They are different. Their training is completely different … there's a different way to use evidence." … Our doctorate is not in science facts, it's in philosophy. We spend all of our professional training learning how to speak about uncertainty and learning about the formalities of what you can and can't prove. Engineers don't learn any of that. They learn how to operate the slide rule and get the number 42. They think, "I have calculated it based on the set standards in my field, and there is an answer … [when natural scientists are asked for an answer], we would say the stomach contents are consistent with them having eaten a mouse. And then someone asks, 'does that mean they ate a mouse?' Well, we don't know, but it's consistent with it.*

A younger scientist at the Smithsonian talked about the lack of preparation he got for the non-research aspects of IDR:

> *From an academic perspective we're not well-trained to do conservation. I've been in biology departments my whole life, but when you come out of school, you don't know how to do conservation policy. You don't know how to raise funding. You look at one of the most critically limiting factors for conservation scientists today, it's conservation funding. Those people who are effective at raising money tend to be effective at conservation. You start looking at some of these other conservation actions that involve capacity building or policy making or education—stuff that seems to be the realm of someone else's discipline, not a research scientist's discipline.*

Another interviewee discussed the value of some kind of training on collaboration that involves different disciplines, since a culture of scientific cooperation does not currently exist at the Smithsonian and such cultural changes do not arise spontaneously:

Collaboration and interdisciplinarity are not innate. They have to be learned, much as we learn to walk, write, or type on the computer—and often we learn the very hard way. We are not trained [to collaborate], except for some programs. (I would say that geography is one of the few.) Many disciplinary educational programs do not train people in collaboration and interdisciplinary work.

The difficulty the Smithsonian has with reviewing interdisciplinary proposals and performance came up frequently, as noted. To deal with this issue, the NSF has taken a formal approach:

We do [interdisciplinary review] panel orientations and that sort of thing, and really emphasize the importance of wearing multiple hats and not being parochial … [For site visits] we bring maybe 8-10 external reviewers and a few people from NSF, and maybe one from anthropology, and maybe someone in philosophy, and the rest may be engineers. We spend time before they do that site visit [to get to know each other] ... Once you get to know people and learn your strengths and weaknesses and what are your concerns about the proposal, then you are kind of leveled off. You may be speaking different languages, but you are talking about the same thing.

Restructuring the Traditional Academic Model

Over the past half century, universities, research centers, and pharmaceutical companies have increased in number and become more bureaucratic and fragmented, with huge departments constructed like silos. As a result, many scientists find it difficult to communicate across fields (Hollingsworth, Muller, and Hollingsworth, 2008). Following this system, graduate education tends to direct graduate students into discipline-specific academic departments, where they are judged and influenced by faculty members trained in an earlier day when cutting-edge research meant working individually or in small groups on highly specialized, narrow research areas. While, as noted throughout this report, there has been movement away from this model, most research at universities continues to be structured along departmental lines, and faculty often regard interdisciplinary programs and centers more as places for pre-professional training than places where the next generation of researchers is cultivated. In addition, departmental culture tends to place value on stability and to have a short-term outlook that is driven by near-term considerations of budgets and funding. Different departments are often sealed off from one another, and often regard each other as competitors for funds and central administration attention. The departmental structure of Smithsonian science units reflects the traditional academic model, and several Institution interviewees cited this fragmented structure as a source of miscommunication, lags in communication, difficulties in accessing information, inter-unit (and interdepartmental) competition, and lack of interchange and feedback among Smithsonian scientists and between Smithsonian scientists and peers at other organizations.

A number of universities, such as Minnesota, Washington, Wisconsin, and North Carolina, have taken active measures to restructure their academic recruitment, hiring, and promotional policies and practices to facilitate interdisciplinary work. Several have created offices tasked with breaking down departmental boundaries, improving intra-university communication, and promoting collaboration within and outside the university. A group of ten research universities led by the University of Minnesota's Office of Interdisciplinary Initiatives make up the Consortium on Fostering Interdisciplinary Inquiry, which has developed a self-assessment tool to identify problems and share best practices. In these cases, frequent face-to-face communication among researchers across disciplinary boundaries is often cited as a key to success.

The literature discussed several informal structures that lead to greater knowledge sharing, including networks/communities of practice, expanded peer groups, and greater openness and problem broadcasting. Researchers who divide their time between traditional disciplinary departments and IDR programs often formed "networks of practice" that yielded important outputs that went beyond publications in academic journals, for example, Congressional testimony, public policy initiatives, mass-media placements, and alternative journal publications (National Academy of Science, 2004). Organizations that supported "communities of practice"—groups that are informally bound by shared expertise and passion for a joint enterprise—found that essential information was shared more readily across organizational units (Ackerman, et al., 2003). Sharp (n.d.) called for a redefinition of professional peer groups to include larger networks of people pursuing work in related or potentially related fields. One mechanism to achieve this was to involve an expanded peer group in annual performance evaluations and in review of proposed new areas of research (Sharp, n.d.). In an interview with Martha Lagace, Karim R. Lakhani spoke about drawing on the practice used in open source software development of "broadcasting problems" to explore a model for encouraging large-scale scientific problem solving to "open up your problem to other people in a systematic way. A problem may reside in one domain of expertise and the solution may reside in another" (Lagace, 2006). Lakhani, based on a study he conducted with other researchers (Lakhani, et al., 2007), found that solutions most often came from outsiders who reconceptualized the problem. The challenge was to find innovative ways to exploit open source principles and at the same time minimize the risk of loss of intellectual property.

Some examples of recent efforts at the Smithsonian to forge stronger connections provided by interviewees included the following:

- The proposal NMNH submitted to NSF for a National Center for Synthesis in Biological Evolution included a range of "synthesis activities" to address fragmentation of knowledge, including working groups, research fellows, a full-time resident informatics team, annual meetings and workshops, electronic tools and research resources, a strong web presence, and a significant public and professional outreach component (Erwin, 2004).

- One Smithsonian scientist created an international listserv to facilitate intellectual exchange; what began with just 10 people grew to 620 over seven years, and has led to joint research and publications.

- A Smithsonian biologist is actively involved with the Society of Conservation Biology, a professional association of 3,000 members who include social scientists as well as researchers in various areas of the natural sciences.

- Recently three departments agreed to share a post-doc; this joint appointment facilitated the flow of communication among scientists in these departments and fostered joint publications.

- Smithsonian Tropical Research Institute (STRI) has appointed two knowledgeable liaisons—one located in Washington, DC and the other in Panama—to enhance exchanges among researchers and external partners.

- Smithsonian Environmental Research Center (SERC) is integrally engaged in a diverse array of research and advisory networks and was lauded in a 2005 external review for its broad-scale approaches to environmental issues and collaboration among scientists who are widely dispersed geographically.

- Publications such as the *Atoll Research Bulletin* (now available digitally), *Inside Smithsonian Research,* and *Listings of Fellowships* are useful sources of information for those seeking a sense of research developments across disciplines and departments, as well as opportunities to work together.

- Presentations and discussions hosted by the Congress of Scholars and Senate of Scientists are useful means of sharing information and promoting discussions.

- Looking to the outside for new ideas—"we've organized a number of broad workshops using people from the broad community, not just people we fund. Those are very useful to find out what is going on and get new ideas in certain areas."

Dedicated Boundary Spanners

A number of interviewees thought the Smithsonian needed to go beyond those individually-initiated efforts. Encouraging work across different domains could better be accomplished through dedicated boundary spanning or knowledge brokering mechanisms and personnel. Boundary spanners in research organizations typically operate by facilitating communications and exchanges among staff internally and with people in other organizations. In some parts of the government, boundary spanners are well-established. For example, the National Security Council has staff charged with gathering information from agencies and organizations such as the State Department, multinational corporations, think tanks, and foreign governments, and transmitting it to various agencies for which it may have relevance. Several high-profile research organizations, both public and private, maintain boundary spanner positions. One is the California Institute for Quantitative Biosciences (QB3), a cooperative effort among three campuses of the University of California and private industry; it employs four former research scientists whose sole responsibility is to broker internal and external connections.

The literature points out the importance of selecting the right people for this role:

- Boundary spanners need to be deeply knowledgeable about both their organization's internal environments and the complexities of the external environment in which it operates. This may involve reading and traveling widely to keep in touch with advances in a number of fields.

- They need to possess expertise in gathering, filtering, interpreting, and transmitting information in written and verbal form, so that it gets to its intended audiences in a usable manner that leads to the desired result.

- They need to be self-assured, flexible, curious, supportive, discreet, and likable; information is less likely to be heeded if transmitted by personnel who are perceived to be biased, untrustworthy, or unreliable.

An interviewee who was a boundary spanner in a government research facility summed up what it takes to be an effective boundary spanner—"Generally, they have been employed as researchers and have developed extensive networks. A key attribute that aligns with extensive professional experience is trustworthiness. It embodies legitimacy, reliability, acculturation, and maturity."

Boundary Spanners at the Smithsonian

That same interviewee added that

> *The Smithsonian needs a different way of communicating its research, or its importance will inevitably lessen. Arguably, a critical communication element is knowledge brokering. In the absence of two-way channels that receive and transmit information vertically and horizontally, externally and internally, the Smithsonian may end up as a bunch of uncoordinated subsystems that do not draw upon its vast resources to help solve serious societal problems that are confronting us today.*

Periodically, the Smithsonian has attempted to use boundary spanners to facilitate collaboration. In almost all cases, however, it did not establish dedicated boundary-spanning positions; rather, that task was assigned as collateral duty, which decreased the effectiveness of the effort. Further, achieving buy-in was difficult; to many researchers at the Smithsonian, the boundary-spanning role suggests the kind of top-down direction that is anathema.

The Institution has had more success with informal boundary spanners. One interviewee recalled that former Secretary Dillon Ripley played a useful knowledge-brokering role. He frequently visited the units and asked scientists about their research, sometimes suggesting connections and cross pollinations, and gained a reputation as a champion of collaboration. The interviewee noted that Ripley "had an enthusiasm for knowledge and [an appreciation for] diverse perspectives," and suggested that Secretary Clough should follow his example and talk directly to scientists.

Several Smithsonian interviewees also mentioned that Scott Miller, currently Senior Program Officer in the OUSS, and former STRI Director and Acting Under Secretary for Science Ira Rubinoff have been effective *de facto* information brokers. At the same time, interviewees pointed out that the Smithsonian has never regarded boundary spanning as a critical organizational strategy.

Some interviewees who had had no experience with boundary spanners were unsure how these would benefit them. Some thought that the concept of boundary spanners appeared useful in the abstract, but expressed doubts about whether a person—or even several people—could master the job at the Smithsonian in the face of organizational impediments such as funding constraints, the culture of autonomy, an inflexible bureaucracy, distrust of the central administration, competitiveness among units, and deep suspicion of anything that promises to create more paperwork. One person suggested that the Congress of Scholars and Senate of Scientists could be adequate boundary-spanning mechanisms, but acknowledged that their workings could be improved.

Creating a Positive Work Climate

> *Basically [you need to find] positive ways of breaking down barriers and making it possible to do these things and creating the situations where people will.*
>
> *In some ways the biggest reward for an investment [of time] is helping the overall atmosphere of the place, being more encouraging and just to strike more sparks through having more people with more diverse expertise and outgoing, intellectually willing to be engaged with others. Give them reasons to talk to one another, and hire people who are inclined to do so.*

What did interviewees say about what constitutes a congenial and personally satisfying work climate, one that fosters and supports collaboration and IDR? Obvious points were financial rewards, good salaries, and potential for promotion. This section looks at some of the more intangible factors that came up, such as academic freedom, compelling research opportunities, the personal satisfaction of teaching and mentoring younger researchers, the professional development that occurs from working with interesting and knowledgeable colleagues including post-docs and other non-employee researchers, and having a voice in planning and programming decisions.

- ***Academic freedom.*** The importance of academic freedom ranked high on the list of factors that make up a good work environment.
- ***Interesting research opportunities.*** Many interviewees emphasized the role of interesting research opportunities and agreed that compelling research questions can be a strong motivator to bring researchers on board with new initiatives. Here, too, post-docs were seen as a foremost driver in the development of innovative and exciting research projects.
- ***Meeting people on their own "ground."*** An interviewee from a university IDR center talked about the need to meet students where they were:

> *My team thought we ought to put something on the Web … with the force of the '20s-something view of science, which is rather different than the '50s-something group of scientists that I represent … It speaks to a wider, more informal side of what my research group does than my [formal university] site.*

- ***Opportunities for input.*** Interviewees wanted to be involved in decisions that affected their work, such as the formulation of directions and programs. To a person, interviewees involved in moving an organization in a new direction talked about the importance of a bottom-up approach—providing scientists the chance to give input—although with the top having final control. This point went hand-in-hand with not forcing scientists to do something—"it is that kind of more encouraged from the top, but let the juices flow from the bottom. That is more likely to lead to much more successful collaboration."

- ***Professional development.*** Interviewees wanted not only opportunities to stay abreast in their own areas of expertise, but also to expand their knowledge of other fields and ways of doing research. Having access to new and varied people, particularly post-docs, emerged as critical in this regard. "That's where the ideas come from—talking with people about what you are doing."

- ***Rewards.*** Funding for research projects emerged as the key incentive for collaboration and IDR. However, interviewees spoke of other rewards that contributed to a positive work climate, such as awards for exceptional performance, dissemination of important research results to peers and the public, nominations of scientific staff for external rewards, sabbaticals, and priority in getting post-docs. One study found that at NSF centers, researchers reported publications as a less important benefit than the intellectual change they were experiencing (Vastag, 2008 with reference to a study by Rhoten [2003]).

- ***Opportunities to do things that are personally satisfying.*** For some scientists, being able to educate younger scientists and see them thrive on their own in part because of the researchers' contributions was very important. Similarly, the study team noted a number of researchers who initiated "side" projects on their own time—interdisciplinary coordinating groups being a common one—to meet needs in areas related to their research and issues they were addressing. Unfortunately, many noted that a lack of support and formal recognition made these efforts, even if worthwhile, very difficult to sustain alongside their regular workloads.

- ***Accommodating the realities of IDR.*** As noted, many interviewees saw the Smithsonian as more of an obstacle to collaboration and IDR than a facilitator. To a large extent its systems were not designed to accommodate how collaboration and IDR are practiced. One university, recognizing this, took a major step to better align itself—

we passed policies just this last year to allow dissertations and theses to have multiple authors because … there will also be integrative works … And so we've teased out the part of the dissertation, where you must make an original contribution to knowledge, but we've stopped conflating it with an individual contribution.

Accountability

Everything has to be evaluated all the time—is this going in the right direction?

Interviewees spoke of two levels of accountability. One took place at the individual level, and is discussed in the workforce section. The other, discussed here, occurred at the unit, department, program, and project levels.

Many interviewees noted the importance of regular assessments of the programs and projects within them because "Things can get stale or can no longer have the driving need they used to have." There were different levels of assessment, as one external interviewee noted. While annual reviews provided "familiarity with the program," deeper reviews were needed at longer intervals to "judge the value" and determine if changes were needed. The "very substantial reviews" performed by external committees of scientists could result in a recommendation to "end programs."

Assessment processes sometimes involved bringing operational managers together to discuss initiatives, confront issues, and deal with program needs. Another approach was periodically to convene a scientific advisory committee, comprised of the directors of the host institutions and their scientists and colleagues. Universities and research organizations, however, typically used external reviewers. The National Research Council, in its 2003 review, *Funding Smithsonian Scientific Research,* recommended that "Regular in-depth reviews by external advisory committees are essential for maintaining the health, vitality, and scientific excellence of the Smithsonian Institution."

An external interviewee talked about the importance of the five-year reviews at his agency, "where we ensure the relevance of our research, its quality, and its impact." Someone from another agency commented on one role of its full reviews, which also occurred every five years:

> *If a problem [on which we're working] has been solved or is no longer an issue, then we may need to start on a different project with totally different objectives. If it's something that's longer term in nature, it can be that we just need to continue it or expand it or take it into a slightly different direction. All those different possibilities are there because it's research, and you can't really predict the future and where you're going to go, what new technological developments may occur.*

Some Smithsonian scientists believed that that type of review was missing at the Institution— "there have been sort of straight allocations [of funds] and not much review about whether programs work or if they don't. At some point, hopefully, we will have a structure where we can say where our really successful programs are, working with our strategic plans and so on." One of the reasons the Smithsonian-wide science strategic

plan had gone nowhere, thought a scientist, was that the Smithsonian "never collectively went back to measure ourselves, so what's our progress?" Another scientist explained why there is resistance to that approach—"resources are short, and people sort of cling on to that [program] … If you allow change to happen, you don't really know if you will come out the other end … There is kind of this tension between moving on to logically good and strategic goals and clinging on to the status quo because of the budget."
An interviewee from an external agency talked about the delicate balance between good oversight and micro-management:

> *[The field] is still going to be answerable to a review committee every three years, and they are still going to have to provide us with annual progress reports, at which time we can say, 'Whoa, you are really getting off target here, we need to talk about it.' Or, if they want to do something radically different, they need to check with us first … but, we're not micromanaging.*

Strategies to Facilitate Organizational Change

> *Scientists are stubborn; they want to do what they want to do; they want to study their area of expertise.*

Many of the external interviewees with whom the study team spoke had been involved in major organizational changes, as their organizations attempted to align with the nature of science today and to refocus around critical issues. All noted the complexity of moving an organization away from traditional ways of doing business embedded in organizational and scientific culture. They described strategies that they used to implement new initiatives at whose core was collaboration and IDR. The following strategies suggested by interviewees are not presented in any particular order, so implications of effectiveness, ease of application, etc. should not be drawn.

Head off Resistance; Get Buy-in

Organizational change, even in times of crisis, always meets with resistance, and the culture within the scientific community, as expressed by interviewees, exacerbates that natural tendency. Many interviewees emphasized that scientists strongly oppose being told what to do; any effort at change involving scientists will have to deal with a strong belief in academic freedom. Many of the strategies described by interviewees and found in the literature addressed ways to minimize resistance and get buy-in while moving forward with change.

Use a mix of top-down and bottom-up

Providing scientists opportunities for input, ranging from large meetings to small working groups, was a common strategy to get buy-in. In some cases of organizational change described by interviewees, the scientists were asked for input and ideas, but in other cases they were given a role in defining goals and objectives, developing strategic plans, designing programs and initiatives, and creating action plans. This strategy offered two benefits—it helped overcome the likely resistance of researchers, and it led to the emergence of exciting ideas. According to Metzger and Zare (1999), "The best ideas often come from the bottom up: that is, from researchers themselves; and some of the most spectacular ideas come from young researchers who are newly tenured or untenured."

A Federal science administrator described the process whereby his agency developed its strategic plan internally and got scientists to have confidence in it—"the fact is that they own the strategy … It required the scientists to take risks, to get outside their comfort zone. So culturally they had to have confidence we were going in that direction, [and they did] by seeing the relevance of the strategy, [and] the fact that it's filling gaps that no one else is doing right now effectively." Through many meetings and discussions, he convinced the scientists that a science strategic plan was important, vetted the strategy through them, and committed the agency to it.

Even while emphasizing the inadvisability of forcing collaboration and IDR, some interviewees acknowledged that the top must play a strong role and take responsibility for final decisions. It's a matter of finding the right balance.

> *You need the real commitment from the top, but that commitment from the top must not be overly prescriptive. So it's not a matter of the top dictating, and the people down in the trenches just following orders. The top needs to establish the commitment that, yes, we really mean this, and when push comes to shove, we're going to back this, and we're going to make it so that those silo barriers don't get in the way. But having said that, now it's up to you folks in the trenches who are really going to be expending the blood, sweat, and tears on this. Now it's up to you to come up with the ideas and shape this thing and really make it work. That's the combination that you want.*

At one organization, senior leadership defined the overall plan and direction, but then involved the various units in how best to implement it.

> *We [the leadership] really tried to say what should this program be like, and we came up with a plan. Then we went and worked with each of the labs and centers as to what their role might be, and they participated in terms of developing the plan further in a whole variety of areas, coming up with actual research and*

implementation plans from the strategy … We broke down the silos and stovepipes, so to speak, by trading this sort of holistic view of something that everybody had some role in.

A few interviewees spoke to a longstanding practice at the Smithsonian that has scuttled many initiatives—reliance on consensus decision making, which goes on endlessly because everyone wants a piece of the pie. Instead, leadership must be prepared to make the hard decisions in timely manner. Another feature of decision making that some Smithsonian interviewees decried was the endless chain of approvals before a decision could be made.

Use leaders/influence brokers

Interviewees talked about involving people within the organization whose status, professional and personal, would lead others to join the effort—"You don't need buy-in from everybody. There are different players at different levels in all these units, with different amounts of influence … If they buy in, everyone else will go along with it." In one example, an external interviewee described how his agency used one scientist to sell the initiative to other scientists:

He does a really good job saying [to researchers] that it still works to be a scientist but work with a big team; he argues that it makes you more successful. He sat down and de-bunked all the arguments against this kind of work. He says, when you start out working with the team, you have to define the outcome big enough so that you know you'll have a lot of publications that come out of it, and you decide ahead of time who will be the first author on each type of paper, and everyone else gets the other authorship. He tells them it really works because you actually get more publications out of it.

Akin to using influence brokers is to encourage the "development of an advocacy network among faculty, students, staff, and post-doctoral fellows engaged in interdisciplinary activity (Dubrow, n.d.).

Inspire scientists to become part of something bigger

A number of people emphasized that if you offer scientists compelling research questions or opportunities, couched so that each individual believes in the importance of the endeavor and of being part of something bigger than themselves, they will readily join in. This strategy works well when coupled with incentives, said one interviewee: "If it is made clear to them that we really need people to be working in this region and there are certain rewards that will come to you if you do that, then you can influence them." Another interviewee talked about how the leader or manager should model collaboration by making clear that he or she is not out to grab power or resources, but to act for the good of the venture and organization. The tradition at this manager's organization had been "The doors were closed, the budget was closed, access was difficult, users had to pay for everything." The manager "opened it up and made it transparent." He made clear that he was putting his personal interests aside so "there will be no conflicts. None of this money will be mine. Anything I do I'll bring in money for."

Create win-win situations

In describing a Smithsonian program that had great potential for cross-unit collaboration, one interviewee explained why not many researchers in his unit chose to participate—the program was presented to them as "you can participate if you play by our rules and give us what we ask for." In this case, researchers felt they were being asked to provide a service function and that there was nothing in it for them. What would have worked better, the interviewee said, was to offer something they valued in exchange for their participation, such as the opportunity "to go in the field and do some major collecting for themselves the way they feel they need to do it. That will be a win-win … as opposed to just being handed something and being told, 'Here, we need you to do this.'"

A number of people pointed to funding as a critical motivator. Dubrow (n.d.) discussed two approaches used at the University of Minnesota: "Incentives for cross-college collaboration as part of the budget compact process that guides central investments in the colleges [and] … New investments to foster collaboration across research, training, and graduate education functions." Bozeman and Boardman (2003) suggested using seed money

> *as a way of diffusing competition over center funds. If there is no central decision making, then it is difficult to develop a center research niche or a strategic research portfolio. One of the ways to develop a strategic approach to research but, at the same time, mitigate conflict is to have a set-aside for competitive award, perhaps complete with peer review.*

One caveat about funds for IDR initiatives emerged strongly from Smithsonian interviewees—it should not come out of existing unit or department budgets. This point was acknowledged in the discussion about funding sources in a Smithsonian proposal for a new NMNH center:

> *Funding for such a center was a concern of most of the Chairs, several of whom felt that such a center could reduce funding for departmental activities. Initial funds will have to be provided by SI/NMNH, but we do not view this as a zero-sum game. To be successful the center will need external funding including a combination*

of NSF, NASA, and other targeted grants. We also encourage the museum administration to include Center initiatives among Development activities.

Build in—and on—early successes

A common change strategy that some interviewees and the literature espoused was finding things that could be carried out quickly, easily, and without a lot of resources in the early stages of a new initiative, because "If things turn out successful … people will usually go toward success." Examples were bringing performance evaluation criteria into line with the nature of collaborative and interdisciplinary research, changing a thesis requirement to permit multi-authored theses, and leveraging resources through strategic partnerships.

Build Collaboration and IDR Capacity

As noted earlier, not all organizations have adequate capacity to support collaboration and IDR, be it the culture, evaluation measures, risk acceptance, support for cross-department or unit interaction, etc. Interviewees described a range of ways in which their organizations had to create or strengthen their capacity to foster and sustain collaboration and IDR. Techniques included: developing a system for reviewing IDR proposals and evaluating collaborative and interdisciplinary research; creating common physical spaces and facilities and means of linking scientists to one another; establishing reward systems and incentives, monetary and other; providing better administrative support, tailored to the needs of interdisciplinary science; giving staff flexibility to work at different units; and paying attention to IDR skill building.

Address the Silos and Inadequate Communication

What one scientist hated about the university's bureaucratic structure was that the deans saw their role as sequestering as many resources as they could for their own colleges; they saw other colleges only as competitors and not co-operators. In contrast,

> *For me, the level was wanting the university to be good. You want the university to have a good reputation, to provide the resources to its faculty that allow them to achieve the most that they possibly can. That means that sometimes you have to improvise, realize that while the College of Engineering won this one, somebody else will win it next time. When new positions come up and you are fighting for those positions, you are going to win some and lose some.*

Perhaps one of the most challenging aspects of organizational change at academic-oriented organizations is breaking down the rigid divisions across departments, schools, etc. The universities that have set up IDR centers have, as discussed, used a range of approaches: developing new buildings, labs, and common spaces designed to maximize interaction; allowing researchers to remain within their home camp while also working in the new IDR camp; arranging regular social get-togethers; facilitating the natural inclination of younger researchers to be collaborative and cross boundaries; sharing staff across departments/units through joint appointments and sabbaticals; including collaboration and IDR in performance plans and performance evaluation criteria; providing financial incentives at the individual and unit/department level; establishing varied means of communication and information-sharing across boundaries; forming cross-department/ unit teams, working committees, and advisory groups; and giving priority access to funds for post-docs. The University of Washington developed a board of senior professors which "harnesses university-wide support, serves as a resource for suggestions for potential faculty for the project, and protects team from unsympathetic senior faculty in departments from which the team might want to recruit" (Saxberg and Newell, n.d.).

Bozeman and Boardman (2003) commented that "it is easy enough for participating institutions to become absorbed by local concerns, with the result that the joint concerns of the collaboration do not receive ample attention. It is important to provide multiple communications opportunities among multiple communications media."

The 2002 NAPA study described a number of mechanisms for breaking down silos and bringing diverse scientists together. Aside from the traditional means of lectures and workshops, the following were mentioned: bringing researchers from various disciplines together to create a "coffee table" book for the public that described the organization's diverse science; establishing two principal investigator positions that would receive funding as long as the incumbents worked on cross-organizational projects; and establishing "virtual" organizations based on long-term interdisciplinary themes or initiatives that might attract diverse researchers (National Academy of Administration, 2002).

A number of the comments that emerged from the 2002 survey of Smithsonian biologists focused on the need to fix the very inadequate communications across the Institution. For example, "There is currently no clear SI-facilitated mechanism for interaction, or communication among SI scientists. How can you find out how many scientists are working in the geographic area and what they are doing?" This scientist suggested a centrally facilitated mechanism to improve communications. Other ideas were "periodic get-togethers between selected people from other Bureaus to let loose what they do and why they find it interesting," "workshops and meetings uniting scientists with common research interests," and a listserv—"For the seeds of such initiatives to be planted, we should start with a list, updated annually, of the research projects currently being worked on by SI scientists, and this list should be e-mailed to every scientist."

Eliminate the Culture of Winners and Losers

One interviewee spoke of a highly respected manager at the Smithsonian who got key leaders from across the Institution to sit down and negotiate resource allocation. They would agree who would get their request this year, and who would get it the next year, and so forth. An external interviewee talked about the role a strategic plan plays: "We learned it's not so much the plan … it's the process. By making sure they sit down around the table and discuss what they are trying to do, what's the bigger vision, which direction are we marching [in]." Commenting on these types of approaches, a Smithsonian researcher observed, "We have never done it that way. We are not set up to do it that way. From the beginning we are set up to compete with our neighbors."

An external museum interviewee offered that a culture of competition is generally caused by people who are threatened by change, and the best scientists are not like that. The best scientists are always reaching out to see how they can leverage things up. A younger Smithsonian scientist observed that everybody wants their own little piece of the pie so they can hire a post doc or a technician—

> *How do we share a technician, or how do we build more collaboration that's more distributed as opposed to getting one grant or one post-doc every year and they distribute it amongst [departments], and usually you get one, and it goes to a particular person as opposed to being more distributed across the department?"*

Cultivate Trust and Respect for Diversity

In setting up interdisciplinary grant programs at NSF, project managers described cultural differences across the different directorates and then across the researchers in different disciplines. "So we had to deal with the differences, and actually it wasn't dealing with as in bulldozing over them, but rather bringing out the best practices." This was accomplished with a team comprised of representatives from all directorates and programmatic offices of the foundation. Success was attributed to the trust that grew among team members—

> *I think there is a tendency for protecting ourselves, and that's what leads to silos. But we were successful in breaking that and the reason why those walls dissolved was because there was a trust among the team members across all the directorates. If you can persuade people, get them to really believe down deep that you're really trying to look past your turfy kinds of interests and to do the right thing for the global program, if people believe that, then they will follow you and buy into that culture.*

Many Smithsonian interviewees talked about the lack of cooperation among science units stemming from insular attitudes and years of built-up ill-will—

> *As soon as you detect disrespect on the part of people you're talking to, that's what they get back. So you could start with a little bit of mutual respect, with everyone understanding what everybody else's job is. And I just don't see that, that's one of the failures. The one thing that the administration could do is simply to tell everyone who works for them, you're going to come back with win-win solutions.*

One interviewee commented,

> *We are an extremely tribally divided community. We have an idea of a common identity, we are the Smithsonian, but we are a tribal people with very little knowledge of each other. A lot of the problems come from ignorance, plain and sheer ignorance of who other people are, how they work, and what their rules are. Ignorance translates into arrogance because we are trying to impose our regulations on other people.*

Another person spoke of the importance of building diverse teams—"gender balance, career stage, geographic distribution … people from lots of research viewpoints … interdisciplinary." Still another called for having different disciplines represented on steering committees or using "rotating leadership … even rotating the positions of science fields on the list."

Be Flexible

Interviewees stressed the need to balance an overall strategy and plan with the need for flexibility and an ability to adapt to rapid changes in science with new tools and new ways of thinking. Talking about the development of an NSF program, one interviewee said, "We had to have a uniform process, the review process, the principles, values, spirit of the program—that had to be uniform without sacrificing the flexibility and recognizing the different cultures and best practices across the foundation."

Choose the Right Start-up Timeframe

One organization opted for a "shock approach" because of a short timeframe in which to institute changes, but also because the organization's leadership believed that "a team will coalesce when under high stress." The working group, which started from scratch, had two months to complete the program design and implementation plan. "Once people bought into the idea of what you are trying to do, everybody knew this was all hands on deck. There was no time for pettiness and the sort of obstacles that often show up when people have too much time on their hands." The group also established a valuable rule:

Problems were not allowed—just bring solutions because when somebody raises a problem, more often than not they have a solution in their back pocket. All of these are our colleagues; the team as a whole has many hundreds of hours of program management experience, they are all high-powered, there is a reason why they were appointed for the task, so negative sentences were not allowed.

Verdin and Van Heck (in Conceição, et al., 2000) discussed a shock versus a slow and steady approach to integrating knowledge across dispersed units of three corporations active in Europe. Considerations that emerged were "the degree of consensus needed for change … the pressure of the market and how powerful the resistance will be." An interesting conclusion of the study was that a medium-paced process worked least well. Whatever path is chosen, the authors emphasized the importance of management preparing the way: "Whichever path is chosen, it has to be carefully prepared and monitored. In the absence of such preparation, the quick route becomes dirty, while the slow and steady route involves high costs for little result, leading to lots of frustration and even more resistance to change in the future." Such preparation includes involving those "who will be most involved in producing the intended results or affected by them" to achieve buy-in, and building a learning culture.

Other interviewees recommended a gradual process in which participation was voluntary, based on the theory that committed scientists were more likely to succeed, and their success would draw others in. Along the same lines, an interviewee told how his agency had come, based on lessons learned, to recognize the need for a clear-cut start-up phase with sufficient time to lay the required foundation:

It takes the first year to do the management, to get ready in terms of management, get organized, and get all the people hired. We require that they [the centers, each of which consists of several partners] have a [full]-time education director or coordinator, and a person who manages the day-to-day activities 100% of their time. That person is not the center director … but a different person who will coordinate throughout the partnerships and at the lead institution. It takes awhile to get grounded, to get well-organized.

Hire the Right People

One Smithsonian scientist offered this strategy –"the way you get more collaborations is to hire more people who want to collaborate and who think about what they do as solving problems rather than becoming an expert on something. It's more a frame of mind of the researchers than it is any sort of institutional structure." A university center director said, "We just simply don't recruit faculty who aren't interested in interdisciplinary research and scholarship." This university also pointed to the importance of the leadership in influencing culture. At his university, the vast majority of faculty had been hired during the past 15 years when an IDR proponent had been in the leadership position—"That means you have somebody who's in the provost's office who is singing from the interdisciplinary hymnal all the time. That ends up having a pervasive effect across the institution.

Reward Contributions to Institutional Goals

One science manager reflected that there is too much history of the Smithsonian functioning like an academic institution that lets everybody do their own thing. While scientists should have a high degree of freedom, sometimes they may also be asked to do some things that they may not particularly want to do but which are good for the organization. People need to expect to contribute to the Institution and its goals—

> *I'm totally into the independent scientist thing and creativity and scientific freedom and so on, but that doesn't mean you get to do whatever you want. That isn't the same thing … Most of us are pretty proud of being part of the Smithsonian and have got to be willing to contribute something to making it great. I don't think it's doing your own thing all the time and being great for yourself. There needs to be some other level of expectation, and most people will respond favorably to that if the right person puts the expectation forward and then either rewards or penalizes appropriately.*