Research Corporation

a foundation for the advancement of science

ANNUAL REPORT **2004**

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John P. Schaefer
president from 1982 – 2004

PRESIDENT'S MESSAGE

The past twenty-two years mark an extraordinary phase of both my personal life and that of Research Corporation. Noteworthy changes have been consolidating the foundation's activities in Tucson, creating Research Corporation Technologies to carry out the foundation's technology transfer mission, placing the foundation on a firm financial footing, and partnering in building the world's largest and most powerful optical instrument, the Large Binocular Telescope.

More important than any of these, however, is the large number of young faculty members in U.S. and Canadian colleges and universities whose teaching and research careers we have helped launch. Programs such as the Cottrell College Science Grants, Cottrell Scholars, Partners in Science, Research Innovation Awards, and Research Corporation's Department Development Program will have an enduring impact on the individuals and institutions that they have touched. Like ripples on a pond, each of these programs will continue to influence future generations of students and faculty far beyond the points of immediate impact.

The success of Research Corporation is due in large measure to the dedication and imagination of its staff and advisors and the wisdom and guidance of its Board of Directors. Hallmarks of Research Corporation have always been a willingness to take substantial risks to fund projects on the cutting edge of science and a culture with the determination to "make a difference." These characteristics have served us well over the past ninety-two years and will continue to be mileposts for the foundation in the future.

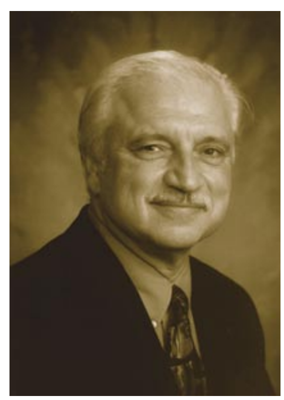
The opportunity to play a leadership role at the foundation for more than two decades has been an extraordinary privilege for which I shall always be grateful.

John P. Schaefer

MESSAGE FROM JAMES M. GENTILE, PRESIDENT-ELECT

I am honored to have the opportunity to succeed John Schaefer as President of Research Corporation. Under John's leadership Research Corporation has made a distinct mark on the future of science not only because of the research initiatives it has funded, but perhaps more importantly through the support and nurturing of young scientists who are the main reason why science moves forward. Research Corporation will continue its legacy of supporting research at the cutting edges of science as well as enhancing the development of the scientists of the future through educational initiatives.

Research Corporation traditionally supports research in the physical sciences and astronomy, and will continue to do so. In addition to these key areas of study, however, we must also understand the climate for science overall. The boundaries of scientific disciplines are converging and will continue to do so at a remarkable pace. Recent reports from the White House-OSTP, Congress, the NAS/NRC, and the NSF all focus on "fuzzy boundaries" of disciplines, particularly the articulations between the physical and life sciences. Such interfaces offer exciting opportunities to unfold the secrets of currently 'unanswerable' scientific questions and probe the frontiers of other questions as yet unimagined. Questions at these interfaces will be the drivers of science for the next decade and beyond. In particular, the study of complex systems is moving to center stage. We will gain a deeper understanding of such systems only through collaborations between physical, computational and life scientists, mathematicians, and engineers. Indeed, new ways of collecting and analyzing data will allow for the exploration of our physical and living world across all levels of organization, both spatially and temporally.



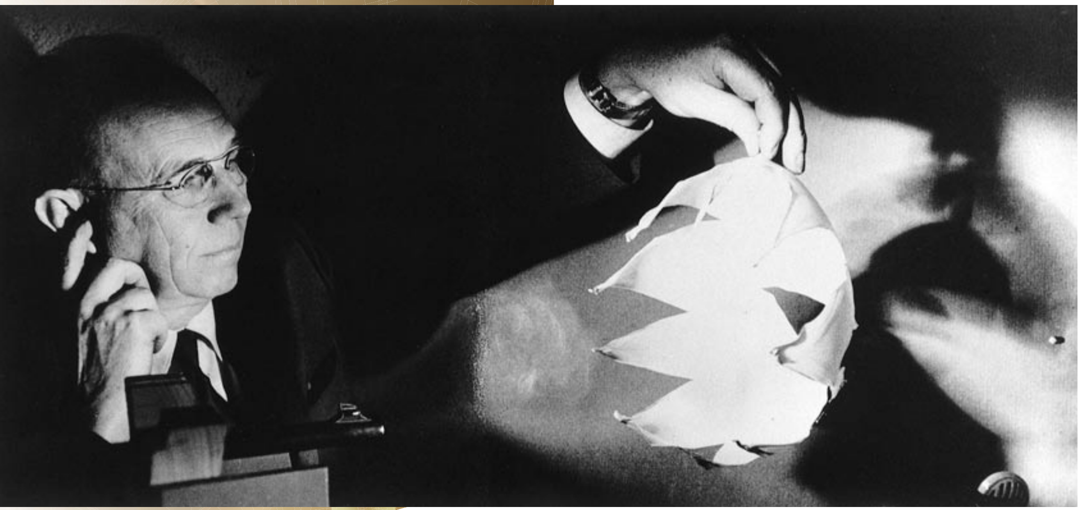
James M. Gentile
began his presidency in 2005

While the primary mission of Research Corporation is to support scientific research, it is also a faculty development enterprise, and we must attend not only to the faculty of today, but also to the faculty of the future. Research and education must go hand-in-hand as we seek to train future scientists (at all levels of education) as well as help to produce a scientifically literate society. Helping science faculty develop as both scholars and educators is a responsibility of the highest order. We are committed to this task.

As noted by John Schaefer in his message in this volume, Research Corporation has always been willing to take substantial risks to fund projects on the cutting edge of science. I look forward with enthusiasm to working hard to insure that Research Corporation will continue to be at the forefront of science and science education and will, indeed, continue to "make a difference."

James M. Gentile

[EXPLORING LIGHT: *Optical Sciences and the Visual Arts*



Science and art both use creativity and technology to explore, understand and give meaning to the world. The relationship between these two activities raises important questions. How do they affect each other? Does science change the way art is created? Does art change the way science is understood? What can scientists and artists learn from each other?

This article examines connections between the optical sciences and the visual arts. Both involve the interactions of energy and matter, as studied through the exploration and manipulation of light and color. History shows that both benefit from an open flow of ideas. However, the barriers between these two disciplines can be formidable.

Many of the lessons that emerge from this examination of the optical sciences and the visual arts can also be found at the interface of other sciences and arts. Although we have chosen to focus on one slice of that interface, possible pairings for further exploration might include mathematics and music; anatomy and dance; or chemistry and the culinary arts. Perhaps this will be a starting point for readers' exploration of the relationship between their particular science and art.

THE MOST BEAUTIFUL THING WE CAN EXPERIENCE IS THE MYSTERIOUS. IT IS THE SOURCE OF ALL TRUE ART AND ALL SCIENCE. HE TO WHOM THIS EMOTION IS A STRANGER, WHO CAN NO LONGER PAUSE TO WONDER AND STAND RAPT IN AWE, IS AS GOOD AS DEAD: HIS EYES ARE CLOSED.

– *Albert Einstein*

SCIENCE AND ART–TODAY'S BARRIERS

In today's world of specialization, individuals examine slivers of experience and nature. Each discipline and subdiscipline of science or art establishes its own paradigm for looking at the world—determining which aspects of life can be examined and which aspects are out-of-bounds; setting the criteria to evaluate merit and reward excellence; and creating a technical language and vocabulary to communicate with others in the field. This disciplinary specialization leads to steady progress in the field, but it can also create barriers around that discipline.

If the barriers surrounding individual disciplines within the sciences (or within the arts) are high, the barriers between the worlds of science and art are even greater. As described most famously by scientist and novelist C.P. Snow in his 1959 Rede Lecture, "The Two Cultures and the Scientific Revolution," a profound gap is often perceived to exist between the sciences and the humanities—and between their practitioners. Snow observed:

> A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have

with considerable gusto been expressing their incredulity of scientists. Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is the scientific equivalent of: *Have you read a work of Shakespeare's?*

I now believe that if I had asked an even simpler question—such as, What do you mean by mass, or acceleration, which is the scientific equivalent of saying, *Can you read?*—not more than one in ten of the highly educated would have felt that I was speaking the same language. So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their Neolithic ancestors would have had.

Within the paradigm of each scientific or artistic discipline, scientists and artists work on advancing their fields. The most significant creative breakthroughs, however, occur when individuals venture outside the paradigm. In *The Structure of Scientific Revolutions,* Thomas Kuhn observed:

> Mopping-up operations are what engage most scientists throughout their careers .... No part of the aim of normal science is to call forth new sorts of phenomena; indeed those that will not fit the box are often not seen at all. Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others. Instead, normal-scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies.

Kuhn's critique of "normal science" might be applied to "normal art"—works of art that are creative yet stay comfortably within the bounds of what the artist's peers consider "good art." Of course, some scientists work at the interface of several disciplines, and many of the important breakthroughs happen at these places. Likewise, some artists cross the barriers between different media and subjects to explore new ways of creating art.

Just as we encourage interdisciplinary research in the sciences, it makes sense to encourage creative work at the interface of science and art. As Snow observed in "The Two Cultures":

> The clashing point of two subjects, two disciplines, two cultures—of two galaxies, so far as that goes—ought to produce creative chances. In the history of mental activity that has been where some of the breakthroughs came. The chances are there now. But they are there, as it were, in a

Theories of Optical Instruments and Art

The media rarely focus their editorial lenses on technical subjects such as optical science. But in the past five years, CBS's *60 Minutes*, a BBC documentary, the *New York Times* and *Daily Telegraph* newspapers, and the *New Yorker*, *Smithsonian* and *Scientific American* magazines have all covered the controversial issue of whether early Renaissance painters used optical instruments while creating their masterpieces.

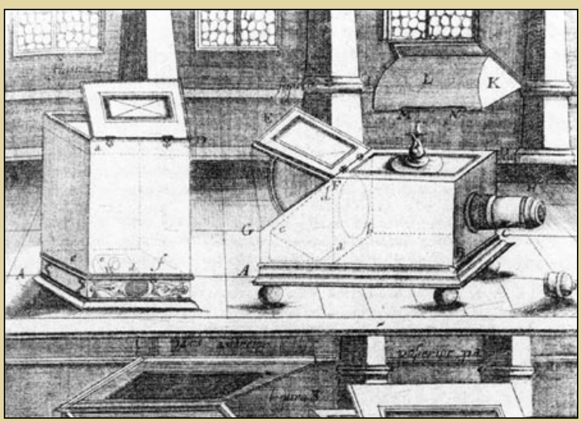
The controversy began when world-renowned artist David Hockney, attending a London exhibition of the works of Ingres (1780–1867), noticed a "photographic quality" to Ingres' portraits. Following a hunch that Ingres may have used an optical instrument—a *camera lucida*—in the process of creating these portraits, Hockney began experimenting with one of these devices. The *camera lucida* is a compact prism-like device, invented by English chemist William Wollaston in 1806, that projects a virtual image of the subject above the paper, allowing the artist to simultaneously see the image and the "tracing" they are making from it.

Intrigued by his experience with the *camera lucida*, Hockney began studying the works of earlier painters; he found that the "photographic quality" could be observed in paintings created as early as 1430. Hockney eventually became convinced that Flemish painters Jan van Eyck (1390–1441) and Robert Campin (1378–1444) used a different, earlier optical instrument—a *camera obscura*—to assist in the creation of their paintings.

According to Hockney, these artists used a *camera obscura* to project an image of the subject onto paper or canvas. Key portions of the projected image could then be quickly traced to capture key elements of perspective, complex geometric detail, and transitory facial expressions. The painter used the notational marks or more detailed tracings made from the projected images as just one of many tools and techniques in the process of creating the final painting.

The use of the *camera obscura,* Hockney argued, played an important role in the dramatic transformation of western art in the fifteenth century, when Flemish artists brought painting to a new and heightened level of natural realism.

Hockney's theory, which drew heavily on his qualitative experience as a practicing artist, attracted the attention of Charles Falco, professor of optical sciences at the University of Arizona. Falco contacted Hockney, and they began a correspondence and collaboration. Falco analyzed a number of paintings, using measurements of elements in the paintings (e.g., interpupil distances, that is, the spacings between the pupils of the portrait subjects' eyes) to determine magnifications, and then using equations from geometrical optics to calculate focal lengths, depths of field and lens diameters. With this analysis, Falco established a quantitative foundation to support Hockney's thesis. Hockney documents his theory and his collaboration with Falco in *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters.* Among the paintings analyzed by Falco were van Eyck's "Portrait of Cardinal Niccolò Albergati" (1432) and "Arnolfini Marriage" (1434). Falco's findings have been widely published in scientific journals, and he has presented over fifty seminars and talks at academic conferences, universities and museums worldwide.



Falco reports that his findings have been warmly received by scientists and practicing artists. On his website, he wrote, "My experience has been that scientists and engineers over-whelmingly under-stand the evidence and our scientific analysis of it, and find our conclusions convincing. …Artists recognize the utility of lenses as an aid for transforming the three-dimensional world onto a two-dimensional surface. Given the opportunity to use a new tool that would make their efforts easier, many working artists have commented that 'of course' they would use it themselves."

However, Falco has found that art historians are much less receptive. He estimates that "fewer than half of art historians accept our basic conclusion that artists such as van Eyck and Bellini used lenses." Falco observes, "The most common objection is the lack of documentary evidence, by which they mean the lack of written description of the use of lenses by artists or by subjects of portraits (of course, David [Hockney] and I point out that the paintings themselves are the documentary evidence). Early on, I often heard the comment that there

vacuum, because those in the two cultures can't talk to each other. It is bizarre how very little of twentieth-century science has been assimilated into twentieth-century art.

Today's barriers between science and art are not absolute. And if we look back in time, to the Renaissance, we will see that the barriers were once much lower.

SCIENCE AND ART DURING THE RENAISSANCE

The barriers between science and art weren't always so strong or so high. During the fifteenth, sixteenth and seventeenth centuries, many scientists and artists were active in both the sciences and arts.

The great astronomer Galileo Galilei (1564–1642) was a master of perspective drawing and attended the *Accademia del Disegno* (Academy of Drawing). His studies of light and shadow on complex geometric forms, an important exercise in the *chiaroscuro* approach (from the Italian words for "light" and "dark," the use of light and shadow in two-dimensional imagery, especially the illusion of rounded, three-dimensional form created through gradations of light and shade rather than line) to drawing allowed him to realistically illustrate the mountains and valleys he observed when he turned his telescope toward the moon.

Albrecht Dürer (1471–1528), German painter and engraver, also studied perspective and originated the field of descriptive geometry. Many of his woodcuts, such as those found in Underweyssung der Messung *(Treatise on Measurement),* elevated scientific illustration to fine art.

During this time period, a number of other scientists, artists and humanists maintained interests in science, mathematics, art and religion. Historians of science land art have documented the accomplishments that emerged from this rich mélange of ideas and experiences. Examples of such individuals include Leone Alberti (1404–1472, mathematician, musician and artist who wrote several important treatises on the visual arts, including *On Painting*, *On Architecture* and *On Sculpture*) and Johannes Kepler (1571–1630, astronomer and mathematician, with a strong interest in geometry, perspective and theology, who described planetary motion with his three laws).

Clearly, many scientists and artists traveled freely between the worlds of science and art during the Renaissance. Among this group of remarkable individuals, however, one towers above the rest.

LEONARDO DA VINCI

The greatest model of the complementary nature of science and art is Leonardo da Vinci (1452–1519). In science, da Vinci is best known for his studies of optics, anatomy and turbulence in water. In technology and engineering, his futuristic designs and inventions include flying machines, weapons and water-lifting devices. In art, his "Mona Lisa" is arguably the world's most famous painting, and his other masterpieces include "The Last Supper," "Virgin of the Rocks" and "The Virgin and Child with St. Anne."

Public fascination with da Vinci's ability to bridge the gulf between science and art goes back several centuries. Roger Shattuck, in *The Innocent Eye*, reported that, during the fifty-year period from 1869 to 1919, an average of one full-length book per year was published on the subject of da Vinci, more than about any other individual. Da Vinci's accomplishments in science, technology and art are documented today in novels, biographies, exhibits, CDs and websites.

Bill Gates purchased one of da Vinci's notebooks, the *Codex Leicester*, for $30.8 million in 1994. On his homepage, Gates wrote,

> I've been fascinated by da Vinci's work since I was 10. Leonardo was one of the most amazing people who ever lived. He was a genius in more fields than any scientist of any age, and he was an astonishing painter and sculptor. His

was no evidence appropriate lenses even existed in the fifteenth century, but now in all my talks I include Tomaso da Modena's 1352 paintings showing concave mirrors, spectacles and a magnifying glass, so that objection isn't raised anymore."

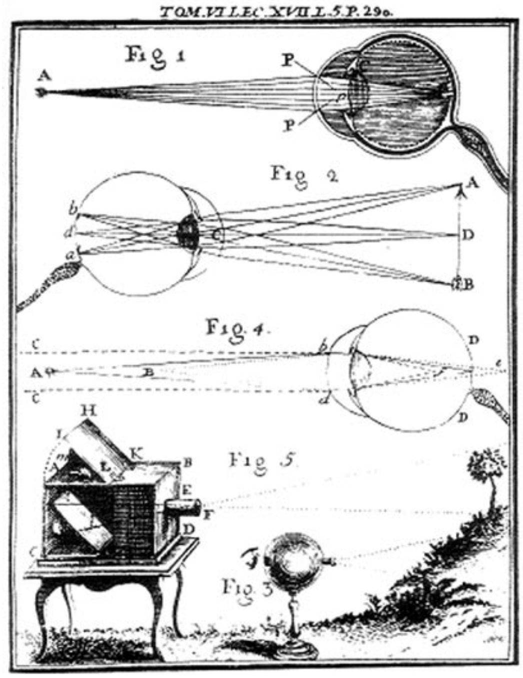
In addition to the criticisms cited by art historians, the Hockney/Falco theory has been critiqued by several scientists, most vigorously by David Stork, chief scientist at Ricoh Innovations and consulting professor of electrical engineering at Stanford University. In a 2004 *Scientific American* article, Stork used computer simulations, geometrical optics and infrared reflectography to raise questions about the multiple vanishing points found in van Eyck's "Arnolfini Marriage." He also expressed doubts about whether a useful *camera obscura* could have been constructed from the limited illumination available in the room and from the relatively small focal length of the mirror depicted in the background of the painting. Stork and others (including Thomas Ketelsen, a curator at the Museum of Prints, Drawings and Manuscripts in Dresden, Germany) have also provided evidence that the remarkable similarity between van Eyck's drawing "Portrait of Cardinal Niccolò

Albergati” and a larger oil painting of the same name could have been achieved by mechanical, rather than optical, copying and enlarging techniques.

Like Falco, Stork has made public and scientific presentations on this subject, and Stork reports that his audiences of scientists find his arguments and analyses compelling. On his website, Stork wrote, “From these lectures and numerous discussions, I think it is fair to conclude that if a scientist hears only the arguments in favor of the Hockney theory, he or she is likely to find it persuasive. However, if that person hears the counter-arguments at the very least he or she will not agree with Hockney and Falco that the case for the projection theory has been ‘proven.’ More likely, the scientist will reject the theory altogether often because they learn of historical or other facts that they’d never even considered before.”

While the question of whether Old Masters such as van Eyck, Campin and Lotto used optical instruments in the fifteenth and sixteenth centuries remains somewhat controversial, the use of a *camera obscura* by Jan Vermeer (1632–1675) in the seventeenth century is widely speculated by both scientists and art historians.

In *Vermeer’s Camera: Uncovering the Truth behind the Masterpieces*, Philip Steadman (professor of urban and built form studies at University College London) built a case that Vermeer used a *camera obscura* while painting many of his masterpieces. Using optical calculations, Steadman reconstructed the precise geometry of Vermeer’s studio, including the location of the camera obscura lens for different paintings. Steadman suggested that Vermeer’s “optical consultant” may have been Antony van



notebooks were hundreds of years ahead of their time. They anticipated submarines, helicopters and other modern inventions.

His scientific ‘notebooks’ are awe inspiring not simply as repositories of his remarkable ideas but as records of a great mind at work. In the pages of the *Codex Leicester*, he frames important questions, tests concepts, confronts challenges, and strives for answers. His writings demonstrate that creativity drives discovery, and that art and science—often seen as opposites—can in fact inform and influence each other.

Among his many interests and studies, da Vinci displayed special interest in optics and visual arts. In particular, he focused on the human eye. In his note-books, da Vinci wrote:

> The eye, which is said to be the window of the soul, is the primary means by which the *sensus communis* [the coordinating center for sensory impressions] of the brain may most fully and magnificently contemplate the infinite works of nature….The eye is commander of astronomy; it makes cosmography; it guides and rectifies all the human arts; it conducts man to various regions of the world; it is the prince of mathematics; its sciences are most certain; it has measured the height and size of the stars; it has disclosed the elements and their distribution; it has made predictions of future events by means of the course of the stars; it has generated architecture, perspective and divine painting. Oh excellent above all other things created by God….And it triumphs over nature, in that the constituent parts of nature are finite, but the works that the eye commands of the hands are infinite, as is demonstrated by the painter in his rendering of numberless forms of animals, grasses, trees, and places.

Da Vinci believed that the eye worked geometrically, like a *camera obscura* [a chamber with a small aperture in one wall through which light passes. Early versions were darkened rooms or boxes, and an artist could climb into the darkened chamber. The image is projected, inverted, onto the wall opposite. Later more sophisticated models added a lens to the aperture, increasing its affinity to the human eye or the photographic camera. Its strength as an aid to drawing resides in its ability to project onto a flat surface the confused visual information which strikes the eye.]. He systematically studied the effects of light on single and multiple bodies, using single and multiple sources of varied sizes. He studied shadows, colors, intensity and reflections, developing a new way to explain how light and color are used in painting. He plotted the secondary reflections of light from illuminated surfaces into shaded areas, and he used this phenomenon to explain the so-called *lumen cinererum* (ashen light) on the shaded side of the moon, which he correctly argued came from reflections off the earth's surface.

Da Vinci's paintings reflect many of the lessons he learned from his optical studies. By treating objects as three-dimensional bodies defined by light and shadow, instead of as flat, two-dimensional outlines, he gave his paintings a soft and lifelike quality. Through his careful studies of objects at a distance, he realized that an object's detail and color seem to change as it recedes in the distance. He superimposed layers of translucent color, a technique called *sfumato*, to create atmosphere and depth in his paintings. As described by art historian Martin Kemp in *The Science of Art: Optical Themes in Western Art from Brunelleschi to Seurat*, "Leonardo's late paintings are full of felicitous subtleties of light and colour: variegated pebbles, semi-transparent veils, floating vapours, intangible atmospherics, translucently blended reflections of colour, the glimmer of back-reflections in the shadows, and so on."

AFTER THE RENAISSANCE: OPTICAL SCIENCES CONTINUE TO INFLUENCE THE VISUAL ARTS

Optical science and technology have played major roles in the history of western art, from the time of the Renaissance to the Enlightenment and beyond. Kemp documented this relationship in *The Science of Art*, commenting on the "special kinds of affinity between the central intellectual and observational concerns in the visual arts and the sciences in Europe from the Renaissance to the nineteenth century." Kemp wrote, "a significant number of those involved in art consciously aspired towards goals that we would now regard as scientific in a broad sense."

Some of the many influences of optical sciences on the visual arts after the Renaissance include:

[THE STUDY OF COLOR

- The publication of Sir Isaac Newton's *Opticks* (Newton's study of the nature of light and color and the various phenomena of diffraction), in 1704, moved color science to firmer scientific ground.
- Ogden Rood, professor of physics at Columbia, published his *Modern Chromatics* in 1879, which helped make the principles of color science more accessible to painters.

> COLOR IS BUT A SENSATION AND HAS NO EXISTENCE OUTSIDE THE NERVOUS SYSTEM OF LIVING BEINGS.
> *– Ogden Rood*

Leeuwenhoek, a pioneer in microscopy, a fellow citizen of Delft, Netherlands, and the executor of Vermeer's estate.

Not all scholars are convinced by Steadman's arguments. One of the skeptics is Walter Liedtke, curator of European paintings at the Metropolitan Museum of Art in New York and the Museum's specialist for Dutch and Flemish paintings. In an article for the online museum, WebExhibits.org, Liedtke wrote, "I don't oppose the notion that Vermeer in some way responded to the *camera obscura*, but I DO oppose drastic devaluations of the role of art.… Vermeer must have admired certain effects of color, light, and focus in a camera obscura, but…he persistently departed from what he actually saw—in the camera, in his studio, or in another artist's work—in accord with his own highly refined aesthetic and expressive goals."

Vermeer's use of a *camera obscura* as a tool in his painting does not diminish his artistic genius, according to Steadman. "The camera allowed the artists to enter a newly revealed world of optical phenomena and to explore how these might be recorded in paint.…As Kemp puts it [in *The Science of Art*], 'the use of a camera in no way prescribes the artistic choices to be made at each stage of the conception and making of a painting.' …Vermeer's obsessions with light, tonal values, shadow, and color, for the treatment of which his work is so admired, are very closely bound up with his study of the special qualities of optical images."

In the end, the specific question—whether a *camera obscura* was used by early Renaissance painters to trace key elements of their subjects—points to broader questions that apply to the relationship between art and science. If artists use scientific instruments or scientific theories while creating art, is their artistic creativity enhanced or diminished? When can an image captured by a camera be considered a "work of art?" Can a closer examination of the relationship between science and art contribute to increased public understanding and appreciation of both science and art? As scientists and artists closely observe nature and develop ways to represent and understand what they've observed, what can they learn from each other?]

[THE INVENTION AND DEVELOPMENT OF PHOTOGRAPHY AND CINEMATOGRAPHY

Some of the key figures and milestones in this timeline include:

- Henry Fox Talbot created permanent negative images using paper soaked in silver chloride and fixed with a salt solution, as well as positive images by contact printing onto another sheet of paper in 1834.
- Louis Daguerre created images on silver-plated copper which was coated with silver iodide and "developed" with warmed mercury in 1837.
- James Clerk Maxwell, Scottish physicist, demonstrated a color photography system involving three black-and-white photographs, each taken through a red, green or blue filter, in 1861.
- Eadweard Muybridge helped Leland Stanford settle a bet on whether "a horse's four hooves ever leave the ground at once" using time-sequenced photography in 1877.
- Harold ("Doc") Edgerton developed strobe photography at MIT in 1931.
- Edwin Land developed the first color instant film in 1963.
- Eastman Kodak Company unveiled the first commercially available digital camera in 1990.

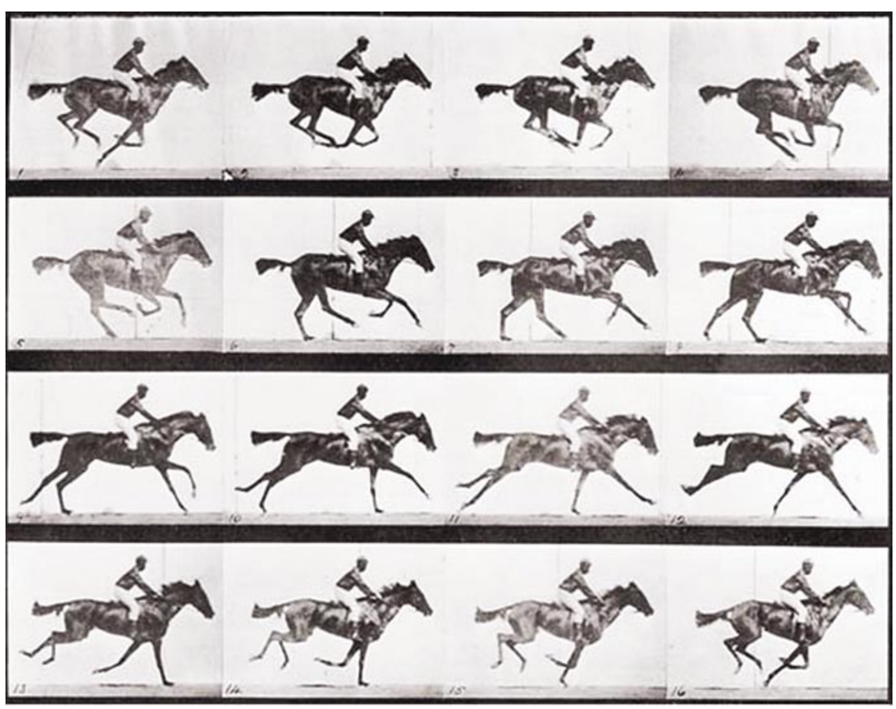
Optical science and photography had another profound influence on the history of art—freeing artists from the goal of approximating nature through realism.

DOES ART INFLUENCE SCIENCE? A MORE CONTROVERSIAL QUESTION

The history of art is full of examples of science and technology giving rise to new approaches to art. More controversial, however, is the question of whether influence also flows in the opposite direction: Do new approaches in art ever give rise to new ideas in science?

In *Art and Physics: Parallel Visions in Space, Time and Light*, Leonard Shlain suggested that many new developments in science and technology arise out of a cultural context that is first perceived and expressed by artists. In fact, Shlain asserted that art often precedes science.

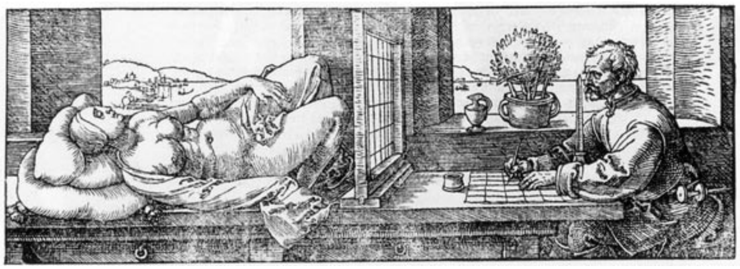
Shlain suggested that the origins of Kepler's laws of planetary motion, published in 1618, can be traced back to the artists Giotto (1267–1337) and Alberti (1404–1472). These two artists, with strong interests in geometry and perspective, demonstrated the necessity of drawing conic sections through cylindrical and circular forms in order to accurately portray objects. Nearly two hundred years later, Kepler immersed himself in the study of conic sections, studying Alberti's book and using the artist's technique of perspective while imagining himself on Mars looking at the earth's motion. Shlain wrote, "Artists anticipated scientists in recognizing the importance of the stationary observer at rest; in perceiving the importance of conic sections; and in discerning the vanishing point of infinity. In the Middle Ages and the Renaissance, as before, the precognition of the intuitive artists foreshadowed the discoveries of the analytical scientist."



At the end of the nineteenth century, according to Shlain, three visionary artists experimented with new ways of looking at time and space. Edouard Manet experimented with well-established rules of perspective—obscuring the vanishing point, curving the horizon, and moving the horizon up off the picture plane. Claude Monet, through paintings such as his haystack series, became the first artist since the Renaissance to investigate the dimension of time. And Paul Cezanne devoted a lifetime to studying and painting the relationship of space, light and matter. Shlain wrote,

> Their revolutionary assaults upon the conventions of perspective and the

> LIGHT IS A THING THAT CANNOT BE REPRODUCED, BUT MUST BE REPRESENTED BY SOMETHING ELSE – BY COLOR.
> *– Paul Cezanne*



integrity of the straight line forced upon their viewers the idea that the organization of space along the lines of projective geometry was not the only way it can be envisioned. Once people began to see space in non-Euclidean ways, then they could begin to think about it in new ways too…. It would take the elegant calculations of Einstein years later to provide the proof in black and white of what had been stunningly accurate artistic hunches expressed in form and color.

Shlain's grand theory, that visionary artists play an important role in scientific revolutions, is thought-provoking, but many scientists and historians remain unconvinced. Art historian Kemp wrote, "I am skeptical of claims that visual discovery in art played a causative role in any major sense in the scientific revolutions of the period."

At the level of individual scientists and artists, however, it *is* possible to find examples of art influencing science. Physiologist/writer Robert Root-Bernstein cites a number of examples in his articles and books. In his essay, "For the Sake of Science, the Arts Deserve Support," which appeared in *The Chronicle of Higher Education* (July 11, 1997), Root-Bernstein wrote:

> As unexpected as it may sound, artists often invent techniques that outstrip the methods of contemporary science and technology. Consider Abbott H. Thayer, a turn-of-the-century nature painter sometimes described as Audubon's successor. Thayer discovered the concept of camouflage. He not only revolutionized our understanding of the co-evolution of animals and their environment, but also suggested that the principles of camouflage be applied to protecting soldiers and their equipment on the battlefield.

The exact nature of how art might influence science and scientists is an ongoing subject of research and controversy. Yet it's clear that there is a two-way flow of influence between art and science.

THE RELATIONSHIP BETWEEN SCIENCE AND ART TODAY

It's just human nature that the barriers that separate art and science tend to go up whenever one side perceives that the other side is moving in on its territory. If we move beyond defensiveness and turf battles, however, we can look at the relationship between science and art as one that can bring about mutual benefits. Here are three ways scientists and artists can help each other.

Art Can Enhance Scientific Creativity and Imagination

As a research scientist, Root-Bernstein, professor of physiology at Michigan State University and a MacArthur Fellow, studies molecular complementarity; chemical basis of physiological interactions between peptides, monoamines and drugs; and theoretical and experimental approaches to autoimmunity and its suppression. He also studies historical and philosophical perspectives on science and its methods. In particular, he looks at the relationship between art and science as it relates to creativity in science, and he's published two books on the topic, *Sparks of Genius: The Thirteen Thinking Tools of the World's Most Creative People* and *Discovering*.

Root-Bernstein believes that scientific creativity taps into visual and nonverbal thinking. In his books and articles, he cited many individual examples from physics, chemistry and biology. Summarizing his conclusions in his 1997 *Chronicle* essay, Root-Bernstein wrote:

> History shows that the sciences and technology have never flourished in the absence of a similar flourishing of the arts. The reasons for this connectedness have become apparent in the past several decades, as a result of studies by historians of science and technology, psychologists, and other scholars who study creativity. A consensus is emerging that scientists and engineers need skills associated with, and often learned from, the arts.
>
> These skills include the abilities to observe acutely; to think spatially (what does an object look like when I rotate it in my mind?) and kinesthetically (how does it move?); to identify the essential components of a complex whole; to recognize and invent patterns (the "rules" governing a system); to gain what the Nobel-Prize winner Barbara McClintock called "a feeling for the organism" or empathy with the objects of study; and to synthesize and communicate the results of one's thinking visually, verbally, or mathematically.

Eric Heller, professor of physics and chemistry at Harvard University, studies few-body quantum mechanics, scattering theory and quantum chaos. He's also an artist who finds inspiration in science. In return, the art sometimes informs the science, suggesting further avenues of research. "Through art, one can sometimes get straight to the essence of the matter and get an almost intuitive comprehension that might otherwise take years of study," says Heller. "I have a compulsion every once in a while. I have to do something [artistic]. This happens to me only in my most scientifically creative periods."

Charles Falco, professor of optical sciences at the University of Arizona, has spent many hours collaborating with artist David Hockney on the theory that an optical device, the *camera obscura*, was used by many of the Old Masters. When artists and scientists collaborate, Falco notes, they can ask each other naïve—and insightful—questions that "professionals would be chagrined to ask." Recently, while Hockney was painting his portrait, Falco used breaks between posing to jot notes on how Hockney worked—where he looked and how long he looked. Falco says, "I ask artists questions and learn from them... [Hockney] taught me how to visualize things. As a result, I'm now exploring some new ideas about computerized image analysis, and it's come from my work with David Hockney."

David Stork, chief scientist at Ricoh Innovations and consulting professor of electrical engineering at Stanford University, has also taught in the Department of Art and Art History at Stanford. He's been a participant in the debate about the possible use of optics by Renaissance painters. Stork's area of scientific expertise is computer vision and pattern recognition, and he's coauthored a widely used textbook, *Pattern Classification*. Stork believes the arts can help scientists expand their abilities to recognize patterns. "If you look at so many scientific breakthroughs, they happen when someone recognizes a pattern in something—a pattern in genes or a pattern in the movement of celestial bodies," says Stork. "The arts can teach you 'pattern recognition,' that is, being able to recognize structure and pattern. It could be rhythm and meter in a poem; melodies and their interrelationships in a sonata or symphony; or the form, structure and style that allows you to recognize a particular painter. Developing these pattern recognition abilities is something that the arts do in a playful, and often rigorous, way."

WATER IN SWIMMING POOLS CHANGES ITS LOOK MORE THAN IN ANY OTHER FORM... ITS COLOUR CAN BE MAN-MADE AND ITS DANCING RHYTHMS REFLECT NOT ONLY THE SKY BUT, BECAUSE OF ITS TRANSPARENCY, THE DEPTH OF THE WATER AS WELL. IF THE WATER SURFACE IS ALMOST STILL AND THERE IS A STRONG SUN, THEN DANCING LINES WITH THE COLOURS OF THE SPECTRUM APPEAR EVERYWHERE.

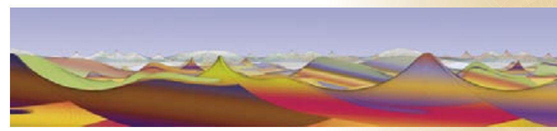
– David Hockney

Roald Hoffmann, 1981 Nobel Prize winner in Chemistry, is a theoretical chemist at Cornell University. He's also a poet, an essayist and a playwright. He says, "I have a very strong interest in the visual arts. I almost went into art history instead of chemistry." When asked whether scientists can learn from artists, he offered a critique of science education and an endorsement of arts education:

We've got a problem in teaching science. It's amazing how something so free at its frontiers can seem so regimented and authoritarian at its beginnings, like a freshman chemistry or physics course. The problem is that there is no time. There's all this material to deal with, stoichiometry, gas laws and the like.

Studio art courses, on the other hand, emphasize creativity and problem-solving in ways which could help a science course. So I'm supportive of hands-on art. Sure, it has a lot to do with the imagination applied to the emotions—that's how you judge whether a work of art works—but it also has a lot to do with craftsmanship and hands-on work, which is exactly what goes on in laboratories. I think we have to have an alliance with the artists. They know that they have to work with hands and mind combined—not just the mind. That's what we do in the laboratory as scientists.

Art Can Enhance Public Appreciation and Understanding of Science



The technical vocabulary, graphs and equations found in journal articles serve scientists well in communicating with each other. However, these dry and precise communication methods often fail miserably when scientists want to convey their science to members of the general public. Nearly half a century after Snow's "Two Cultures," it is still common for nonscientists—including leaders in business, politics and academe—to claim unapologetically that they never liked or understood science or math.

Optical scientist Falco, while giving dozens of presentations on optics and the Renaissance, has found that art can be a "wonderful entrée into the sciences" for members of the general public. Says Falco, "I reach a point in my talk when I tell them I'm going to teach them the optical science that they will need to understand my conclusions. I can see the audience getting pale, but they are interested and follow along."

Lynette Cook, a science illustrator who specializes in space art, believes that good science illustrations help draw the audience into a subject. "So many people are visually oriented," says Cook. "If you put a picture there, they see a planet with an alien landscape and think, 'Wow, that's just like *Star Trek*.' Then they want to read the caption. Once they find the caption interesting, they might glance over the whole article. The illustration hooks them to want to learn more."

Theoretical physicist Heller believes art can convey a sense of excitement and the essence of the phenomenon being displayed. "The public may not come away understanding it [quantum physics]—nor do I expect them to, because it requires a lot of time on somebody's part to really understand it. The point of art is to get an intuitive understanding, maybe even a subconscious 'gut reaction,' brought to you directly. It comes through some mysterious conduit rather than through information transfer of the normal sort, like reading or listening to a lecture. This direct-line-to-your-subconscious approach is part of good art, and the public seems to appreciate that."

The experiences of Falco, Cook and Heller are examples of a phenomenon that's been observed by other scientists through the years. By turning to art—including visual arts, music, dance, theater, architecture and the literary arts—scientists are able to reach out to the public.

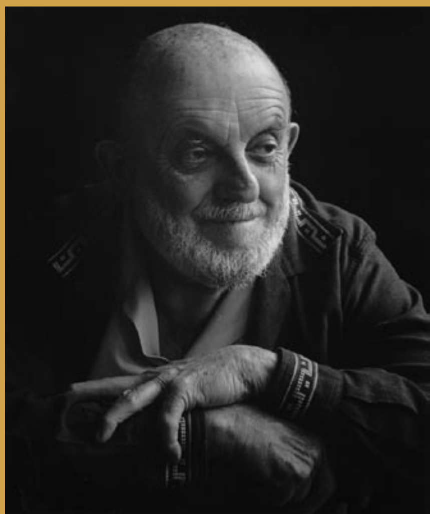
Institutions also realize the important role art can play in bringing science to new audiences. When designing new buildings or redesigning existing spaces, Research Corporation, as well as other scientific organizations—such as the American Association for the Advancement of Science, the Howard Hughes Medical Institute, the National Academy of Sciences and the National Institutes of Health — are now including gallery space. Some scientific institutions, including NASA, the Jet Propulsion Laboratory at Cal Tech, and MIT, have artists-in-residence on their scientific staff.

Science and Art Together Can Open Up New Frontiers

Optical instruments like the camera, telescope and microscope have enabled us to explore new frontiers of time and space. With cameras, time can be frozen for a moment, speeded up, slowed down, collapsed and reversed. Time can even be rolled back to its very beginning—cosmologists are using today's powerful cameras, computers and telescopes to study the Big Bang and the earliest moments of the universe. Telescopes and microscopes have opened vast new realms of size and space. As scientists, artists and the public began traveling freely between the world of atoms and the world of galaxies, they needed a map to guide them on their journey.

Designers and filmmakers Charles and Ray Eames provided that new conceptual map in *Powers of Ten*, a film developed for the 1968 annual meeting of the Commission on College Physics. Over the subsequent decade, working with

Photography and Science: Ansel Adams and John Schaefer



The black-and-white photographs made by Ansel Adams (1902–1984) are among the most-recognized and best-loved images in the world. His pictures of the American West, especially those of Yosemite National Park, resulted from an approach—at once both precise and passionate—that combined science and art. Adams' images captured the heart of the American public, helped launch the American environmental movement of the 1960s and 1970s, and earned him America's highest civilian honor, the Presidential Medal of Freedom.

Adams' synthesis of artistic vision, technical knowledge and meticulous experimentation stands as testament to what can be achieved when art and science become partners.

John P. Schaefer, president of Research Corporation from 1982 to 2004, had the good fortune of working with and learning from Ansel Adams. Schaefer first met Adams in 1974 when Schaefer, a chemist by training and an accomplished amateur photographer, was president of the University of Arizona.

In 1975, Schaefer and Adams helped establish the Center for Creative Photography (CCP) at the University of Arizona, envisioning it as a unique blend of archive, museum and library, where art and research materials presented together would offer a full understanding of photography as a creative medium. Today, the Center for Creative Photography is world renowned.

CCP's Ansel Adams archive includes voluminous correspondence, book layouts and manuscripts, ledgers, periodicals and monographs, camera equipment, memorabilia, and over 20,000 negatives and proof prints. Approximately 2,500 exhibition prints crown the world's most extensive public holding of Adams' photographs.

"Ansel is one of my artistic heroes. We became good friends over the years and he taught me a lot about photography," says Schaefer. "Ansel approached photography with the soul of an artist, but the mind of a scientist. He was clearly an artist, but he was an artist really dedicated to understanding the craft of photography. He was meticulous about testing all his equipment and materials so that he could remove as much of the uncertainty in the photographic process as possible. He knew what the outcome would be of everything he did—before the print or the negative appeared." Schaefer remembers Adams as "the kind of person I would have loved to have had as a graduate student, because he was just so clear and precise about the way he did things, the way he approached questions."

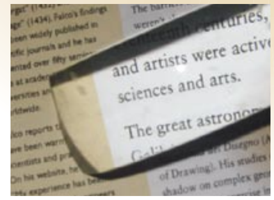
Adams developed an approach to photography that became known as the "zone system," a technique that allows photographers to translate the light they see into specific densities on negatives and paper, thus giving them better control over finished photographs. Adams also pioneered the idea of "visualization" of the finished print based upon the measured light values in the scene being photographed. According to Schaefer, "Ansel put the concept and technique for exposing and developing film down in a quantitative sense in a way that no one else had ever done. "With his system, one could understand—very precisely and predictably—the consequences of exposing and developing film."

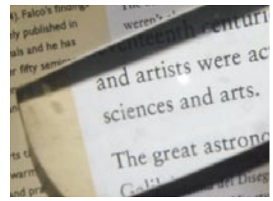
Because of his technical expertise, Adams was pursued as a consultant by the major photographic institutions. He was a consultant to Edwin Land and Polaroid for many years, and he also worked closely with Kodak. "He kept meticulous notes," says Schaefer. "His correspondence with Polaroid fills a filing cabinet, and it's quite technical. A scientist could have an intelligent conversation with him about optics or the chemistry of developing and processing. He very much knew what he was talking about. He may not have had all the up-to-the-moment scientific jargon down, but he certainly understood the principles."

With Adams' careful attention to craftsmanship, materials, equipment and technique, he was considered by some of his fellow photographers to be a scientist as well as an artist. But Adams disagreed, writing the following in his autobiography: "Brett [Edward Weston] states, 'Ansel is a scientist.' I am not a scientist. I consider myself an artist who employs certain techniques to free my vision." Adams continued, "There is something magical about the image formed by a lens. Surely every serious photographer stands in some awe of this miraculous device. We must come to know intuitively what our lenses and other equipment will do for us, and how to use them."

According to Schaefer, "The mind of a scientist shows up in the technique that he used. The technique is part and parcel of the impact that his images have. At the end of the day, technique really is invisible—it's the image that you see."

physicist Philip Morrison and educator Phylis Morrison, they expanded a refined their ideas, releasing a more polished version in 1977, titled *Powe Ten: A Film Dealing with the Relative Size of Things in the Universe and t Effect of Adding Another Zero*.





The film takes the viewer on a nine-minute journey exploring the very large a the very small. The movie starts with an image (on the scale of 1, or 10^0, meter) of a man sleeping in a Chicago park. The camera gradually pulls back, moving ten times further away for every ten seconds of time that passes, eventually reaching the edge of the universe (10^{25} m). Then, zooming forward, the camera travels into the sleeping man's hand, finally reaching the inside of a carbon atom (10^{-18} m).

Between the 1968 and 1977 versions of the movie, the filmmakers added two orders of magnitude, reflecting new frontiers opened up by science. Since 1977, scientists and artists have continued exploring the worlds found at each level of this journey, from large to small. Science writer Ivan Amato documents that journey through both art and science. In *Super Vision: A New View of Nature*, Amato wrote:

> For all but the most recent pages of the human story, to see nature has been to see the world as one's own eyes—and ears and nose and other sensory anatomy—could take it in.
>
> The compulsion to record this sensory experience of nature seems to be as fundamental a part of being human as is using that sensory input to perceive what matters in the environment—attractive mates, sharp-clawed predators, the color and smell of nutritious fruit, the bitter taste of poison. Those famous Paleolithic cave paintings, such as in the *Chauvet-Pont-d'Arc* cave in France, where lions, bears and sparring rhinoceroses grace the walls, provide hard evidence that the drive to depict nature was being expressed 30,000 years ago and earlier. That drive has never stopped.

> What has changed utterly in the meanwhile, particularly in the past half-millennium, and most particularly in the last few decades, is that we now have the ability to assist and boost our raw senses with miraculously capable technologies.

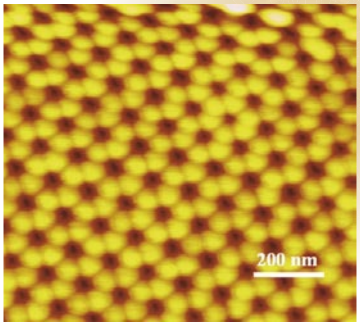
In the foreword to Amato's book, Philip Morrison wrote, "Since the 1970s and 1980s, when my wife and I worked with the office of Charles and Ray Eames on … *Powers of Ten*, an examination of the sizes of objects in the universe and their relative scale, scientific imagery has only become more varied and revealing. What's more, it is increasingly blurring the lines between two Grand Categories, science and art."

THE FUTURE

As our knowledge of the world expands, so does its exploration by scientists and artists. How can we pursue this exploration?

One possibility might be found in *The Third Culture: Beyond the Scientific Revolution* by John Brockman. In it, Brockman argued that "the third culture consists of those scientists and other thinkers in the empirical world who, through their work and expository writing, are taking the place of the traditional intellectual in rendering visible the deeper meaning of our lives, redefining who and what we are."

Continuing collaborations between scientists and artists are important for both disciplines to move forward, separately and together. History shows that significant progress can be made when such communication occurs. Research Corporation has always been at the cutting edges of science and will continue to make a difference at the evolving "fuzzy boundaries" of disciplines.]



Randy Wedin is a science writer, trained as a chemist and based in Wayzata, Minnesota. He authored this article as a consultant to Research Corporation. For references cited in this article, please see www.rescorp.org/references

ART AT ITS MOST SIGNIFICANT IS A DISTANT EARLY WARNING SYSTEM THAT CAN ALWAYS BE RELIED ON TO TELL THE OLD CULTURE WHAT IS BEGINNING TO HAPPEN.

– *Marshall McLuhan*

PROGRAM REVIEW 2004

Raymond Kellman
Vice President

Since 1946, the Award Programs Advisory Committee, more commonly called the "Advisory Committee," has played a crucial role in the success of our awards programs. In our evaluation process, it is they who make the final recommendations on all proposals submitted by individual faculty to our regular awards programs. They also advise us on issues of importance to the scientific community. The committee, chaired by the president of Research Corporation, is made up of academic scientists from beyond the foundation and throughout the nation. These men and women have established strong records of research productivity, broad scientific interests, and a deep understanding of the issues facing the research community. They display fairness, open flexible minds, and extraordinary judgment of proposals. These scientists give generously of their time – time that many of their peers are unable or unwilling to give – so that others might maintain their independent research programs. They do so without compensation and for terms of three to six years.

Every year committee members are asked to evaluate several hundred proposals that have been submitted to our Cottrell Scholar, Cottrell College Science and Research Opportunity Award programs. Each committee member individually receives these proposals along with their peer-reviews, and provides individual evaluations. Advisors meet in full committee twice a year, in spring and in fall, to discuss and to render decisions on each proposal. In addition to evaluating scientific merit, the committee carries the obligation of making decisions that adhere to the mission of the foundation and to the specific goals of each program. That will, from time to time, mean that our advisors' decisions are not coincident with those of our peer-reviewers. Whatever the circumstances, decisions are made only after each committee member has an opportunity to express his or her point of view, and the committee has come to consensus. Once rendered, committee decisions cannot be altered by foundation staff.

Our advisors strive to fund the most significant, innovative and challenging research in the realm of the physical sciences. Perhaps more importantly, it is they who provide the imprimatur of integrity and scholarly excellence to our selection process. We at Research Corporation are proud of the work they do. The scientific research community owes them great gratitude for their extraordinary efforts to identify and support individuals whose research ideas are most likely to advance science significantly. Pages 24 through 27 list those proposals recommended by our Advisory Committee for funding in 2004.

I encourage you to visit our website and see which of your colleagues serve and have served as members of our Award Programs Advisory Committee.

Raymond Kellman

PROGRAM SUMMARY

One hundred and three awards were made in support of faculty research, research-enhanced teaching and special projects in science in 2004. Funding for the foundation's programs noted below totaled $4,120,179. Fourteen additional awards were made, totaling $962,214.

COTTRELL COLLEGE SCIENCE AWARDS

Cottrell College Science Awards are the foundation's largest program, supporting faculty in chemistry, physics and astronomy at primarily undergraduate institutions. The program, which encourages student research involvement, funded eighty-two out of 258 faculty applicants. Two cycles of awards are featured each year; in 2004, the foundation granted a total of $2,896,032, averaging $35,317 per award.

COTTRELL SCHOLAR AWARDS

Cottrell Scholar Awards support excellence in both research and teaching in chemistry, physics and astronomy at Ph.D.-granting institutions. Each award totals $75,000, to be used largely at the discretion of the scholar. Out of ninety-six requests submitted, eleven Cottrell Scholar Awards were made, totaling $825,000.

RESEARCH OPPORTUNITY AWARDS

Research Opportunity Awards support midcareer faculty of demonstrated productivity who seek to explore new experimental research at Ph.D.-granting institutions. Out of twelve candidates nominated by their department chairs for awards in 2004, eight proposals were funded for a total of $399,147.

RESEARCH INNOVATION AWARDS

Research Innovation Awards were instituted in 1997. The Research Innovation Awards program is open to beginning faculty at Ph.D.-granting institutions and encourages innovation by scientists early in their academic careers. During an assessment of the feasibility of this award, it has been suspended for 2004–2005.

OTHER AWARDS

Also in 2004, five Special Opportunity in Science Awards were awarded, totaling $857,139. In addition, nine Discretionary Awards for the year totaled $105,075.

COTTRELL COLLEGE SCIENCE AWARDS

Acadia University
Amitabh Jha, Department of Chemistry: Design, synthesis and bioevaluation of potential antibacterial agents –$30,606

Berea College
Kingshuk Majumdar, Department of Physics: Study of vortex deconfinement in condensed matter physics –$22,184

Boise State University
Jeffrey McNamara Peloquin, Department of Chemistry: The applicability of photoexcited manganese salts in the treatment of water contamination –$34,608

Boise State University
Don L. Warner, Department of Chemistry: Investigation of alkyl migration from silicon to carbon for the stereocontrolled synthesis of carbon-carbon bonds –$37,036

Brock University
Stuart M. Rothstein, Department of Chemistry: Towards generating the complete structure distribution of a protein: Exploiting novel and established pattern recognition techniques –$18,420

Bucknell University
Eric S. Tillman, Department of Chemistry: Anthracene photodimers in atom transfer radical polymerizations –$41,566

California State University, Long Beach
Michael P. Myers, Department of Chemistry and Biochemistry: NOCKS- Nitric Oxide Chemistry and K$^+$channels role in umbilical cord Stem cell differentiation –$37,840

California State University, Long Beach
Zoltan Papp, Department of Physics and Astronomy: Integral equation approach to the three-body coulomb scattering problem –$37,682

California State University, Long Beach
Krzysztof Slowinski, Department of Chemistry and Biochemistry: Conductivity of two-component monolayers at the air-water interface –$38,944

California State University, Los Angeles
Krishna L. Foster, Department of Chemistry and Biochemistry: Laboratory studies on the affect of substrate on the kinetics of PAH oxidation –$42,603

Calvin College
Douglas A. Vander Griend, Department of Chemistry and Biochemistry: Exerting mathematical and chemical control to rationally synthesize discrete and infinite coordination networks –$38,606

Central Michigan University
Marco Fornari, Department of Physics: Interacting pseudo Jahn-Teller effects: Application to perovskite alloys –$24,218

Central Washington University
Eric L. Bullock, Department of Chemistry: Mixed thiolate self-assembly on gold and silver surfaces –$37,899

Colby College
Jeffrey Katz, Department of Chemistry: Synthesis of azacalixarenes, oxocalixarenes, and dicalixarene cages –$39,684

Colgate University
Kenneth J. Segall, Department of Physics and Astronomy: Nonlinear dynamics in superconducting networks –$36,109

College of the Holy Cross
Kevin J. Quinn, Department of Chemistry: Synthesis of dihydropyrans by ring expansion of vinyl epoxides –$35,040

Denison University
Steven D. Doty, Department of Physics and Astronomy: Thermal balance in three-dimensional sources: The next step in modeling and understanding the structure of star-forming regions –$42,000

Denison University
Prabasaj Paul, Department of Physics and Astronomy: Investigation of the scattering of light at photonic crystal interfaces using Padé approximation techniques –$23,682

Dickinson College
R. David Crouch, Department of Chemistry: Design, synthesis and assay of cyclopropane-containing agonists of α-adrenergic agents –$36,101

East Carolina University
Kwang Hun Lim, Department of Chemistry: NMR studies of ligand recognition properties of SH3 and WW proline-rich binding domains: Structure and dynamics –$35,000

Eastern Michigan University
Harriet A. Lindsay, Department of Chemistry: A versatile approach to polyhydroxylated pyrrolizidine alkaloids via an aza-Cope rearrangement-Mannich cyclization–$32,684

Eastern Washington University
Jamie L. Manson, Department of Chemistry: Hydrogen bonds and other weak intermolecular interactions as magnetic exchange mediators in complex materials –$34,770

Franklin and Marshall College
Edward E. Fenlon, Department of Chemistry: Polymethylene knots via a metal-templated synthesis –$38,088

Franklin and Marshall College
Scott M. Lacey, Department of Physics and Astronomy: Wave-chaotic dynamics in three-dimensional asymmetric optical resonators –$40,963

Franklin and Marshall College
Jennifer L. Morford, Department of Chemistry: Investigating the utility of silver and rhenium as complementary tracers for changing reducing conditions –$24,463

Gustavus Adolphus College
Scott K. Bur, Department of Chemistry: The development of vinyl glycine derivatives for use in 1,5-electrocyclizations and their application to natural product synthesis –$36,218

Harvey Mudd College
Ann Esin, Department of Physics: A study of photometric variability of stars in nearby star-forming clusters –$31,218

Hobart and William Smith Colleges
Justin S. Miller, Department of Chemistry: Solid-phase synthesis of cyclic, cysteine-containing natural products and analogues –$40,218

> … THE ONLY WAY OF DISCOVERING THE LIMITS OF THE POSSIBLE IS TO VENTURE A LITTLE WAY PAST THEM INTO THE IMPOSSIBLE.
>
> — *Arthur C. Clarke,* Profiles of the Future

Hofstra University
Oleg A. Starykh, Department of Physics: Effect of geometric frustration and disorder on weakly coupled spin chains –$28,583

Illinois State University
Gregory M. Ferrence, Department of Chemistry: σ-Bond metathesis reactions mediated by N-confused porphyrin lanthanide complexes and the divalent lanthanide hydride, $[(Tp^{tBu,Me})Yb(\mu\text{-}H)]_2$ –$40,000

Illinois State University
Shang-Fen Ren, Department of Physics: Investigations of phonon modes in semiconductor nanocrystals by 3-D simulations –$35,000

Illinois State University
Jean M. Standard, Department of Chemistry: Computer simulations of atmospheric sulfur oxide reactions –$37,643

Illinois State University
Q. Charles Su, Department of Physics: Relativistic quantum dynamics of one-and two-electron systems –$34,018

Illinois Wesleyan University
Ram S. Mohan, Department of Chemistry: Use of ionic liquids as environment-friendly and novel solvents for organic synthesis –$29,019

Illinois Wesleyan University
Gabriel C. Spalding, Department of Physics: Brownian particle streams in tuned optical lattices –$40,000

Ithaca College
Luke D. Keller, Department of Physics: Spectroscopic characterization of proto-planetary disks orbiting intermediate-mass stars –$33,484

John Carroll University
Yuh-Cherng Chai, Department of Chemistry: The regulatory role of cellular thiols on activation of caspase(s) in apoptotic cells –$35,007

Miami University
S. Burcin Bayram, Department of Physics: Polarization spectroscopy of highly excited state diatomic molecules –$33,939

Miami University
Paul Urayama, Department of Physics: Development of a novel imaging chamber for high-pressure biological fluorescence microscopy –$36,815

Mount Allison University
Glen G. Briand, Department of Chemistry: Synthesis and characterization of models for novel indium radio-pharmaceuticals –$28,000

Mount Allison University
Stacey D. Wetmore, Department of Chemistry: A computational study of how nature repairs damaged DNA purines –$21,089

Oakland University
Alberto G. Rojo, Department of Physics: Sequential fragmentation and the origin of quasihexagonal patterns –$30,684

Otterbein College
Uwe Trittmann, Department of Physics and Astronomy: Non-perturbative calculations in supersymmetric Yang-Mills theories –$34,980

Pacific Lutheran University
Myriam Cotten, Department of Chemistry: Solid-state NMR investigations of molecular recognition and biological function at interfaces using antimicrobial peptides –$45,465

Rowan University
Michael J. Lim, Department of Chemistry and Physics: Fast recombination in strongly coupled, ultracold plasmas –$41,176

St. John's University/College of St. Benedict
Jim Crumley, Department of Physics: The variation of ion cyclotron waves during the solar cycle due to composition effects- –$37,224

St. Joseph's University
Mark F. Reynolds, Department of Chemistry: Determining the mechanism of heme binding and inhibition in mammalian BK channels –$41,530

St. Mary's College of Maryland
Charles Adler, Department of Physics: Moving contact line measurements using twin-rainbow metrology –$38,138

St. Olaf College
Jeffrey J. Schwinefus, Department of Chemistry: Stability of the DNA double helix in mixed cosolvent systems –$35,218

San Diego State University
William F. Welsh, Deparment of Astronomy: Observations and modelling of transiting extrasolar planets –$37,850

San Francisco State University
Debra Fischer, Department of Physics and Astronomy: Detection of "hot Jupiter" planets orbiting nearby stars –$38,803

Santa Clara University
John Birmingham, Department of Physics: Neuromodulation of sensory feedback in a motor control system –$25,682

Seattle University
Paul W. Fontana, Department of Physics: Sheared-flow suppression of turbulence in two-dimensional flows –$50,184

Southern Illinois University at Carbondale
Samir M. Aouadi, Department of Physics: Real time spectroscopic ellipsometry study of the growth of nitride/metal nanocomposite and nanolaminate coatings –$42,000

Southwest Missouri State University
Kartik Ghosh, Department of Physics, Astronomy and Materials Science: Ferromagnetism in oxide-based dilute magnetic semiconductors –$34,604

Texas State University, San Marcos
Gary W. Beall, Department of Chemistry and Biochemistry: Development of a theoretical model for gas transport in polymer nanocomposites –$37,316

Towson University
M. Rajeswari, Department of Physics: Photoresponse and electrical noise in thin films of 2-phase manganites –$36,468

United States Naval Academy
Shirley Lin, Department of Chemistry: Synthesis and assembly of block copolymers containing noncovalent interactions –$37,000

University of Akron
Ang Chen, Department of Physics: Study of the physical mechanism of induced dielectric anomalies in $SrTiO_3$-based quantum paraelectrics –$41,000

University of Arkansas, Little Rock
James P. Luba, Department of Chemistry: Biochemical activity of glutathione peroxidase homologs from Staphylococcus aureus –$41,884

University of Dayton
Shawn M. Swavey, Department of Chemistry: Mechanistic studies of the reduction of O_2 in acidic solution at electrodes modified with redox-active multi-metallic porphyrins –$30,548

University of Illinois at Springfield
Keenan E. Dungey, Department of Chemistry: Porous heterobimetallic oxides for energy storage –$33,494

COTTRELL COLLEGE SCIENCE AWARDS (continued)

University of Louisiana at Lafayette
Radhey S. Srivastava, Department of Chemistry: Copper-catalyzed allylic amination of olefins –$41,783

University of Memphis
Andrew Richter, Department of Physics: High-resolution, time-resolved, in situstudies of protein adsorption onto functionalized surfaces using X-ray reflectivity –$39,912

University of North Carolina at Greensboro
Gregory M. Raner, Department of Chemistry: Stopped-flow and freeze quench techniques for the study of transient cytochrome P450 intermediates –$36,074

University of North Carolina at Greensboro
Jason J. Reddick, Department of Chemistry and Biochemistry: Polyketide biosynthesis in *Bacillus subtilis*: New chemistry from a familiar bacterium –$41,984

University of North Carolina at Wilmington
Paulo F. Almeida, Department of Chemistry and Biochemistry: Dynamics of membrane domains –$39,682

University of North Carolina at Wilmington
Sridhar Varadarajan, Department of Chemistry and Biochemistry: Design of molecules forming cytotoxic DNA-adducts in pancreatic b-cells –$41,968

University of North Florida
Lev Gasparov, Department of Natural Sciences: Raman and infrared studies of the layered transition metal chalcogenides –$40,384

University of Portland
Kevin Cantrell, Department of Chemistry: An investigation of the redox driven biogeochemical cycling of iron in the subsurface environment –$31,218

University of San Diego
David O. De Haan, Department of Chemistry: Secondary organic aerosol formation by acid-catalyzed surface reactions –$42,754

University of San Diego
Peter M. Iovine, Department of Chemistry: Synthesis and spectroscopy of conjugated light-harvesting compounds containing boroxine cores –$35,706

University of Texas at San Antonio
David M. Johnson, Department of Chemistry: Fundamentals of radical copolymerization: Do penultimate units exert an electronic effect on propagation kinetics –$24,884

University of Wisconsin, Eau Claire
Michael J. Carney, Department of Chemistry: Octahedral coordination geometry and its impact on polymerization catalysis –$30,000

University of Wisconsin, Eau Claire
Nathan A. Miller, Department of Physics and Astronomy: Probing the temperature structure and geometry of hot star x-ray emission –$23,218

University of Wisconsin, La Crosse
Todd Michael Weaver, Department of Chemistry: Structural studies of fumarase C mutants and transition state analogue complexes –$30,874

Vassar College
Zachary J. Donhauser, Department of Chemistry: Characterization of molecular-level inhomogeneities in the structure of microtubules –$35,666

Western Kentucky University
Colin D. Abernethy, Department of Chemistry: N-heterocyclic carbene complexes of early transition metals in high oxidation states –$39,672

Western Kentucky University
Christopher J.A. Daley, Department of Chemistry: Nitrile hydratase active site models: Study of structure, function, and role of post-translational modification using the synthetic analog approach –$40,803

Western Kentucky University
Ralph Nicholas Salvatore, Department of Chemistry: Investigations in organobarium chemistry: Novel mechanistic concepts and synthetic applications –$34,958

Westmont College
Allan M. Nishimura, Department of Chemistry: A study of water-halobenzene clusters on Al_2O_3(0001) surface by emission and cavity ringdown spectroscopy-$36,218

Wheaton College
Daniel L. Burden, Department of Chemistry: One-color, single-molecule optical and electrical recording of protein channel dynamics –$42,804

William Paterson University
Song H. Chung, Department of Physics: Ionic transport in phosphoric acid in aqueous media –$39,984

Williams College
David Tucker-Smith, Department of Physics: Phenomenology of warped unification –$31,218

COTTRELL SCHOLAR AWARDS

Cornell University
Paul J. Chirik, Department of Chemistry and Biochemistry: Nitrogen fixation with group 4 transition metals –$75,000

Northwestern University
Vassiliki Kalogera, Department of Physics and Astronomy: Genetic algorithms in gravitational wave astrophysics –$75,000

Purdue University
Garth J. Simpson, Department of Chemistry: Nonlinear optical probes of structure and function in biological systems; anatomy of a green laser pointer –$75,000

State University of New York at Buffalo
John Cerne, Department of Physics: Infrared hall effect in strange magnetic metals –$75,000

University of California, San Diego
Seth M. Cohen, Department of Chemistry and Biochemistry: A bioinorganic approach for designing improved matrix metalloproteinase inhibitors –$75,000

University of Chicago
Rustem F. Ismagilov, Department of Chemistry: Using minimal chemical model to understand complex biochemical networks and to create biomimetic functional systems –$75,000

University of Massachusetts, Amherst
Anthony D. Dinsmore, Department of Physics: Photonic glasses: Influence of the topology of random media on light propagation –$75,000

University of Missouri-Rolla
Carsten A. Ullrich, Department of Physics: New approaches for electron dynamics in semiconductor nanostructures and for teaching modern condensed-matter physics –$75,000

University of Pennsylvania
Bhuvnesh Jain, Department of Physics and Astronomy: Gravitational lensing as a probe of dark energy and cosmology –$75,000

University of Pittsburgh
Christian E. Schafmeister, Department of Chemistry: The development of rigid bivalent inhibitors of influenza hemagglutinin –$75,000

University of Toledo
Rosa Alejandra Lukaszew, Department of Physics and Astronomy: Investigating the structural and magnetic properties of nano-magnets –$75,000

RESEARCH OPPORTUNITY AWARDS

Ohio State University, Columbus
Gregory Lafyatis, Department of Physics: Optical lattices on chips: A possible solution to the "scaling-up" problem for ultracold atom quantum computing –$50,000

Rensselaer Polytechnic Institute
Alan Cutler, Department of Chemistry: Acetic acid synthesis catalysis: Transforming two greenhouse gases methane and carbon dioxide into acetic acid –$50,000

University of California, Los Angeles
Craig A. Merlic, Department of Chemistry and Biochemistry: Copper promoted synthesis of vinyl ethers –$50,000

University of California, Santa Cruz
Rebecca L. Braslau, Department of Chemistry: Design and preparation of ABA triblock copolymers as lipid bilayer mimics –$50,000

University of Illinois at Urbana-Champaign
Alexander Scheeline, Department of Chemistry: Levitated drop reactor: Towards highly parallel enzyme kinetics measurements –$50,000

University of Kentucky
John P. Selegue, Department of Chemistry: Organometalic heterocycle: Synthesis, structure, and applications –$50,000

Virginia Commonwealth University
Sarah C. Rutan, Department of Chemistry: Characterization of drug metabolism using chemometrics –$49,376

Wake Forest University
Keith D. Bonin, Department of Physics: Optical torquing and nanofluidics –$49,771

LOOK AT LIGHT AND ADMIRE ITS BEAUTY. CLOSE YOUR EYES, AND THEN LOOK AGAIN: WHAT YOU SAW IS NO LONGER THERE; AND WHAT YOU WILL SEE LATER IS NOT YET.

– Leonardo da Vinci

Research Corporation's condensed financial statements of financial position and of activity for the years ended December 31, 2004 and 2003 are presented in this section.

The Foundation's audited financial statements for 2004 and 2003 can be viewed online at www.rescorp.org/financials

CONDENSED STATEMENTS OF ACTIVITY AND CHANGES IN NET ASSETS YEARS ENDED DECEMBER 31, 2004 AND 2003

	2004	2003
REVENUE		
UNRESTRICTED REVENUES AND GAINS:		
Investment income, net	$15,801,148	$34,276,554
Other income	11,100	785,785
Total unrestricted revenues and gains	**15,812,248**	**35,062,339**
Contributions released from restrictions	250,000	
TOTAL REVENUE	**16,062,248**	**35,062,339**
EXPENSES		
Grants approved	4,954,942	6,305,473
Science advancement	1,392,532	1,072,600
Program-related	475,875	1,561,330
Information and communications	192,085	90,619
General and administrative	1,822,190	1,355,152
Interest and other expense	387,918	547,958
TOTAL EXPENSES	**9,225,542**	**10,933,132**
INCREASE IN UNRESTRICTED NET ASSETS	6,836,706	24,129,207
(DECREASE) INCREASE IN TEMPORARILY RESTRICTED ASSETS — Contributions received for restricted purpose	(250,000)	250,000
INCREASE IN NET ASSETS	6,586,706	24,379,207
NET ASSETS — Beginning of year	135,101,123	110,721,916
NET ASSETS — End of year	**$141,687,829**	**$135,101,123**

CONDENSED STATEMENTS OF FINANCIAL POSITION
DECEMBER 31, 2004 AND 2003

ASSETS	2004	2003
INVESTMENTS	$ 147,120,739	$ 142,461,511
Cash and cash equivalents	118,338	3,513,753
Restricted cash	1,028,880	250,000
Accrued dividends and interest receivable	317,012	257,461
Property and equipment—net	424,045	255,154
Notes receivable	4,318,404	6,043,404
Prepaid pension cost	1,143,780	1,295,000
Other assets	64,525	31,712
TOTAL	**$ 154,535,723**	**$154,107,995**

LIABILITIES AND NET ASSETS		
LIABILITIES:		
Grants payable	$4,556,243	$5,098,651
Line of credit	4,500,000	9,000,000
Notes payable	1,414,459	1,982,459
Other	2,377,192	2,925,762
TOTAL LIABILITIES	12,847,894	19,006,872
NET ASSETS:		
Unrestricted	141,687,829	134,851,123
Temporarily restricted		250,000
TOTAL NET ASSETS	**141,687,829**	**135,101,123**
TOTAL	**$154,535,723**	**$154,107,995**

OFFICERS

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John P. Schaefer President

Raymond Kellman Vice President

Suzanne D. Jaffe Treasurer

Sherri R. Benedict Secretary

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Suzanne D. Jaffe is President of S.D.J. Associates. She is a member of the Research Corporation Executive Committee, Audit and Finance Committee, Science Advancement Committee and Governance and Nominating Committee.

Patrick S. Osmer is Chair and Professor in the Department of Astronomy at Ohio State University. He is a member of the Research Corporation Audit and Finance Committee, Governance and Nominating Committee and Science Advancement Committee.

John P. Schaefer is President of Research Corporation. He is a member of the Research Corporation Executive Committee, Audit and Finance Committee, Science Advancement Committee and Governance and Nominating Committee.

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George L. Shinn is Chairman and Chief Executive Officer Emeritus of The First Boston Corporation.

G. King Walters is the Sam and Helen Worden Professor Emeritus of Physics at the Department of Physics and Astronomy at Rice University.

AWARD PROGRAMS ADVISORY COMMITTEE

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Nancy M. Haegel is a Professor of Physics at the Naval Postgraduate School.

Brent L. Iverson is a Professor of Chemistry and Biochemistry at University of Texas at Austin.

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Mats A. Selen is a Professor of Physics at the University of Illinois at Urbana-Champaign.

Thomas D. Tullius is a Professor of Chemistry at Boston University.

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Front and back covers: Photogenic drawing by Ellen Carey. Page 6: Self Portrait with Balloon and Bullet, 1959, by Harold Edgerton, © Harold & Esther Edgerton Foundation, 2005, courtesy of Palm Press, Inc. Page 7: Large Binocular Telescope Observatory. Page 8: Camera obscura, from Johannes Zahn's *Oculus artificialis teledioptricus,* 1685, Würzburg. Page 9: Top, Portrait of Johannes Kepler, The Observatory of Kremsmünster; Bottom, The Arnolfini Marriage, 1434, by Jan van Eyck. Page 10: Early eighteenth-century illustration comparing the function of the *camera obscura* and the function of the eye. Page 11: Virgin and Child with St. Anne and St. John the Baptist, 1499–1500, by Leonardo da Vinci. Page 12: Diana and Her Companions, ca. 1653-1656, by Johannes Vermeer, Mauritshuis, The Hague. Page 13: Top, Portrait of Louis-Jacques Mandé Daguerre, 1844, by Jean-Baptiste Sabatier-Blot; Bottom, Galloping Horse, 1878, by Eadweard Muybridge. Page 14: Top, Albrecht Dürer's interpretation of Leon Battista Alberti's "Reticolato," a transparent grid that could be placed in front of a scene as an aid to drawing in perspective, a precursor of the *camera lucida*; Bottom: "Haystack" series, 1890–1891, by Claude Monet. Page 15: Exponential, electrons launched from the upper right fan out and then form branch, as indirect effects of traveling over bumps, by Eric J. Heller. Page 16: M.C. Escher's "Rippled Surface," 1950, Linoleum cut, © 2005 The M.C. Escher Company-Holland. All rights reserved. www.mcescher.com. Page 17: Rotating Rotator II, by Eric J. Heller. Page 18: Starbirth in the Milky Way, © 2001 by Lynette Cook. Page 19: Portrait of Ansel Adams, ca. 1980, by John P. Schaefer. Page 20: Top, Magnify, 2005, Dena McDuffie; Bottom, Chauvet-Pont-d'Arc, France. Page 21: An atomic force microscope image of a hexagonally-ordered array of alumina nanopores that were fabricated by anodization, as viewed from the top. The size of the image is 1 micron by 1 micron. Robert M. Metzger, University of Alabama; National Science Foundation.

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