spoke out for inventors and for technical education. Unfortunately, however, much of the Parsons tale is from a time now gone. The heroic inventor with a small staff, choosing his problems as he pleases, obsessed with perfection, creative, honest, indifferent to riches — such as Parsons, Thomas Edison and Polaroid inventor Edwin Land — may be no more. The quick fix, the fast buck, the multinationals and the prevailing greed make their birth difficult and their survival unlikely.

From Galaxies to Turbines is stuffed with facts, figures, diagrams, pictures and quotations, many from archival sources. The pile of details helps to measure the breadth and height of the Parsons' achievements. These have an authoritative analyst in Scaife, formerly a power engineer, lecturer in mechanical engineering and fellow of Trinity College, Dublin. He could have let himself go even further than he has, for some diagrams need more explanation than they are given. But it is not necessary to follow all the details. You do not need them to freeze vicariously with William and his friends on clear, cold, winter nights looking for nebulae, or to broil near the furnaces where he melted his mountains of glass. With a little attention you can shiver with Charles in the spray and sicken with the swells as *Turbinia* suffers through her many trial runs, or feel the fatigue and frustration of his incessant tinkering. Scaife's unpretentious text makes plain the courage, stubbornness and stamina that created the Parsons family Leviathans and offers welcome refreshment among the gimcracks and glitter of more fashionable histories of science. ■

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Science in culture

Art advances science

Today's scientists stand on the shoulders of pioneering artists

Robert S. Root-Bernstein

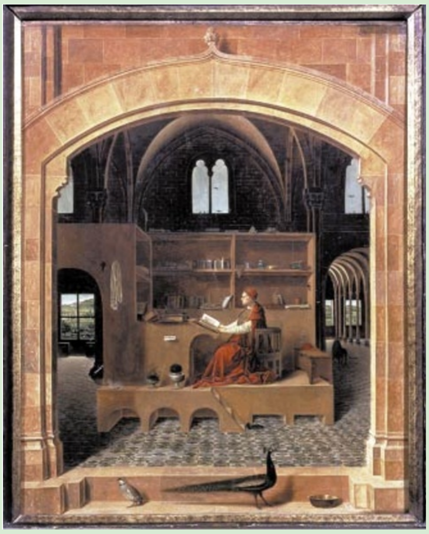
At the Nobel conference in 1980, director Thomas Gover asked his colleagues: "Can you think of an example where an artist has supplied the missing piece in some understanding of the physical world?". William Lipscomb, a laureate in chemistry, replied: "Not an original one." Escher, he suggested, may have added something to the scientific exploration of colour symmetry. The physicist Freeman Dyson offered Goethe's colour theory, cautioning that it "turned out to be a rather dismal failure". Art, the participants concluded, has provided nothing to science.

I hesitate to disagree with men as accomplished as Dyson and Lipscomb, but they are wrong. The arts often contribute to modern science. While space permits only a few exemplars, these contributions can be found in every science and include the invention of new structures, techniques and aesthetic sensibilities.

Artists often invent new structures that scientists then discover in nature. Virologists attempting to understand the structure of the protein shells that surround spherical viruses such as polio during the 1950s were directed by knowledge of Richard Buckminster Fuller's geodesic structures. These also became the models for numerous carbon molecules aptly named fullerenes, including the perfect geodesic dome C_{60} — buckminsterfullerene.

Sculptor Kenneth Snelson has had a similar impact on scientific thinking through his role in the invention of tensegrity, a principle by which a stable structure is created by linking stiff, non-compressible units (such as rods) with highly flexible material (such as a rope) under tension. Donald Ingber and Steven Heidemann recognized that tensegrity sculptures have many similarities with protein structures and have been modelling them using this art.

Artist Wallace Walker, while studying in the 1960s, was asked to make a three-dimensional object out of a sheet of paper only by folding and gluing it. The result was a complex doughnut that could be folded through its centre hole into a kaleidoscopic variety of shapes. Doris



Renaissance perspective painting, as seen in *St Jerome in His Study* by Antonello da Messina.

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Schattschneider, a mathematician specializing in geometric objects, determined that Walker's paper sculpture was the first of a novel class of geometric objects, now called kaleidocycles.

Many scientific techniques also originate in art. Anamorphosis — 'shape change' — derived from the Renaissance discovery of perspective drawing: mapping a three-dimensional object onto a flat surface. Artists then realized that two-dimensional objects could be mapped onto three-dimensional surfaces, including spheres, cones and rods. Such transformations became central to D'Arcy Thompson's *On Growth and Form* and Julian Huxley's *Problems of Relative Growth*, both of which describe evolutionary and embryological processes as anamorphic distortions. Anamorphosis also underlies Wilder Penfield's and Clinton Woolsey's studies of the motor and sensory mappings of primates onto the cortex of their brains, which yield homunculi with huge lips, hands and feet, and tiny bodies.

Another striking example is the reification of logic in modern computer chips. Chips are manufactured using methods adapted directly from silk screening and etching. Logical operations are carried out in electronic gadgets only because the art exists to transform them into physical patterns, and these patterns exist only because their designers understand how to transform logical operations into images.

Finally, the arts can foster scientific advances through the development of new aesthetics. The process of breaking a picture into discrete areas of colour (pixels) was invented by pointillist painters such as Seurat. The technique of false-colouring objects, which scientists use to emphasize inobvious elements of data, was invented by Fauvist painters. Abstract art, in which a single element of a complex phenomenon (such as its pattern, structure or colour) is chosen for selective description, was pioneered by Picasso and Kandinsky in the 1920s.

Indeed, there is growing understanding that art fosters science. Mitchell Feigenbaum, one of the pioneers of chaos theory, believes that understanding how artists paint will provide the cognitive insights necessary to do better science. "It's abundantly obvious that one doesn't know the world about us in detail," he said. "What artists have accomplished is realizing there's only a small amount of this stuff that's important, and then seeing what it was. So they can do some of my research for me." C. S. Smith of MIT spent a lifetime studying oriental arts and crafts for the insight they gave him into metallurgy. "I have slowly come to realize that the analytic, quantitative approach I had been taught to regard as the only respectable one for a scientist is insufficient," he said. "The richest aspects of any large and complicated system arise from factors that cannot be measured easily, if at all. For these, the artist's approach, uncertain though it inevitably is, seems to find and convey more meaning."

In short, the arts and sciences are as integral today as they were in the Renaissance. We must foster the connections and the people who can make them. For as Robert Mueller, an MIT-trained engineer and artist, wrote in his stimulating book, *The Science of Art*, "Art may be a necessary condition for constructing the new consciousness from which future science gets its structural realities to match nature, in which case it is more important then we generally admit." ■

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