Music, Creativity and Scientific Thinking

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ABSTRACT

Are music and science different types of intelligence (as posited in the context of Howard Gardner's multiple intelligences), or are they two manifestations of common ways of thinking? By focusing on scientists who have been musicians and on the ways they have used their musical knowledge to inform their scientific work, the author argues in this article that music and science are two ways of using a common set of "tools for thinking" that unify all disciplines. He explores the notion that creative individuals are usually polymaths who think in trans-disciplinary ways.

Mathematics and music! The most glaring possible opposites of human thought! and yet connected, mutually sustained! It is as if they would demonstrate the hidden consensus of all the actions of our mind, which in the revelations of genius makes us forefeel unconscious utterances of a mysteriously active intelligence.

—Hermann von Helmholtz,
"On The Physiological Causes of Harmony in Music," 1857 [1]

Imagine that you are attending an orchestral concert. You listen with great appreciation to compositions by William Herschel (1738–1822), Hector Berlioz (1803–1869), Aleksandr Borodin (1833–1887), Sir Edward Elgar (1857–1934) and Ernest Ansermet (1883–1969); and new pieces by Iannis Xenakis (b. 1922) and Richard Bing (b. 1909). At the end of the concert, the conductor, Tom Eisner (b. 1930), motions for silence and makes the following announcement:

> This has been a very special concert in ways in which most of you are probably unaware. Everything about this concert is permeated with science. I, myself, am an expert in insects. The entire orchestra is made up of scientists and physicians. Indeed, you may well know that "doctor's symphonies" exist in most major cities in the United States. But most importantly, all of the composers whose music we have played tonight also have ties to science. Herschel was perhaps the most famous astronomer of the early nineteenth century and some of his compositions have recently been recorded on the Newport Classics label [2]. Berlioz was a practicing physician; Borodin was a Professor of Chemistry who pursued two professional careers simultaneously throughout his life; Ansermet trained as a mathematician and taught mathematics at the University of Lausanne before turning his attention solely to music [3]. Iannis Xenakis is also a mathematician, who adds to his accomplishments those of a practicing architect, and he has written extensively on the interconnections between the arts and sciences [4]. Elgar not only had a private chemistry laboratory, but actually filed a patent for a process for producing hydrogen sulfide [5]. Bing is a cardiologist and medical researcher of international repute who has been awarded such international prizes as the Claude Bernard Medal for his scientific work [6].
>
> What you have heard, then, is not just music, but music created by people with an unusual facility to cross the boundaries of disciplinary knowledge. In our super-specialized world, it is worth considering what they, and their musical accomplishments, tell us about creativity. Thank you, and good night.

The concert just described never happened and Tom Eisner never said the words I have put into his mouth. But Eisner, Schurman Professor of Biology at Cornell University, really is an entomologist who plays piano and conducts concerts. He was trained by the conductor Fritz Busch [7]. The list of scientist-composers and of composers who have dabbled in science is actually much longer than the one I have had Eisner use (see Table 1) and could be extended significantly if scientists who have set their science to music were included [8]. For example, biochemist Harold Baum's *The Biochemists' Songbook* [9] is a complete guide to biochemical pathways—available on cassette—that is scientifically accurate and amusing. (Imagine the tricarboxylic acid pathway sung to the tune of "Waltzing Matilda." That gives you the idea . . .) Or think of Harvard-trained mathematician and professional entertainer Tom Lehrer and his song "The Elements" [10]. As I have Eisner say, there really are doctors' symphonies and other orchestras, such as the New Orchestra of Boston, composed largely of medical and scientific professionals and, once again, the participants include an unusually large proportion of well-known scientists, including many Nobel laureates [11]. Less formal concerts take place regularly at institutions such as the Woods Hole Oceanographic Institute and meetings of the Geological Society [12]. In fact, in 1987, Walter Thirring (b. 1927), an internationally known physicist and composer at the Institut fur Theoretische Physik of the University of Vienna, actually carried out a concert like the imaginary one described above. Thirring tells me he studied with Anton von Webern during World War II, with Josef Marx and with two pupils of Arnold Schönberg—Edwin Ratz and Josef Polnauer—after the War. For the concert, he gathered his scientific colleagues together to perform music, including some of his own, all of which was composed by scientists.

Enough scientists have actually designed or built musical instruments that one could even play such a concert with those instruments alone. Hermann von Helmholtz, for example, was an accomplished poet and a fine pianist who had a piano built with an unusual tonal development upon which he experimented both privately and for his physics and psychology students [13]. Walther Nernst, the Nobel laureate who coined the third law of thermodynamics, is also credited with inventing the first electronically amplified musical instruments [14] (although that honor may arguably belong to inventor Elisha Gray, whose attempts to invent the telephone

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utilized electrified keyboards and violins [15]). James Dewar, the ultra-low temperature physicist who invented flasks designed to hold frozen gases, made his own violins [16]. Virginia Apgar, the obstetrician whose name attends the birth of every child when they are given an Apgar score, made her own stringed instruments. Colleagues recently played a quartet using her instruments [17].

Okay: so what? What difference does it make that so many scientists indulge in musical avocations? Well, on the one hand, we have cognitive theories, such as Howard Gardner's multiple intelligences [18], which argue for domain-specific ideation linked to disciplinary specialization. In other words, skills learned in one domain do not inform work in another. I, on the other hand, believe that creative thinking is trans-disciplinary and transferable from one field to another. More specifically, I believe that musical and scientific abilities are what I call "correlative talents" [19]. By correlative talents, I mean skills or abilities in several different areas that can be integrated to yield surprising and effective results. Skills associated with music—pattern-forming and pattern recognition, kinesthetic ability, imaging, aesthetic sensibility, analogizing and analysis—and indeed an understanding of music itself—have often been important components of the correlative talents of many famous scientists. One way to summarize my basic thesis would be to say that correlative talents represent harmonious ensembles of skills that enable musical scientists to "duet" better.

How does music help the scientist perform better (yes, the puns are purposeful!)? Musical scientists often make scientific use of their musical training and interests. A musical geophysicist at the California Institute of Technology, who wished to remain anonymous, justified his dual interests to me as follows: suppose, he said, "someone is getting interested in musical problems. He may then apply what he finds there back to his scientific research. That is something that may affect very much the result. I think it is good. I think for a scientist who is working very hard, anything is good that brings from time to time another angle about general ideas into the picture" [20]. Numerous historical examples bear him out [21].

Rene Leannec, an early nineteenth-century physician, painted, played the flute and invented the stethoscope [22]. Is it really conceivable that chance dictated that his invention, and even its specific form (a long, thin wooden tube), is so similar to the instrument he played? Could he have made the instrument without the kinesthetic skills of an artist? Could he have used it effectively without the trained ear of a musician that can hear the whisper of a valve not closing properly as easily as the difference between the styles of James Galway and Jean-Pierre Rampal? The answer I get from my cardiologist colleagues is that you certainly do not want a tone-deaf doctor performing stethoscopy!

Karl Rudolph Koenig was a violinist and one of Helmholtz's physics students, who also melded music and science. As a young man, he became so interested in musical instruments that he apprenticed himself to the violin maker Vuillaume. Melding vocation and avocation, he began to invent new types of acoustical and optical equipment, some of which was incorporated into Edison's inventions and the apparatus used by Michelson and Morley to measure the speed of light [23]. Many inventors of scientific instruments, including physicists Dewar and Charles Wheatstone and physical chemists Wilhelm Ostwald and Martin Kamen, have similarly musical backgrounds [24].

Helmholtz himself not only invented a new tonal development for the piano but was also one of the major developers of the siren, which he used, notably, not to make obnoxious noise as we do today, but more in keeping with the original meaning of its name, to make beautifully pure tones that would woo the listener. Helmholtz used his sirens to investigate the psychological and physiological bases of harmony. He also invented a variety of new harmonic oscillators, including the "resonator," and worked out the basic physical laws governing their function [25]. He used these resonators to demonstrate that complex sounds can be generated by adding simple, pure tones—the logical and historical basis for modern-day synthesizers.

Helmholtz's resonators became models both mechanistically and mathematically for the development of black body theory—the historical basis of quantum theory—at the hands of two other musically talented scientists, Ludwig Boltzmann and Max Planck, at the beginning of this century. Planck's notion of the quantum—meaning simply a discrete state—is based purely on the mathematics of resonating strings, or harmonic frequencies. Electrons, as the Prince Louis de Broglie, another of our musically active physicists, discovered, can vibrate like strings around the nucleus of the atom. It followed from this discovery that electrons, like strings, should have harmonic frequencies, a musical analogy that de Broglie published with predictions of what these harmonic frequencies would be; these harmonics were experimentally verified.

Table 1. Scientist-Composers [76]*

Ernest Ansermet (1883–1969)	Mathematician
George Antheil (1900–1959)	Endocrinologist and Inventor
Joseph Auenbrugger (1722–1809)	Physician
M.A. Balakirev (1837–1910)	Mathematician
Hector Berlioz (1803–1869)	Physician
Theodor Billroth (1829–1894)	Surgeon
Richard Bing (b. 1909)	Cardiologist
Aleksandr Borodin (1833–1887)	Chemist
Diana S. Dabby (contemporary)	Mathematician
Edward Elgar (1857–1934)	Chemist
John Conrad Hemmeter (1863–1931)	Physiologist
William Herschel (1738–1822)	Astronomer
Elie Gagnebin (1891–1949)	Geologist
Hilary Koprowski (b. 1916)	Microbiologist
B.G.E. Lacepede (1756–1825)	Zoologist
Alexis Meinong (1853–1920)	Experimental Psychologist
Albert Michelson (1852–1931)	Physicist
Arthur Roberts (nd — 20th century)	Chemist
Ronald Ross (1857–1932)	Epidemiologist
Camille St. Saens (1835–1921)	Astronomy
Bela Schick (1877–1967)	Microbiologist
Joseph Schillinger (1895–1943)	Mathematician
Walter Thirring (b. 1927)	Physicist
Georges Urbain (1872–1938)	Inorganic Chemist
Emile Votocek (1872–1950)	Chemist
Iannis Xenakis (b. 1922)	Mathematician and Engineer

* Based on material from references [2], [4], [5], [8], [65] and [76].

These harmonics, like those of a vibrating string, are "quantized," or divided, into discrete standing waves. Planck's discovery of quantum states also resulted directly from treating these electron waves as if they were vibrating strings making music. The mathematical formalisms of these cases are identical [26]. Thus, the histories of music and quantum physics are inextricably linked, as Einstein recognized when he proclaimed Planck's version of Bohr's atomic model "the highest form of musicality in the sphere of thought"—a double tribute to its "miraculous" harmony with experimental results and its literally musical structure [27]. Einstein went on to say that his own relativity theory ". . . occurred to me by intuition. And music is the driving force behind this intuition. My parents had me study the violin from the time I was six. My new discovery is the result of musical perception [28]."

Contemporary scientists continue this integrative tradition. Almost everyone has heard of Johann Kepler's music of the spheres; analogously, Heinrich Kaiser has written out De Broglie's tonal harmonies and harmonics of the atoms [29]. The use of musical techniques to analyze scientific data is also coming into its own: biochemists at Michigan State University, for example, have invented musical urinalysis [30]. This transformation makes data accessible to visually impaired individuals and to physicians whose eyes and hands may be busy elsewhere (e.g. operating on the patient). Also, people are much more sensitive to tonal discrepancies than they are to visual alterations in peak height or numerical differences, so that they can analyze musical data more quickly and accurately than visual forms. For these reasons, geneticist Susumo Ohno has converted DNA sequences into musical equivalents that sound like Chopin nocturnes in order to listen for the patterns that lie hidden within our genes [31]. Meanwhile, John Dunn and Mary Anne Clark [32] and Phil Ortiz [33] have transformed protein sequences into musical equivalents that convey not only linear but conformational data simultaneously. And physiologist Hugh S. Lusted and electrical engineer R. Benjamin Knapp have collaborated to convert electrical signals and muscle movements into music by means of a simple electronic instrument known as the Biomuse. They note that their research reveals that "the body is literally a symphony (or society) of electrical voices, sounding at different frequencies and intensities" [34]. Physician Lloyd Morey notes (another pun!) that the symphonies that emerge through Biomuse or similar technologies may someday "help us understand various psychiatric problems, mood swings and probably brain-dysfunction disorders as well" [35]. After all, we are not merely a set of parameters, such as blood pH, hematocrit, blood glucose and melatonin levels, but a complex interweaving of all of these and many more—multi-stranded interweavings that only music can allow us to eavesdrop upon in real time.

These selected examples illustrate a phenomenon I call *synosia*. Synosia is a term I invented as an analogy to the neurological concept of synaesthesia [36]. In neurology, synaesthesia refers to a phenomenon in which a person experiences a sensation in one of the five senses when another of the senses is stimulated. For example, a person eating a banana may experience the sound of bells, or a person seeing the color red may smell a cake baking. While only a small percentage of people experience such unusual synaesthetic experiences, we all know things ("know" being from the root word *gnosis*) in several ways simultaneously. An equation can have mathematical, verbal, aural and visual meanings, and some people experience all simultaneously. We may know a gene sequence as music, chemistry and a set of alphabet letters all at once. Synosia, then, is derived from the words *synaesthesis* and *gnosis*—to know and feel simultaneously in a multi-modal, synthetic way.

Music plays a special role in my concept of synosia because it can simultaneously be kinesthetic (we must move to make music), emotional, analytical and sensory. "Music is unique in combining quality and quantity precisely and spontaneously so that sense impression can be measured and proportion can be experienced," writes Siegmund Levarie [37]. "The human sense of hearing has remarkable powers of pattern recognition," adds chemist Robert Morrison, "but hearing has largely been ignored as a means of searching for patterns in numerical data" [38]. "We have really great computers between our ears," agrees Joseph Mezrich, formerly of AT&T Bell Labs [39]. In consequence, these and other researchers at Lucent Technologies, Exxon, Xerox, and various universities are exploring methods for transforming complex data such as taxonomic and economic data into music. Very simply, it is possible for the ear to hear the patterns in dozens of variables changing simultaneously, just as it can hear and analyze an entire symphony orchestra with dozens of separate musical parts, whereas it is impossible for the eye (or even for most computers) to handle that many changing variables and derive sense from them [40]. Thus, the mathematician, poet and musician Joseph Sylvester asked himself a century ago: "May not Music be described as the Mathematic of sense, Mathematic as Music of the reason? The soul of each the same! Thus the musician feels Mathematic, and the mathematician thinks Music—Music the dream, Mathematic the working life" [41].

I believe Sylvester is right, and I would add that mathematics (like most ways of knowing) is convertible into many other forms, including visual and kinesthetic ones, as well as into music. Certainly, most scientists and mathematicians of any stature in their field report a semi-conscious stream of thought composed of kinesthetic feelings, images, verbal or acoustical patterns, and/or musical themes accompanying their problem-solving. Einstein said that he never thought in equations; he felt or visualized the answers, then converted his insights into mathematics at a later stage for communicating his insights to others [42]. Richard Feynman, arguably the most creative physicist since Einstein, also described this translation process following an initial period of imagistic and kinesthetic insight consisting of a literally synaesthetic sense of equations that appeared to his imagination as specifically colored symbols. Equations also manifested themselves to him as particular sounds that he would express to colleagues and students as whoops, glissandos or patterns of drumbeats. He even described thinking in "acoustical images" [43]. Rolf Nevanlinna, a Scandinavian mathematician who was also a concert-caliber violinist and president of the Sibelius Society, remarked that music was in some mysterious way a constant accompaniment to his mathematical researches [44]. Similarly, Philip Davis and Reuben Hersh, the authors of *The Mathematical Experience,* report having worked on a mathematical problem for many months to the accompaniment of various mathematical images and repetitive musical themes. Other commitments caused them to lay aside their work for several years, but when they took it up again, the images and musical themes also recurred [45].

The synosial phenomenon is common enough that many scientists report working best to the sound of music. Metallurgist Charles Martin Hall, who discovered how to extract aluminum from its ore in economical quantities, was reported to go to his piano whenever an intractable problem presented itself, thinking more clearly as a result of the music [46]. Einstein's son also said of his father that, "Whenever he had come to the end of the road or into a difficult situation in his work, he would take refuge in music, and that would usually resolve all his difficulties" [47]. Einstein himself said, "both [music and research] are born of the same source and complement each other through the satisfaction they bestow" [48]. Richard Bing, our cardiologist-composer, has also stated, "Writing music enriches me to look at science in a different way. It helps me emotionally to *feel* more about science. You see, I am a romanticist. I perceive science as an emotional exercise of searching the unknown" [49]. For Charles Darwin, music was *too* effective in stimulating the mind. He found that he had to avoid concerts as he became older because they "set my mind to too rapid perambulations" [50].

Is synosia all-pervasive? Does everyone do their best problem-solving while doing something else? Does the musical theme link and carry diverse thoughts, bridging the silences or gaps between them? Do its patterns provide structured guidance, or themes, along which ideas can travel and merge like the carrier waves of radio frequencies? Or, do these musical patterns simply remove the intellectual constraints that have blocked the paths of creative solutions by focusing the conscious mind elsewhere, so that intuition can do its work? Recent work by Rauscher and other investigators on the so-called "Mozart effect," in which students listening to Mozart regularly or learning how to play musical instruments scored higher on visual problem-solving tests, suggests that something like this phenomenon may be going on [51]. A physical basis for this may exist, since structural brain asymmetries have been observed in musicians that are not present in non-musicians [52] and it appears that the unusual necessity of using the left hand (especially in string players) actually restructures the right, visual side of the brain [53].

Indeed, I have found that musical scientists use visual forms of thinking to a greater degree than even scientists with visual arts avocations [54], but this is a topic on which much more needs to be known.

The critical point here is that ideas manifest themselves to creative scientists as sensory images, musical themes or kinesthetic feelings and must, as Faraday and Maxwell pointed out long ago [55], then be translated laboriously into formal languages such as words or mathematics in order to be communicated. The creative individual must therefore be synosic in order to link the preverbal, intuitive forms in which ideas occur to their descriptive, communicable forms. Thus, no one with monomaniacal interests or limited to a single talent or skill can, to my mind, be creative, since nothing novel or worthy can emerge without making surprising and effective links between things—like the puns with which I have purposefully peppered this article in order to reveal commonalities between musical and scientific language. To create is to combine, to connect, to analogize, to link and to transform.

Thus, everyone of eminence, to quote novelist Henry Miller (himself an artist), "has his or her violin d'Ingres" [56]. Ingres, of course, was one of many artists (Henri Matisse and Ansel Adams also come to mind) well known for musical performance. Miller's point is that all creative individuals have avocations that they practice at very high levels along with their vocations. This is not to equate having multiple interests or skills with creativity; it is not simply that the people I have described are multi-talented, or polymathic. Their talents are correlated in such a way that they interact *fruitfully*. I stress the fruitfulness. Creativity comes from finding the unexpected connections, from making use of skills, ideas, insights and analogies from disparate fields. Thus, my concept of correlative talents and its own correlate, synosia, help explain for me why true creative ability is so rare. Of the set of multi-talented people, who are in turn a subset of all the people who are singly talented, only some will develop the necessary integration of thinking modes necessary to make their talents interactive. It is my belief, after many years of study, that those who do develop interactive or correlative talents often do so because they have a predisposition—learned or innate or a combination of the two, I cannot tell—to view their intellectual world globally and holistically. Thus, the view I have just given of music as a manifestation of thinking, rather than as an independent type of thinking, is colored by my interest in these polymaths and by my particular theory of creativity as being an integrative, transformational process.

Needless to say, I am stretching the available data, but there are hints that my interpretation may be correct. Many very successful scientists have themselves associated their success with their polymathic aptitudes. Flautist-poet J.H. van't Hoff, the first Nobel laureate in chemistry [57], physicist-artist Pierre Duhem [58], biologist-artist David Nachmansohn [59], physicist-historian-philosopher Gerald Holton [60] and physicist-inventor-novelist Mitchell Wilson [61] all claim that the entire complex of skills and experiences that we call personality are reflected in the specific form that individual scientists' discoveries take. Two other Nobel laureates, artist-neuroanatomist Santiago Ramon y Cajal [62] and novelist-immunologist Charles Richet [63], both argued that the great advances in science are not due to monomaniacal specialists, but to people who have excelled broadly in their vocations and avocations [64].

Pioneers of psychology such as Francis Galton [65], Henri Fehr [66], P.J. Moebius [67], R.K. White [68] and Jacques Hadamard [69] have verified this idea with anecdotal evidence, showing that scientific and mathematical "geniuses" have always been unusually "versatile" in their range of skills and hobbies. Historian Paul Cranefield found the same thing when he did research on the founders of biophysics, such as Helmholtz, Du Bois Reymond and their students. The more hobbies and cultural pursuits each scientist had, the more discoveries he made [70]. More recently, Roberta Milgram has been studying the professional success of thousands of Israeli students who have performed extremely well in the sciences and mathematics. She has found that a much better predictor of career success than IQ, grades or discipline-specific test scores, or any combination of these, was presence or absence of challenging leisure-time activities that require substantial cognitive input and practice. Playing an instrument or composing music, painting, writing poetry, carpentry, building electronic devices and computer programming are examples [71]. I and my collaborators have compiled similar data. We have shown in a group of 40 male scientists that success (whether measured by impact of publications or other related measures) was statistically correlated with their active participation in music, arts and literature as adults. We also found that the scientists' styles of thinking (visual, verbal, auditory, kinesthetic, etc.) were correlated with their hobbies in that visually oriented scientists have more images in their imagination, while verbally oriented ones are more likely to become science commentators and theorists [72].

So, if we are to succeed in understanding creativity, we must understand polymathic people and their multiple talents. We must understand how to deal with integrative intersections in the field of creativity, where music and science meld too completely to be differentiable. Inventions are a result of a continuum of experiences that necessitate the rethinking and re-categorization of all that went before [73]. We will therefore be able to recognize the greatest breakthroughs in the use of the human imagination precisely by their inability to be subsumed into the existing categories of sciences or arts. Each such advance will create new possibilities that we could not even have imagined before, which is just why biologist John Rader Platt believes that the melding of sciences and arts will remain so exciting: "Our verbal and musical symbols scarcely represent the whole field of possible sounds; painting, sculpture and architecture scarcely scratch the surface of the organization of visual space; and I am not sure that mathematical symbols represent all the forms of biological logic. What new kinds of symbols are we preparing to manipulate, color organs, Labanotation for the ballet, or a dozen others, calling for new talents and developing new types of youthful genius? . . . What symphonies they will compose! What laws they will discover!" [74] And what insights can polymaths such as Apgar, Bing, Borodin, Dewar, Einstein, Thirring and Xenakis provide for our understanding of creativity!

> Music the dream, Mathematic the working life—each to receive its consummation from the other when the human intelligence, elevated to its perfect type, shall shine forth glorified in some future Mozart-Dirichlet or Beethoven-Gauss—a union already not indistinctly foreshadowed in the genius and labors of a Helmholtz!
>
> —Joseph Sylvester, 1864 [75]

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