Chapter 42

Multiple Giftedness in Adults: The Case of Polymaths

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Abstract Creativity researchers often assert that specialization is a requirement for adult success, that skills and knowledge do not transfer across domains, and that the domain dependence of creativity makes general creativity impossible. The supposed absence of individuals who have made major contributions to multiple domains supposedly supports the specialization thesis. This chapter challenges all three legs of the specialization thesis. It describes individuals who have made major contributions to multiple domains; reviews prior literature demonstrating polymathy among creative adults; and presents data from an ongoing study of literature, science, and Nobel laureates in economics that confirms this creativity–polymathy connection.

Keywords Polymathy · Polymaths · Creativity · Specialization thesis · Domain dependence of creativity · General creativity · Multiple domains · Creative adults

Introduction

Whether gifted adults are generally or particularly creative and what the relationship of polymathy to giftedness may be are contentious issues for cognitive psychologists (Amabile, 1996; Gardner, 1993; Baer, 1998; Sternberg, Grigorenko, & Singer, 2004; Kaufman & Baer, 2005). The main issue being debated in the field is whether people are generally creative or specifically creative. Many psychologists assert that individuals can contribute to only one specialized profession or domain (Carey & Spelke, 1994; Feist, 2005; Gardner, 1983; Gardner, 1999; Karmiloff-Smith, 1992). The reasons specialization is thought to be required are diverse. Some psychologists suggest that the detailed knowledge and skills that must be acquired to contribute creatively to a discipline are too great for any individual to master more than one set in a lifetime. Others propose that non-overlapping and cognitively different types of intelligence are required to excel in different fields of endeavor and the likelihood of inheriting or developing multiple types of intelligences to the level necessary to be creative is vanishingly small. And a few have argued that even if an individual had the inherent set of intelligences and could acquire the necessary training in several disciplines, there is no evidence that transfer of knowledge and skills occurs between them, and therefore no reason to believe that a person who is creative in one discipline will be any more likely to be creative in another discipline. In sum, many psychologists argue that gifted adults are specialists and that their creativity stems from intensive application to a single domain. From this creativity-stems-from-specialization perspective, polymathy is rare and unrelated to creative ability.

A minority of psychologists disagree, arguing that creativity is not limited to single domains, but is a more general trait. In particular, Catherine Cox argued that among historical personages, the more creative an individual was, the more varied their intense interests (Cox, 1926, Table 41). R. K. White found similarly that “the typical genius surpasses the typical college graduate in range of interests and. . .he surpasses him in range of ability” (White, 1931, p. 482). Lewis Terman summarized his findings concerning gifted individuals by saying that “Except in music and the arts, which draw heavily on specialized abilities, there are few persons who achieved great eminence in one field without

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displaying more than average ability in one or more other fields" (quoted from Seagoe, 1975, p. 221). Eliot Dole Hutchinson similarly concluded in his 1959 study of creative individuals that multiple talents were the norm: "It is not by accident that in the greatest minds professions disappear.... Such men are not scientists, artist, musicians, when they might have just as well have been something else. They are creators" (Hutchinson, 1959, pp. 150–152). Finally, Roberta Milgram has found that career success in any discipline is better correlated with one or more intellectually stimulating and intensive avocational interests than IQ, grades, standardized test scores, or any combination of these (Milgram & Hong, 1993).

The observation that creativity is associated with polymathic ability has been validated by historians as well. Historian of science Paul Cranefield found that among the men who founded the discipline of biophysics during the mid-19th century (a group including Helmholtz, Mueller, and Du Bois-Reymond among its stellar cast), there was a direct correlation between the number and range of avocations each individual pursued, the number of major discoveries he made, and his subsequent status as a scientist (Cranefield, 1966). Historian Minor Myers, Jr., found a similar correlation between the range of developed abilities and the diversity and importance of an individual's contributions for great figures from the Renaissance through the modern era. Myers proposed that creativity is governed by a combinatorial function such that the greater the diversity of knowledge and skill sets that an individual can integrate, the greater the number of novel and useful permutations that will result (Myers, 2003; 2006; Basbanes, 2006).

The controversy between specialized creativity versus polymathic or general creativity spills over to who is gifted. For those psychologists who favor specialization as the key to creativity, giftedness is often defined by precocity and always by unusual accomplishment in a single domain. Amabile, Gardner, Csikszentmihalyi, and their colleagues argue that creativity always occurs within domains and that specialized knowledge, training, and practice are required to achieve creative potential (Amabile, 1996; Feldman, Csikszentmihalyi, & Gardner, 1994). From the creativity-is-domain-specific perspective, polymathy is not only unnecessary to creativity but actually inhibits its achievement by diverting an individual's focus away from activities that bring professional success.

Those who favor polymathy as a basis for creativity view giftedness quite differently and, in fact, are asking a different question than the creativity-is-domain-specific crowd. Cranefield, Meyers, and others such as Poincare (1946), Koestler (1976), and Rothenberg (1979) who discuss integrating ideas from diverse fields as the basis of creative giftedness ask not "who is creative?" but "what is the basis of creative thinking?" From the polymathy perspective, giftedness is the ability to combine disparate (or even apparently contradictory) ideas, sets of problems, skills, talents, and knowledge in novel and useful ways. Polymathy is therefore the main source of any individual's creative potential. The question of "who is creative" must then be re-examined in light of what is necessary for creative thinking. In light of this distinction, Santiago Ramon y Cajal, one of the first Nobel laureates in Medicine or Physiology, argued that it is not the precocious or monomaniacal student who is first in his class who we should expect to be creative, but the second tier of students who excel in breadth: "A good deal more worthy of preference by the clear-sighted teacher will be those students who are somewhat headstrong, contemptuous of first place, insensible to the inducements of vanity, and who being endowed with an abundance of restless imagination, spend their energy in the pursuit of literature, art, philosophy, and all the recreations of mind and body. To him who observes them from afar, it appears as though they are scattering and dissipating their energies, while in reality, they are channeling and strengthening them..." (Ramon y Cajal, 1951, pp. 170–171).

So, monomaniacal precocity or profligate breadth? Intense focus or combinatorial permutations? Given the fundamentally contradictory nature of the two positions, identifying who is gifted will only be possible once the proper relationship between creativity and polymathy is understood. Understanding that relationship will, in turn, be necessary in order to foster the most creative people.

One set of definitional issues must be addressed before proceeding. To whom something is novel and how it is useful are also problematic aspects in defining creativity. The operational manner in which creativity is defined translates necessarily into functional criteria for its recognition and testing, which in turn determine what an investigator finds. Psychologists such as Runco (2004) and Csikszentmihalyi (1996) argue that every person either is or is capable of being creative in the sense of inventing *for themselves* a novel and useful insight. Others argue that the term creative can only be applied to *domain-altering activities* and is therefore limited to extraordinary and very rare individuals ("geniuses") operating in unusual times and places. Between these two extremes exists a sort of stepladder approach to creativity: Everyone is capable of personal (little "c") creativity (in the form of personal insights, artistic expressions, and re-inventions of things already known to a wider public); some people will master the sets of disciplinary skills and knowledge sufficiently to practice the full range of disciplinary activities; of these masters, an even smaller set will encounter and solve problems that require innovative tools, techniques, and practices that will push the boundaries of what can be done a bit further than before; and from the innovators, an even smaller set – the domain-altering or "Big C" creators – will invent or discover entirely new realms that require new sets of techniques and skills to address previously unforeseen problems and possibilities. The ladder approach to creativity bridges the "everyone-is-creative" and "only-geniuses-are-creative" approaches to creativity and is inherently developmental: It assumes that one cannot become a paradigm-altering creator without passing through the prior stages of personal creator, master, and innovator. The stepladder approach to creativity is employed here.

Einstein as a Polymathic Exemplar

The importance of definitional issues becomes evident when attempting to determine who is polymathic, how many polymathic individuals there may be, and whether polymathy denotes adult giftedness. Some psychologists insist that to qualify as polymathic, an individual must attain significant professional stature and success in at least two different fields of endeavor. If we accept, in addition, as some psychologists do, that creativity must be domain altering, then the number of creative people in any discipline is extremely small to begin with, and the probability that any individual would make domain-altering contributions to two disciplines in a single lifetime is even smaller. Kaufman & Baer (2004, p. 5) have, for example, noted the "apparent lack of creators who have reached the highest levels of creativity in two or more domains."

Yet "Renaissance people" certainly have existed in the 20th century, and some are even alive today: Sofya Kovalevskaya was one of Russia's greatest poets and playwrights and also one of the 20th century preeminent mathematicians. George Washington Carver, the African-American inventor, also won numerous awards in national art exhibitions. Charlie Chaplin not only acted in and directed films, but was at one time or another a professional dancer, musician, composer and photographer and amateur artist as well. George Antheil revolutionized modern music with his Ballet Mecanique, wrote novels (under the pseudonym Stacy Bishop) and non-fiction columns about endocrinological mysteries, and in collaboration with actress Hedy Lamarr, invented "frequency hopping," a technique for encrypting information that remains the basis for protecting all sensitive communications to this day. J. B. S. Haldane, with only an undergraduate degree in Classics, managed to become one of the most important physiologists, geneticists, and statisticians of the 20th century and a writer who published a science fiction novel, children's stories, and poetry. Bertrand Russell, a world-class mathematician, also won a Nobel Prize in Literature for his philosophical writings. Linus Pauling won two Nobel Prizes, one in Chemistry and the other in Peace for his political efforts to ban atmospheric nuclear testing. Herb Simon not only won a Nobel Prize in Economics, but was also a founder of the field of computer artificial intelligence. John Kenneth Galbraith, another Nobel laureate in Economics, also published several best-selling novels (e.g., *Triumph* and *A Tenured Professor*). C. P. Snow became one of the leading physicists and science administrators in Britain and also a world-renowned novelist. Hannes Alfven published (under the pseudonym Olaf Johannesson) a worldwide best-selling science fiction novel called *The Great Computer* – the prototype of the *Matrix* movies – more than a decade before he won a Nobel Prize in Physics. Carl Sagan, the astronomer, also wrote the novel *Contact* (upon which the movie of the same name is based). A. L. Copley, an expert in the physiology and biophysics of blood flow, painted under the pseudonym Alcopley and became one of the founders of gestural art. Desmond Morris, an Oxford don whose book *The Naked Ape* revolutionized anthropology and sold millions of copies, is also an award-winning filmmaker, novelist (*Inrock*), and surrealist painter who has exhibited with other great artists such as Joan Miro. Loren Eisely and Jacob Bronowski wrote poetry and essays that were at least as important as their scientific contributions. Gordon Parks managed professional careers as an internationally acclaimed photographer, movie director, composer, poet, and musician; Tan Dun is internationally acclaimed as a composer, sculptor, and artist. Miroslav Holub is considered by many people to be the foremost non-English language poet of this age and is also an immunologist of international reputation.

These people must certainly qualify as gifted, in the sense of achieving international recognition, and they are certainly gifted in more than one discipline. Additional examples of multiply gifted creators will be described below. These people must prove, even to the most recalcitrant creativity-derives-from-specialization advocate, that polymathy can be associated with the highest levels of creativity in more than one field.

Such multiply successful individuals are often contrasted with those who, in greater numbers, have become world famous in one field of endeavor and have demonstrable competence (and even excellence) in one or more avocations that they have not developed to professional levels. Since this essay will describe dozens of such people, I will only consider here the example of Albert Einstein. Einstein attained the highest possible stature in physics but was only a good amateur musician. Thus, while there is no doubt of Einstein's "Big C" creative contributions to physics, there is equally little doubt of his lack of "Big C" creative contributions to music. For many psychologists, Einstein would not, therefore, qualify as polymathic. In fact, Gardner has used Einstein as a prototypical exemplar of a "logico-mathematical mind" who contributed to a single domain – science (Gardner, 1993).

But Einstein *is* polymathic from the stepladder perspective on creativity. He is polymathic on two counts. First, he pursued music as an avocation along with his science throughout his life. Second, he *integrated* his music into his scientific thinking to produce surprising and effective innovations. Vocation and avocation intersected fruitfully. "If I were not a physicist," Einstein said in an interview with George Viereck, "I would probably be a musician. I often think in music. I live my daydreams in music. I see my life in terms of music.. . . I get most joy in life out of music" (Viereck, 1929). He told Alexander Moszkowski, one of his earliest biographers, that some unexplainable connection existed between his music and his physics (Moszkowski, 1973). Moreover, he was able to use this connection. His son reported that "Whenever he [Einstein] felt that 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" (Hans Einstein, quoted in Clark, 1971, p. 106). His daughter confirmed that after playing, he would often get up from his piano saying, "There, now I've got it" (Maja Einstein, quoted in Sayen, 1985, p. 26). Einstein even told Shinichi Suzuki, the famous inventor of the Suzuki method for teaching music, that "The theory of relativity 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" (Suzuki, 1969, p. 90). Moreover, when Niels Bohr unveiled his planetary model of electrons orbiting the atomic nucleus, Einstein described it as being, "the highest form of musicality in the sphere of thought" (Schilpp, 1969, vol 1, p. 116).

Such statements (of which there are many more) lend credence to Moszkowski's conjecture that for Einstein, as was certainly the case for his mentor Ernst Mach, "Music and the aural experience were the organ for describing space" (quoted from Muller, 1969, p. 170). Robert Mueller, himself a musician and scientist, has expanded on how such aural experience might have shaped Einstein's image of space. Mueller begins by noting that Einstein was particularly attracted to the structure of music, or its architecture. "It is also conceivable to me. . .that this disposition to the architectonic logics of abstraction was formulated by Einstein's early musical experiences, and even enlarged by a constant struggle for musical experiences which helped him build a rich mental perceptual fabric of space and time in which to perform his scientific theorizing" (Mueller, 1967, p. 171). In sum, there is good evidence to argue that Einstein was not the "logico-mathematical" thinker that Gardner (1993) has portrayed and who one might expect if creativity were domain limited, but rather was an individual who used mental skills developed outside of his field to inform his work, as one would expect from a creativity-is-combinatorial approach to creativity (Root-Bernstein, 1989; Root-Bernstein & Root-Bernstein, 1999).

Einstein, in short, is a good example of a person whose talents were "correlative," meaning that the individual finds useful connections between content, skills, methods, structures, or materials that link their diverse activities (Root-Bernstein, 1989; Root-Bernstein & Root-Bernstein, 1999). John Dewey called these "integrated activity sets" (Dewey, 1934) and Howard Gruber "networks of enterprise" (Gruber, 1984; 1988a, 1988b). Both men have linked such integrated gifts to unusual creative ability. The key point for all of us is that polymaths are not dilettantes. Polymaths put a significant amount of time and effort into their avocations and find ways to use their multiple interests to inform their vocations, whereas the dilettantes merely acquire skills and knowledge for their own sake without regard to understanding the broader applications or implications and without integrating it.

Does Polymathy Denote General Creativity?

Many psychologists have supposed that polymathy, whether of the correlative or dilettante variety, signifies *general* creativity. In the case of correlative talents, this is not at all the case. Einstein (and many other examples to be described below) demonstrates that they are not. His music informed his physics, but there is no evidence that he used his physical thinking to create a novel form of music. Thus, the issue being addressed here is not whether people are generally creative or specifically creative but rather *how* they are creative in whatever way their creativity is manifested. It must be emphasized, therefore, from the very outset, that the interactions between skill sets and activities can be, and probably most often are, asymmetrical. Avocations may influence vocations without vocations influencing avocations, or vice versa. Thus, the issue is not whether Einstein could have been a great musician or composer had he chosen to direct his efforts toward a musical career. The important issue is *how* polymathy is a source of a person's specific creativity and whether that creativity could have been manifested without its polymathic source. If Einstein did, in fact, think "musically" rather than logico-mathematically, and if he invented his general theory of relativity through his musical intuition as he claims, then we must accept the fact that domain-defined thinking was not the key to his creativity. The cognitive issue is therefore whether it would have been possible for him to have invented his scientific theory without his musical training or to have understood the nature of space–time in physics without a deep appreciation for the space–time architecture of music.

On the issue of how non-scientific thinking influenced and directed his thinking, Einstein is again instructive. "The greatest scientists are artists as well," he said (Calaprice, 2000, p. 245). Since such a great scientist mixes up artistic thinking with scientific thinking, it gives him a choice of modes of expression. "If what is seen and experienced is portrayed in the language of logic, then it is science. If it is communicated through forms whose constructions are not accessible to the conscious mind but are recognized intuitively, then it is art" (Calaprice, 2000, p. 271). By these criteria, Einstein himself was both a scientist (since he expressed his results mathematically) and an artist, since he did his thinking intuitively. In fact, he told both Jacques Hadamard and Max Wertheimer that he never thought in logical symbols or mathematical equations, but in images, feelings, and musical architectures that have no domain-specific identities (Wertheimer, 1959, pp. 213–228; Hadamard, 1945). Words or other symbols (presumably mathematical) were only employed in an *explicitly secondary translation step* after he was able to solve his problems through the formal manipulation of these images, feelings, and architectures: "I very rarely think in words at all. A thought comes, and I may try to express it in words *afterwards*" (Wertheimer, 1959, p. 213).

Notably, Root-Bernstein & Root-Bernstein (1999) have demonstrated that such non-symbolic, privately subjective forms of thinking followed by translation into public forms of communication are not only a common phenomenon but may be typical of much creative thinking. Thus, while Gardner has described dancer Martha Graham as a primarily bodily-kinesthetic thinker, a good case can be made from her own writings and interviews that much of her actual creative thinking and dance composition was verbal and visual and only bodily-kinesthetic in a secondary, translation step (Root-Bernstein & Root-Bernstein, 2003). Similarly, Gardner identifies poet T. S. Eliot as primarily a verbal thinker, but Eliot himself was a trained musician who wrote a great deal about the musicality of sound and said that he never thought in words, but rather in bodily feelings and visual images. Like Einstein, Eliot claimed that words were used merely as a translation of these feelings and images into a form fit for public discourse about things that in reality could never really be expressed in words at all (Root-Bernstein & Root-Bernstein, 1999). Thus, the mental tools an individual uses in order to reach a creative idea may have little or nothing to do with the mode in which the idea is finally expressed, and to conflate creative thinking with the form in which it is communicated is a fundamental error that can only blind psychologists to the mental processes by which creativity is actually manifested.

My thesis is that creative thinking, as opposed to the expression and communication of a creative idea or product, is inherently multimodal, trans-disciplinary, and independent of domains. Creativity, by definition, is effective novelty that requires the integration of ideas, concepts, practices, problems, skills, methods, or materials that have not previously been integrated. Thus, creativity, by definition, requires polymathic breadth accompanied by correlative talents and linked by integrated activity sets or networks of enterprise. Only by understanding *how* creative ideation occurs can we eventually learn to identify *who* has the cognitive abilities required to be creative.

The Ubiquity of Polymathy Among Gifted Scientists

So what is the relationship between polymathy and adult giftedness? Giftedness among adults is a difficult characteristic to identify since adults, unlike children, are not usually subject to generalized and widespread testing. For the purposes of this essay, I have therefore adopted a simple definition of adult giftedness that is perhaps overly stringent and only applicable in retrospect, but which is easily implemented and reasonably objective: An adult is creatively gifted if they produce work that is recognized by their peers, or by history, as being extraordinarily important. For present purposes, "extraordinarily important" is functionally defined as national or international recognition as manifested by major disciplinary awards, inclusion in "Who's Who" compilations or encyclopedias, textbook accounts of primary contributors to a field, and so forth. It will immediately be noted that Einstein's example is once again informative. Einstein was a slow developer who displayed, as far as is known, no unusual precocity or outstanding intellectual gifts prior to his extraordinary outpouring of revolutionary papers in 1904. Einstein therefore demonstrates what can be taken to be a relatively general proposition: There may be no necessary correlation between childhood giftedness and adult giftedness. Gifted children (particularly precocious ones) often do not become gifted adults and gifted adults are not necessarily precocious nor may they even be identified as gifted when young.

Following up on the example of Einstein, polymathy is certainly very common among eminent scientists and highly correlated with professional success. The earliest study suggesting such a correlation was performed by J. H. van't Hoff (who became the first Nobel laureate in Chemistry in 1901) in 1878. He noted that virtually all of the scientists from Kepler and Galileo through Newton, Davy, and Priestley excelled at arts such as poetry, painting, and music and were often deeply engaged in non-conformist spiritual or religious activities as well (van't Hoff, 1878). Early studies of other pools of eminent scientists and mathematicians by Ostwald (1907–1909, 1909), Moebius (1900), Fehr (1912), and Hadamard (1945) confirmed van't Hoff's observation, but all of these studies were based on small, uncontrolled, investigator-selected samples.

Root-Bernstein and his collaborators performed the first studies to compare the avocational interests of eminent scientists with those of average achievement. The initial investigation involved 40 young scientists recruited in 1955 by Bernice Eiduson for the first (and perhaps only) longitudinal psychological study of scientists over the course of their careers. Each scientist was interviewed and given a variety of psychological tests every 5 years through 1980. The 40 scientists diverged widely in their achievements. Four won Nobel Prizes by 1985 and they and seven additional colleagues had been elected to the US National Academy of sciences. These 11 scientists would clearly qualify for the label "gifted" under the criteria being employed here. At the other extreme, several scientists had failed to obtain tenure and had obtained non-academic positions, while another dozen or so had quite average academic careers. Various other measures of success such as number of publications, number of citations, and impact factors all correlated well with various assessments of success (Root-Bernstein, Bernstein, & Garnier, 1993). A survey of the scientists in 1988 determined the number and types of their adult avocations and these were then correlated with the scientists' publication, citation, and impact factor data and evaluated in light of their previous interviews.

Significant correlations were found between the number of adult avocations each scientist participated in and their success, as well as between specific avocations and success. Scientists who painted and drew were very significantly more likely to be among the Nobelists and National Academy members than were those who did not. Those who wrote poetry, did photography, or participated in various technical crafts, and those who had the widest range of hobbies were also more likely than the average scientist to be recognized as influential by their peers (Root-Bernstein, Bernstein, & Garnier, 1995). Unexpectedly, musical avocations had no predictive value for success as a scientist in this group, perhaps because they were equally common among gifted and average scientists.

Notably, a very significant correlation also existed between the kinds of mental "tools" that the scientists used (such as visual thinking and kinesthetic thinking) and the type of avocations they pursued (painters tend to be visual thinkers, poets verbal thinkers, etc.). A further set of significant correlations were then found between the types of mental tools used by each scientist and their likelihood of success. Various forms of visual thinking (3D, 2D, graphic, etc.), kinesthetic feelings, and verbal/auditory patterns were each independently correlated with success, as was employing a greater-than-average range of modes of thinking. Thus, avocations may reflect or even build a range of mental skills that complement or enhance logico-mathematical thinking among scientists (Root-Bernstein et al., 1995).

Interviews with the scientists (all of which were done many years prior to and independently of the survey of avocations, and therefore could not have been influenced by the survey) revealed that many were, like Einstein, conscious of the role that their avocations played in promoting their scientific creativity. One unusually adept experimentalist and Nobel Prize winner said that "I have a big tendency to use my hands and I also have a tendency to use my intellect. Well, the sciences are a great way of combining these operations and there aren't too many professions that do that. . .. My concept of the ideal 'scientist,' is that you do one thing real well, and its a very specialized thing, and then you do a lot of other things, but not too many, maybe 5 or 6 or 10 different other things, which you do well enough to give yourself and possibly others pleasure. This should be distributed quite widely among sports and artistic things and carpentry, and things that involve using your hands and a little music, perhaps and things of that sort" (quoted from Root-Bernstein et al., 1995, p. 136). Another Nobel laureate said, "Every scientist realizes in his science only a small portion of his total ability. I suppose that's true in general – that you don't do everything you're capable of by a big factor. I don't" (quoted from Root-Bernstein et al., 1995, p. 136). Avocations were a way of employing some of his only partially used abilities. And a member of the National Academy rationalized his own interest in music by saying, "[Suppose] someone is getting interested in musical problems. He may then apply what he finds there back to his scientific research. That's something which may affect very much the result. I think it's good. I think for a scientist who is working very hard, anything is good which brings from time to time another angle about general ideas into the picture" (quoted from Root-Bernstein et al., 1995, p. 136). Yet other gifted scientists recounted how building things, electronics hobbies, photography, and other avocations developed skills and knowledge that they employed in their scientific work. Thus, like Einstein, the polymathic individuals in the Eiduson study wove their vocational and avocational interests into integrated networks of mutually reinforcing enterprise. On the other hand, the least successful scientists in the study not only had fewer avocations than the successful ones, but almost universally considered these avocations as distractions that competed with their work.

The results of the Eiduson study have been validated by investigation of a larger pool of scientists. In 1936, Sigma Xi, the National Research Organization, a US-based society for scientists, surveyed its membership about their avocations. This survey provides baseline data for average-to-above-average scientists during the first half of the 20th century. These data were compared with avocations mentioned in biographical and autobiographical writings of Nobel Prize winners in Chemistry from 1901 through 2000. Data on avocations were found for approximately 70% of the laureates. The most conservative treatment of the data show that Nobel laureates are twice as likely to play a musical instrument as the Sigma Xi members; 5 times as likely to engage in crafts; 8 times more likely to engage in a visual art; 10 times more likely to write poetry or fiction; and more than 20 times more likely to engage in a performing art such as acting or dancing as an adult (Root-Bernstein & Root-Bernstein, 2004). All of these differences were very highly statistically significant.

Once again, these statistical data are supported by personal statements from a large number of the laureates concerning the variety of functional professional uses they find for their avocations. van't Hoff, the first Nobel laureate in Chemistry (1901), argued that avocations practice and expand the imagination (van't Hoff, 1878). His colleague Wilhelm Ostwald (Nobel Prize, 1909) turned his painting hobby into a new profession by studying the chemical basis of color and by producing the first gray scale and scientific color theory (Ostwald, 1905; Ostwald, 1906). Donald Cram (Nobel Prize, 1987), a craftsman, artist, poet, and musician, wrote that "In my opinion, organic chemists are part artist and part scientists, and thus apply both lobes of their brains to their work. To the extent that they are artists, they develop a research style expressed in their choice of research problems, how they address these problems, the degree of craftsmanship they bring to their research results, the extent to which they document their results, the readership they address in their papers, and their style of writing papers" (Cram, 1990, p. 122). Indeed, Roald Hoffmann (Nobel Prize, 1981) has written several essays explaining explicitly how writing poetry is similar to creating a chemical theory (Hoffmann, 1988a, 1988b; Hoffmann, 2006). Peter Debye (Nobel Prize, 1936), for his part, argued that scientific thinking is much more akin to the visual and performing artist's thinking than most scientists are willing to admit. He said that the key to his insights was to become an actor in the chemical process, "to use your feelings – what does the carbon atom *want* to do? You had to. . .get a picture of what is happening. I can only think in pictures" (Debye, 1966, p. 81). These are only some of the myriad connections that Nobel laureates have made between their avocations and vocations (others can be found in Root-Bernstein, 1987; 2000; 2001a; 2003; 2005a, 2005b; 2006a, 2006b, 2006c). These links demonstrate that domain- or discipline-bounded thinking is too limited for understanding the creative thought of gifted scientists.

The Ubiquity of Polymathy Among Gifted Artists

Polymathy is also very common in the arts, but unlike the sciences, only one, incomplete statistical study has yet been made linking artistic success with avocational pursuits. Michele Root-Bernstein investigated the avocations of Nobel laureates in Literature from 1901 to 2002 using standard biographical and autobiographical sources. Avocational information was found for 58 of the 101 laureates. Of these 58, 25 (43%) had a visual arts or sculpture avocation; 14 (24%) had a musical avocation; 13 had a performing arts avocation (22%); and 21 (36%) had a science or engineering vocation or avocation. Many of the Literature laureates, like their scientific counterparts, had multiple avocations (Root-Bernstein & Root-Bernstein, 2004).

Many of the Noble laureates in Literature have also written about the importance of their avocations for their vocational success, demonstrating that the same kinds of correlative talents that inform great scientific thinking also inform innovative literary creativity. Winston Churchill, for example, wrote a very popular book on *Painting as a Pastime*, in which he wrote that "One begins to see, for instance, that painting a picture is like fighting a battle. . .. It is, if anything, more exciting than fighting it successfully. But the principle is the same. It is the same kind of problem as unfolding a long, sustained, interlocked argument. It is a proposition which, whether of few or numberless parts, is commanded by a single unity of conception" (Churchill, 1950, p. 19). The connections between Derek Walcott's painting and his poetry and plays are even more obvious. Walcott has not only written about painting but illustrated what he has written, finding that many of his skills transfer from one medium to the other: "I approach every canvas with a pompous piety," he once wrote, "faithful to the lines of the drawing, a devotion transferred from a different servitude, to lines of poetry proceeding by a systematic scansion, brushstroke and word" (Walcott, 2005). Similarly, George Bernard Shaw (who turned down the Nobel Prize, but is nonetheless listed by that institution as a recipient) saw a similar unity in his own vocational and avocational activities. He once wrote to G. K. Chesterton that just as no one could understand Chesterton's work in ignorance of his love for painting, no one could understand Shaw's own work without appreciating his love of music (Dale, 1985, p. 83). Indeed, Shaw not only earned his early living by writing reviews of concerts, but was known to sing opera to himself throughout his life.

Scientific training has also played an unexpectedly important role in the thinking of many Nobel laureates in Literature. Shaw maintained in a self-written obituary that his greatest contribution to society was not his plays, but his essays on "metabiology," the study of the impact of biological science on human society and psyche. Not only is the influence of his metabiology apparent in plays such as "Man and Superman, but, "he [Shaw] quite seriously and emphatically claimed to be a pioneer in science, though he had never worked in a laboratory" (Pearson, 1950, pp. 86–87). Vladimir Nabokov, on the other hand, did work in a laboratory, specifically the Harvard Natural History Museum, where he discovered several new species of butterflies and organized the taxonomy of several important groups (Johnson & Coates, 1999). Readers of Nabokov's novels have recognized his penchant for including butterflies, and butterfly collectors, among his characters, but only in light of the recent rediscovery of his entomological work has the extent to which his science informed his art become apparent. Many readers of Johannes Jensen's novels, on the other hand, will be aware of his explicit use of scientific knowledge. Jensen wrote in his Nobel autobiography that "The grounding in natural sciences which I obtained in the course of my medical studies, including preliminary examinations in botany, zoology, physics, and chemistry was to become decisive in determining the trend of my literary work" (Nobel, 2002). Similarly, John Steinbeck's scientific interests permeate not only his novel *To a God Unknown* (Liukkonen, 1999; Pribic, 1990) but also his non-fiction collaborative work with ecologist Edward Ricketts on *The Sea of Cortez* (1941/71), which he prefaces by admonishing his readers to bear in mind that non-fiction is just as much an imaginative creation of the writer's mind as is fiction. Recognizing the interlinked bases of fictional and non-fictional thinking seems to be a common thread among Nobel laureates in Literature.

Although statistically robust studies for an arts–polymathy connection are still lacking, artists themselves, and those who study them, have often remarked on such a connection. "It is not unusual for great artists to practice in media other than those in which they excel," writes art historian Andrew Wilton. "The *violon d'Ingres* is a common enough phenomenon" (Wilton, 1990, p. 7). Novelist Henry Miller has put it even more succinctly: "Every artist worth his salt has his 'violon d'Ingres'" (Hjerter, 1986, frontispiece). The reference both Wilton and Miller make is, of course, to the fact that the great French painter Ingres was as well known for his ability and proclivity to play the violin as he was for his painting. Miller himself has painted throughout his life even while turning out best-selling novels.

A connection between writing and painting seems to be particularly strong, perhaps because a writer often needs to be able to visualize what she or he writes about. Two books, Kathleen Hjerter's *Doubly Gifted* (1986) and Lola Szladits' and Harvey Simmonds' *Pen & Brush* (1969), portray the visual arts of a hundred of the most famous novelists, playwrights, and poets of the 19th and 20th centuries. These include George Sand, Harriet Beethcer Stowe, William Makepeace Thackeray, Oscar Wilde, Thomas Hardy, Paul Verlaine, Robert Loius Stevenson, John Masefield, T. S. Eliot, E. E. Cummings, John Dos Passos, William Faulkner, Evelyn Waugh, T. H. White, Hermann Hesse, Lawrence Durrell, Henrik Ibsen, Dylan Thomas, Tennessee Williams, Allen Ginsberg, Gunter Grass, John Updike, and Anne Sexton. Whole books have been devoted to analyzing the relationship of the paintings, drawings, and photographs of various writers to their writings, including William Blake (Keynes, 1970), Lewis Carroll (Cohen, 1989), August Strindberg (Hedstrom et al., 2001), Wyndham Lewis (Handley-Read, 1951), G. K. Chesterton (Dale, 1985), Henry Miller (Miller, 1974), J. R. R. Tolkien (Hammond & Scull, 1995; Tolkien, 1992), E. E. Cummings (Cohen, 1987), and Derek Walcott (Walcott, 2000; King, 2000).

Among these artistic authors, several succeeded at more than one vocation. George du Maurier, author of the famous novel *Trilby*, actually earned his living as a professional artist for the magazine *Punch*, turning out over a thousand published drawings (Kelly, 1996). Playwright August Strindberg's originality as a painter is considered among Scandinavians to be on a par with the best modern artists so that Strindberg's painting *Underlandet* ("Wonderland") holds the Swedish record for the highest price paid for any painting at auction: 23 million kroner (approximately $3.5 million) (Hedstrom et al., 2001, pp. 9–10).

Even those for whom visual arts were merely avocations often benefited vocationally in ways expressed by painter and poet J. M. W. Turner: "Painting and Poetry flowing from the same fount mutually by vision, constantly comparing Poetic allusions by natural forms in one and applying forms found in nature to the other, meandering into streams by application, which reciprocally improved reflect and heighten each others' beauties like. . .mirrors" (Wilton, 1996, p. 10). Poet E. E. Cummings wrote rhetorically in the introduction to a catalogue to a one-man show of his paintings and drawings, "Tell me, doesn't your painting interfere with your writing? Quite the contrary: they love each other dearly" (Cummings, 1945). Indeed, he is famous in part for his translation of the cubist painting style to poetry to create a novel form that he called "poem/pictures," in which the arrangement of the words on the page create a simultaneously literary, visual, and kinesthetic effect on the reader. J. R. R. Tolkien would often draw variations of scenes or places that he would then describe in words in his novels (Tolkien, 1992; Hammond & Scull, 1995), while G. K. Chesterton would literally storyboard his novels with hundreds of drawings, just as is done with movies today, so that he could literally "see" the action (Dale, 1985). While the influences are more subtle in Lewis Carroll's work, most scholars agree that one cannot understand his Alice books without also understanding his vocational devotion to mathematics and his avocational devotion to photography (Cohen, 1989). What is surprising is not that such connections exist, or that they become transparently obvious when pointed out, but that so many scholars ignore the existence of avocations in their biographical and analytical studies of creative individuals.

Polymathy in New Synthetic Disciplines

If polymathy is relatively common among groups of eminent scientists and writers who work in well-established disciplines (and indeed among eminent artists, composers, filmmakers, actors, and almost any other group one examines with care), then it should not be surprising that polymathy is virtually ubiquitous among the founders of new synthetic disciplines. Consider two examples: kinetic sculpture and electronic music.

The history of kinetic sculpture is virtually synonymous with a coterie of artist-engineers. It begins with a pair of autodidacts, Giacomo Balla and Fortunato Depero, in Italy during the nineteen-teens who founded the Futurist movement. Both Balla and Depero were widely trained in music, painting, sculpture, and design, and they began to realize that a very important element of the modern world was being ignored by their contemporary artists: technology. Consequently, one element of their Futurist movement called for the "Fusion of art + science. Chemistry, physics, continuous and unexpected pyrotechnics all incorporated into a new creature, a creature that will speak, shout and dance automatically" (Depero, 1915). Balla, in particular, began teaching himself scientific techniques and applying them to the analysis and display of movement. Among his innovations were sculptures with moveable parts.

Contemporaneously, Naum Gabo initiated the Constructivist movement in Russia. Gabo was trained as a physicist and engineer, acquiring a thorough grasp of non-Euclidean geometries and Einstein's theory of relativity, as well as other contemporary advances in physics and mathematics. Gabo left science when he began to question what these advances meant for the social and emotional understanding of nature. He translated his scientific knowledge into the intuitive forms that Einstein also recognized as valid ways of understanding concepts. "I realized that the image I had been given by my teachers, the scientists," wrote Gabo, "by their way of looking at Nature, was just another stage setting with all the magnificence and ingenuity that the genius of any artist produces in a work of art. I realized that in my scientific journey I had been under the power of a magic spell of a work of art whose reality was just as true as the verity of the image in an artist's vision" (Gabo, 1962, p. 21). And so Gabo looked for the art in science. Mathematical equations took on 3D forms and human portraits and busts were constructed along the lines of 4D geometries (Nash & Merkert, 1985). In 1920, Gabo motorized at least one of his sculptures providing it with the same dynamic qualities that were to be found in the equations upon which it was based (Nash & Merkert, 1985, p. 60).

Neither Balla, Depero nor Gabo took their kinetic sculptures beyond tentative trials. The exploration of a fuller range of possibilities was left to a second generation of young sculptors who would fully liberate sculpture to swing freely as mobiles or become fully autonomous mechanical devices in and of themselves. The most notable of these were Alexander Calder and George Rickey. Calder was the son of a sculptor, but his earliest leanings were toward mechanical things, and he had a series of engineering jobs as a young man that taught him many of the technical skills (such as ship building and repair) that he would use when he began making his stabiles and mobiles a decade or two later (Marter, 1991, pp. 10–15). George Rickey also had a technical background, spending the years 1940–1945 as an Army Air Corps engineer before going to art school (Valdez, 2000; Anonymous (Eds), 1956). The impact of his training on the mobiles and mechanical sculptures he subsequently designed is unmistakable. Of the early kinetic sculpturists, only Jean Tinguely lacked a formal engineering background, which he made up for as a teenager by building numerous mechanical devices to harness wind and water to make sound and movement. Later he learned by apprenticeship and collaboration (Schwarz, 1969). The key point here is simply that in order to be able to meld sculptural form with mechanical or free movement required knowledge of both sculpture and engineering and only those individuals either trained in both or willing to train themselves (as Balla and Tinguely did) made fundamental contributions.

The development of electronic music required a similar melding of previously disparate disciplinary knowledge and practice. There are three distinct aspects of this disciplinary melding. One is the use of computers to produce music; another is the use of computers to compose music; and the third is the invention of electronic instruments other than computers. The creative individuals who pioneered each field were polymaths.

The first people to use computers as instruments were, not surprisingly, drawn from the musically trained engineers and mathematicians who first developed computer technologies. By chance, almost all of these were at Bell Labs in New Jersey, and they included J. R. Pierce, Claude Shannon, and Max Matthews. Pierce was an engineer and Vice President for Research at Bell Labs. He oversaw the group that invented the transistor (which won William Shockley a Nobel Prize) and had over 90 patents to his personal credit as well. His most important and long-lasting invention was the communication satellite, a device that his colleague Arthur C. Clarke suggested as a possibility in an article in 1954 and which Pierce turned into reality. Like Clarke, Pierce was also a respected science fiction writer, publishing most of his work under the pseudonym J. J. Coupling. He was also a musician who almost immediately saw the possibilities of using computers to analyze and synthesize sound and gathered a group of like-minded Bell Labs people to implement the idea (Sanford, 2005; Pierce, 1990; Bell Telephone, 1961).

Claude Shannon was one of Pierce's collaborators in these early computer-generated music experiments. Shannon was a mathematician and computer designer who became the major architect of modern information theory. It was said that he could juggle ideas almost as adroitly as he juggled balls while riding his unicycle. While Shannon did not personally develop his initial exploration into computer-generated music, and remained devoted to his mathematical theorizing, his work on information theory nonetheless had a huge influence on music theory and methods of composition (Katterman, 1999).

Pierce, on the other hand, maintained an active part in developing computer-generated music throughout his career, becoming a professor of music at Stanford University's Center for Computer Research in Music and Acoustics upon his retirement from Bell Labs. Stanford's CCRMA had been founded by avant-garde composer and computer enthusiast John Chowning. Chowning was also the inventor of frequency modulated sound synthesis, a technique that became the basis of the early Yamaha line of synthesizers (Levitin, 2006, pp. 47–50). Pierce found the CCRMA environment congenial and while there, explored three very different facets of music. One was the psychoacoustical properties of sound. Another was novel electronic means to generate novel sounds. And finally, he also invented a new acoustical bridge for stringed instruments that earned him yet another patent (Sanford, 2005).

Max Matthews was the man who gave the experiments of Pierce and Shannon long-lasting impact. Matthews was another musically trained engineer. His greatest contribution was to develop the first digital tools that permitted computer programmers and composers alike to make use of the possibilities offered by computer-generated sound. He also programmed the first computer-generated voice, coaxing the Bell Labs computer to sing "Daisy." This innovation inaugurated computer-generated speech research. For many years, he directed the Acoustical and Behavioral Research Center at Bell Labs. He also collaborated with composer Iannes Xenakis (on whom more below) as a scientific advisor to the Xenakis's Institute de Recherche et Coordination Acoustique/Musique (IRCAM) in Paris. After 1987, Matthews also became a Professor of Music at Stanford University's CCRMA (Max Matthews, Wikipedia).

The first person to program a computer to compose music – an innovation quite distinct from the contemporaneous innovation of using computers as musical instruments – was Lejaren A. Hiller, Jr. Hiller had dual training as a chemist and a composer. He majored in chemistry and also obtained his Ph.D. in that subject at Princeton University. During his Princeton years, he studied with a Who's Who of American composers, including Milton Babbit and Roger Sessions. He went to work for the Dupont Chemical Company after graduate school, where he learned to use a computer to do the theoretical calculations necessary for his chemical research. He quickly realized that the composition of music by a computer would not be different from the calculation of a chemical reaction or chemical structure by a computer. In each case, one needed to know the set of rules governing the operation (an algorithm) and needed to provide the computer with a set of variables upon which to perform the operation. Hiller therefore set about trying to discover what properties defined a "good" piece of music and the process by which a composer identifies and elaborates a musical theme. He then began programming the Dupont computer to create music based on these rules. After several years, two publications, three patents, and half-a-dozen musical compositions, Hiller moved to the Chemistry Department of the University of Illinois, which had one of the first ILLIAC computers. At Illinois, while serving as an Assistant Professor of Chemistry, Hiller also earned an MA in Music. His computer compositions, particularly the "ILLIAC Suite," soon created such a stir that the Dean of the Graduate Faculty transferred him to the Music Department as a faculty member. Several years later, Hiller moved to the University of New York at Buffalo, where he held the position of Frederick B. Slee Chair of Composition and was co-director of the Center for Performing Arts. It is clear from his history that only an individual with access to one of the rare and very expensive early computers (that is, a scientist or mathematician), skilled in programming, and also trained as a composer could have created the novel discipline Hiller inaugurated (Hiller website and archives; Hiller, 1986; Wamser & Wamser, 2006).

I will simply mention in passing what should be obvious, which is that the inventors of new electronic instruments other than the computer have also all had formal training in both music and electronics or physics. These innovators include (among many others) Walther Nernst, a Nobel laureate in Chemistry and the inventor of the first electronically amplified piano (Hiebert, 1983); Thadeus Cahill, the inventor of the telharmonium; Lee De Forest, the inventor of the electronic Audion piano; Leon Theremin, the inventor of the theremin, the theremin cello, and, in collaboration with composer/inventor Henry Cowell, the rhythmicon; Friedrich Trautwein, inventor of the Trautonium; Laurens Hammond, the inventor of the electronic organ; Robert Moog, the inventor of the Moog synthesizer; and of course Chowning with his frequency modulated sound synthesizer (Anonymous, "120 years…"; Burns, "History of electronic…."; Wikipedia, "Electronic musical…"). What is particularly important about these individuals is that by combining their diverse talents and skills, they expanded the means of generating sounds as well as the range of sounds possible to musicians and composers who lacked the inventors' polymathic backgrounds. Thus, polymaths create bridges between disciplines that benefit specialists as well.

The people who did the most to develop the new field of electronic music were also, not surprisingly, multitalented. Raymond Scott, one of the pioneers of electronic musical compositions, was a "composer, orchestra leader, pianist, engineer, recording studio maverick, and electronic music inventor" ("Raymond Scott," Wikipedia). Iannes Xenakis, probably the most influential innovator in electronic music, was formally trained as, and worked as, an engineer and architect. Apprenticed to the great architect Le Corbusier, he carefully transformed the equations describing his building plans (e.g., the award-winning Philips Pavilion designed for the Brussel's World's Fair in 1958) into musical compositions (*Metastaseis*) and vice versa, using a wide range of mathematical and statistical concepts and techniques in his music (e.g., Matossian, 1986; Capanna, 2002). He is certainly proof that it is possible to excel in more than one discipline simultaneously and to transfer detailed knowledge and methods from one discipline to another across domains. The mere titles of his books are sufficient to illustrate some of his integrative themes: One was entitled *Musique, Architecture* (Xenakis, 1971a), another *Formalized Music: Thought and Mathematics in Composition* (Xenakis, 1971b), while the subject of his Sorbonne *dissertation d'etat* (a post-doctoral degree awarded in France only to the most extraordinary individuals) was *Arts-Sciences Alloys* (Xenakis, 1985).

Polymathy and Creative Giftedness Reconsidered

The examples of polymaths and their polymathic innovations provided above permit a re-examination of the issue of how creative giftedness is related to polymathy. The most important point is simply that none of the innovations described above could have been created by anyone other than a polymath. This is not a matter of theory or debate. It is a fact imposed by the logical structure of the creative ideas that people like Xenakis, Hiller, Pierce, Gabo, and other multiply talented individuals integrated.

The requirement of polymathic abilities to create novel, integrative forms of human endeavor sheds important light on the question of who is creative. Most psychologists have approached this problem from the perspective of personality traits. This focus leads to attempts to find behavioral and genetic traits (divergent thinking, need for novelty, etc.) that predispose to creative activities. The focus of the present study is very different. It asks *how* people are creative and *what* particular skills are required to express any specific form of creativity. Putting these questions first leads to a very different view of *who* is creative. Creativity becomes not a set of traits that can be ascertained by appropriate psychometric measures, but a set of skills, knowledge, talents, and experiences that can be acquired and applied to particular problems in particular situations. Creativity is therefore never general because creativity is not a personality trait that imbues all of an individual's actions. Rather, creativity is a strategy for problem finding and problem solving. Like any strategy, its application is limited by personality, talent, skill acquisition, practice, experience, and opportunity.

This functional rather than personality-based perspective on creativity explains why creative individuals can be polymathic without necessarily being generally creative. Polymathy provides the set of skills, knowledge, and experiences required to become creative, but talent, opportunity, persistence, environment, and other factors determine whether that polymathic ability becomes manifested creatively. Some individuals are able to find opportunities in multiple fields to apply their polymathic abilities professionally; others, due to circumstances or choice, apply their creative ability only in one field, using their remaining skill sets for personal or social enjoyment as avocations. In whatever way polymathic abilities are manifested, however, it should be clear from all that has been argued above that such abilities are absolutely necessary to generate the novel and useful ideas that underlie all creativity. Creativity is, after all, the result of combining previously disparate elements in surprising and useful ways.

Two specific examples may help to clarify the issues. Kaufman & Baer (2004, p. 5), two proponents of the specificity of creativity, have asked rhetorically in one of their essays whether the entertainer Madonna could have been a great mathematician. This is a silly question that confuses different types of intelligence with different types of creativity. No one has ever been shown to have an equal distribution of all possible "intelligences" or talents at the very highest levels of performance. It must surely be obvious to anyone that creativity can only be manifested, no matter how general it may be, in areas in which an individual has talent and interest. The real question is whether Madonna could turn her range of talents (which is surely extraordinary by any criteria: dancer, singer, songwriter, actress, and author of a dozen children's stories) to become highly successful at something other than entertainment. Here the answer must almost surely be in the affirmative, since the singing, dancing, and acting star Shirley Temple was able to become Shirley Temple Black, diplomat and US Ambassador to the United Nations.

Kaufman and Baer's similar question, "Could Heisenberg have been a great poet?" (ibid.) is much more interesting. Kaufman and Baer immediately answer, "Probably not, but given the time required to prepare for creative productivity in a given domain (and the limits of the human life span), that's an assertion difficult to prove." I must disagree. Their assertion that Heisenberg could not have been a great poet – or at least great at some art – is not only wrong but it can be proven to be wrong. Had Kaufman and Baer bothered to learn anything about Heisenberg, they would have found out that he did, in fact, write poetry and paint as well as play the piano (Cassidy, 1992, pp. 14, 17, 23, 24, 82). What is particularly striking is that he seriously considered a professional career as a musician (Heisenberg, 1972, pp. 18–19). He rejected such a career on grounds very relevant to the issue of why polymathy is often expressed asymmetrically. Heisenberg argued that he had a greater probability of making a major contribution to physics than to music (ibid.). He nonetheless played at a semi-professional level for the rest of his life (Cassidy, 1992, pp. 81, 85, 139, 219, 269, 272–3, 323) and his biographer, David Cassidy, remarks that his performances often opened social and political doors that were of considerable importance to the furtherance of his career. Moreover, he, like Einstein, argued that mathematics was only a translation of "intuitive pictures and distinct types of force," but "not the content" of physics (Heisenberg, 1974, p. 83). He also believed that music and physics shared content and beauty (Heisenberg, 1974, pp. 166–183; Heisenberg, 1971, pp. 10–11; Cassidy, 1992, p. 545).

Even more striking is the fact that Heisenberg is hardly unique. Boris Chain, who earned a Nobel Prize in Medicine or Physiology for developing the processes required to mass produce penicillin, also had the ability to have been a professional pianist, but like Heisenberg, chose to use his skill to advance his career socially (Clark, 1985). Max Planck, the Nobel laureate who invented quantum physics, was also a talented enough pianist to face a decision as to whether to become a professional physicist or a professional musician. He resolved his difficulty by realizing that "The creative scientist needs an artistic imagination" (Planck, 1949, p. 14). Again, like Heisenberg, he made a conscious choice that he described in his autobiography to devote his efforts to the field in which he could make the greatest impact. And like Heisenberg, he continued to play as an amateur for the rest of his life, creating a musical salon at which many other musically inclined giants of physics, such as Otto Hahn and Lise Meitner, would meet weekly to play. Thus, anyone asking whether any particular individual could have succeeded at more than one profession must also ask whether the individual made explicit or implicit decisions concerning the uses of their talents.

The point is that historians (and those who use historical documents) *know and can demonstrate* that many creative people have the ability, but not always the desire or opportunity, to succeed professionally in more than one field. Documentation exists for many of these people concerning the decisions they made either to choose one field in which to focus their efforts while retaining an amateur status in the others (Heisenberg, Chain, Planck, Einstein, etc.), to balance more than one career simultaneously (Borodin, Kovalevskaia, Desmond Morris, Galbraith), or to have serial careers (Herb Simon, Lejaren Hiller, etc.). Polymathy may be expressed in many different ways.

The diversity and multitude of polymathic individuals, combined with the paucity of psychological literature discussing polymathy, suggest that the analytical tools being developed and used by psychologists studying creativity in laboratory and testing situations are not capturing some essential elements of creative giftedness. Tools only reveal what they are designed to reveal. If the tools do not elicit information about polymathic abilities, avocational interests, choices among possible careers, or perceived connections among diverse skill sets, then such information will not, and cannot, become part of the discussion about giftedness, creativity, and polymathy. Psychometricians need to take some lessons in devising future metrics from historians and from those psychologists, such as Cox, White, Terman, and Hutchinson, who have used historical sources.

Conclusions

The importance of the debate over polymathy and creativity cannot be overestimated. The main implication of the specialized-knowledge-is-required-for-creativity camp is that early specialization in a domain is the surest means to develop creative ability. Such early specialization clearly requires domain-specific testing methodologies of great predictive value. Precocity should be identified and developed. Training in multiple domains is not only useless, because there is no transfer between cognitive domains, but is actually counter-indicated because it diverts energy from the full development of domain-specific abilities.

On the other hand, the polymathy-develops-creativity camp would argue that early specialization is the surest means to stifle creativity. Precocity is only valuable when used as a springboard to the intensive development of the widest possible range of abilities and skills. Precocity is not necessary for the development of adult creativity and, without additional interests and training outside of the discipline in which the precocity is displayed, will be a dead end. What characterizes the most creative individuals is an ability to discover connections between apparently unrelated domains of activity – the artist in the scientist, the sculptor in the mathematician, the musician in the programmer. In such cases, transfer of knowledge, skills, and cognitive tools is not only possible but necessary. In fact, the most creative individuals are not those who work within existing fields but who synthesize new fields (along with new modes of thinking and working) from combinations of existing ones – kinetic art, electronic music, sociobiology, and so forth. The polymathy-develops-creativity camp argues that giftedness will be a function of the range of intensively developed vocational and avocational talents, skills, knowledge, and experience combined with the degree to which an individual can correlate these to form integrated networks of enterprise.

The polymathy–creativity connection therefore suggests a novel way to identify potential creative giftedness among young adults, which involves surveying two fundamental parameters of vocational and avocational practice. One parameter involves the range of avocations practiced by an individual and their attitudes toward those avocations with regard to vocational activities. Root-Bernstein et al. (1995) demonstrated that scientists with the widest range of avocations and who could explain how these avocations benefited their vocational activities were the most successful professionally. Root-Bernstein et al. (1993) also found a second parameter that correlated with professional success among scientists. While most scientists work on one problem at a time, highly successful and creative scientists simultaneously investigate multiple problems and employ explicit self-imposed constraints on how much time is to be devoted to each. Creative polymaths, in other words, diversify their efforts and are excellent managers of time and effort. Both sets of parameters are evident in the majority of those who become highly successful scientists by the age of 40 years. These findings, along with Milgram's observation that intellectually intensive avocations among adolescents are an excellent predictor of career success in any field, suggest that it should be possible to identify young adults with high creative potential early in their careers.

This issue is not merely of importance to those who study cognitive psychology. Cognitive psychology is influencing educational practice to an ever greater extent. Minor Myers, Jr., in his capacity as President of Illinois Wesleyan University, pointed out that secondary school and university curricula can foster or discourage the polymath (Myers, 2003; Anderson, 1999). If, as is argued here, polymathy is linked to creativity, then the ways in which our cognitive understanding is translated into curricular practice will have a major impact on the pool of creative individuals in the future. Precocious students and those who excel in one subject are just as unlikely to be the creative standard-bearers in the future as they have been in the past. Time must be made in the curriculum and in leisure time for the development of correlative talents. Much as the diversification of talents may seem to be a waste of time and energy, there is good reason to believe that such diversity will enhance creative potential. Two studies, in fact, demonstrate that scientists in general are more likely to make their breakthroughs while working on unrelated problems and away from their workplace than they are while directly addressing a problem in their laboratory (Platt & Baker, 1931; Root-Bernstein et al., 1993). If these findings are generalizable to other disciplines, then intensive training and focus on single tasks for long periods of time may be seriously detrimental to creativity.

In sum, polymathic creativity clearly exists among gifted adults among whom it is not only common but may be ubiquitous. Only by encouraging gifted polymaths can polymathic creativity itself ever be manifested. Given that many of the most important innovations in the past few centuries have resulted from integrating problems, skill sets, knowledge, and experience across established disciplinary and domain-defined boundaries, such polymathic creativity is something we cannot afford to ignore. As Myers has asked, "Are we going to be citizens of the world of knowledge or subjects in the petty principalities of disciplines?" (Anderson, 1999). If creativity is more than just a personality trait, then how we answer this question will also determine how creative our society will be in the future.

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