The Art & Craft of SCIENCE

Scientific discovery and innovation can depend on engaging more students in the arts.

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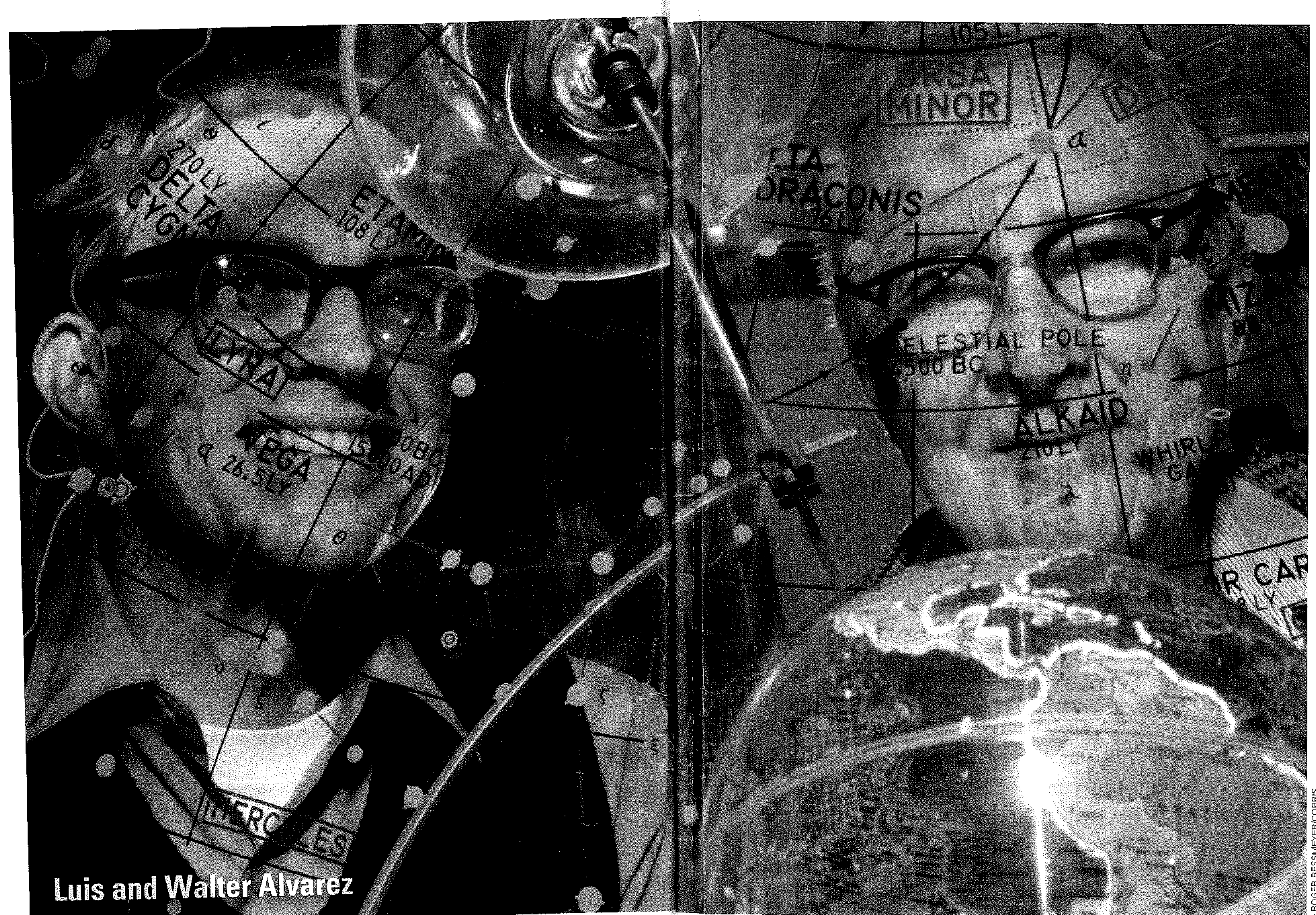
Suppose you have a talented child with a profound interest in science. This child has a choice of going to an academically elite high school or to a high school where the curriculum focuses on training mechanics, carpenters, and designers. Where do you send her? It's a no-brainer, right? To the academically elite high school.

Except that Walter Alvarez, a doctor and physiologist of some renown, decided to send his scientifically talented son, Luis, to an arts and crafts school where Luis took industrial drawing and woodworking instead of calculus. Big mistake? Not exactly. Luis Alvarez won the Nobel Prize in physics in 1968. He attributed his success to an uncanny ability to visualize and build almost any kind of experimental apparatus he could imagine (Alvarez, 1987).

Suppose you have a baby Einstein. The question is, would you know it? After all, Einstein was certainly not a standout in his mathematics and physics classes. Yet he also ended up with a Nobel Prize.

So what were his special talents? One was clearly an ability to visualize concepts in his mind, a talent that was fostered by Aargau Cantonal School in Switzerland, where he completed his secondary education. Based on Johann Pestalozzi's philosophy of education, the school encouraged individual differences, sense perception, visualization, and modeling, all developed through a student's self-directed activity. One outcome of this training was Einstein's habit of imagining himself riding a light beam or falling in an elevator at the speed of light, the basis of thought experiments that yielded his revolutionary insights. Another outcome was his facility with devices, which he developed further as a patent examiner and through several inventions of his own.

Einstein also melded a talent for music with his thinking. Although he is well known for his improvisational ability on both the violin and the piano, few people are aware that he attributed many of his greatest scientific insights to "musical thinking" (Root-Bernstein & Root-Bernstein, 2010). As he put it, "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 6. My new discovery is the result of musical perception" (Suzuki, 1969, p. 90).



Luis and Walter Alvarez

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And what about the Swedish biochemist Hans von Euler-Chelpin? He was a direct descendant of the Swiss mathematician and physicist Leonhard Euler; Hans's science-centered family may not have been too happy when he focused on fine arts in college. What they couldn't foresee was that his painting classes would introduce him to experiments in color theory carried out by physicist Ogden Rood and chemist Wilhelm Ostwald. Amateur painters themselves, both Rood and Ostwald had discovered through their artistic avocations that many phenomena concerning the optical and chemical properties of colored materials were complete mysteries. Fascinated by the scientific questions involved, von Euler-Chelpin began taking chemistry and physics classes. Twenty years later, in 1929, he won the Nobel Prize in chemistry.

Crucial—But Overlooked

There's a pattern here. As exemplars of the highest order, Alvarez, Einstein, and von Euler-Chelpin highlight the often overlooked, yet unexpectedly widespread and profoundly important interactions that occur among the arts, crafts, and sciences. These scientists carry the banner for arts-infused science education.

Arts and crafts develop such skills as observation, visual thinking, the ability to recognize and form patterns, and manipulative ability. They develop habits of thought and action that include practicing, persevering, and trial-and-error problem solving. They pose new challenges, such as those that intrigued Rood, Ostwald, and von Euler-Chelpin. And they provide novel structures, methods, and analogies that can stimulate scientific innovation.

For all these reasons, finding ways to foster arts education alongside science education—and, even better, finding ways to *integrate* the two—must become a high priority for any school that wants to produce students capable of creative participation in a science-dominated society like ours.

Observation

Let's start with skill development. One of the skills that all science textbooks and curriculums nominally value is that of observing. There was a time not too long ago when scientists required their students to take drawing or painting lessons as part of their scientific training in the belief that whatever you haven't drawn, you haven't seen. Although this requirement has lapsed, it's still true that drawing enhances seeing. Indeed, all forms of observation, whether visual, aural, tactile, olfactory, or gustatory, take training and practice to develop to the fullest extent (Root-Bernstein & Root-Bernstein, 1999). Further, all types of sensory observation have applications to scientific practice.

For example, it's well established that physicians who have musical training are much better able to diagnose patients using chest and abdominal percussion and stethoscopy than are those who are not musically trained (Mangione & Nieman, 1999; Smith et al., 2006). Although the application of musical, olfactory, and related skills to science training has yet to be developed in any comprehensive fashion, the web is full of classroom lessons exercising visual and aural observational skills through the arts. In particular, the National

Science Foundation teacher guide, *Foundations* (2000); the Stanford Solar Center project "Observing the Sun for Yourself" (2012); and the publication *Fostering Outdoor Observation Skills* (Dvornich, Petersen, & Clarkson, 2011) each provide teacher-tested strategies for incorporating drawing, graphing, and related activities into science and math curriculums.

Visual Thinking

Learning to observe through drawing and painting has another benefit for students studying the sciences and mathematics. It turns out that one of the best predictors of success in scientific subjects in grades K–16 is visual imaging ability. Surprisingly, students who excel in science and mathematics usually outperform even those majoring in the arts in visual imaging and visual memory tests (Winner & Casey, 1992).

Conversely, students who have poor visual memory and imaging ability often do poorly in science and mathematics. As a rule, women and minorities are more likely than white males to display deficiency in these skills. However, many studies have shown that providing students who have visualizing deficits with drawing and painting classes improves their visual imaging and memory test scores. This training also results in a significant increase in the students' ability to perform well in their science and mathematics classes and to succeed in standardized testing situations (Alias, Black, & Grey, 2002; Deno, 1995; Sorby, 2009; Sorby & Baartmans, 1996).

Recognizing and Forming Patterns

Scientific thinking is almost synonymous with recognizing and forming patterns. Every hypothesis and theory is the discovery of a pattern within some set of observations. For this reason, artists, choreographers, and musicians, whose works invariably invent and play with patterns, have a great deal to teach scientists (Root-Bernstein & Root-Bernstein, 1999).

The father of the famous physicist Richard Feynman clearly understood this connection. He introduced his son to patterning games very much like those taught at such art schools as the Bauhaus when the boy was still a toddler. One of those games involved colored tiles like those used to make mosaics. Feynman senior would start a pattern and see whether Richard could finish it. Soon the boy was making up his own patterns and yet another pattern was set in motion (Feynman, 1988). As an adult, Richard Feynman discovered many new patterns in physics, which later won him a Nobel Prize.

The more arts and crafts that scientists, engineers, and entrepreneurs **engage in across their lifetimes, the greater their likelihood of achieving important results** in the workplace.

Ned Seeman, one of the founders of the new science of nanotechnology (the making of functional objects out of molecule-sized materials), was similarly inspired by M. C. Escher's patterns. Stumped by a problem concerning ways to make cubic structures out of DNA, Seeman realized that an Escher print that pictured a school of fish-like creatures swimming in three dimensions provided the solution (Nadrian Seeman, n.d.). Seeman now studies artists' patterns explicitly for their insights into the processes of making structures (Seeman, in press).

Other scientists have also looked to the work of artists—or used their expressive forms—to hunt for clues to hidden patterns. Physicists, for instance, have worked with choreographers to illuminate the movement patterns of electrons; microbiologists have square-danced their way through the processes of gene regulation. Some educators have likewise used creative movement in the science classroom. Witness Zafra Lerman's work teaching chemistry through dance and theater.

Although much remains to be done on a wider scale to bring the embodied understanding of patterns as accessed through visual art, dance, theater, and music into science instruction, certain initiatives, such as the John F. Kennedy Center's Partners in Education Program (www.kennedy-center.org/education/partners), actively promote the forming of art-science connections as part of a larger agenda for arts-integrated learning.

Manipulative Ability

As Luis Alvarez's story suggests, craftsmanship, often evidenced by the development of fine motor control, is also highly relevant to scientific success, especially among those who wish to succeed at experimentation (Waddington, 1969). As fewer and fewer students take art, music, and crafts classes in school, with some students even failing to learn cursive writing, fine motor control and simple manipulative skills that were taken for granted 50 years ago are today increasingly absent. Many of our students are truly "all thumbs." They cannot carry out the simple procedures that introductory laboratory exercises demand, and the highly specialized and intricate experimentation that professional science requires is simply beyond their imaginations.

This sad state of affairs is the result of a lack of appreciation of these skills—not among scientists, but among education "experts" who have lost contact with actual scientific practice. Long before Alvarez did so, many other Nobel laureates, most notably William and Lawrence Bragg (1928) and P. M. S. Blackett (1933), rued the loss of craftsmanship and with it, the ability to perform—and here the artistic and musical connotations of that term are all too appropriate—experimental procedures. We teachers need to remember that implementing knowledge, even in the information age, must still be accomplished through inventions first constructed by hand.

Backed by Research

There are real and measurable consequences to integrating arts and crafts education with science and mathematics education. Perhaps the most obvious and most startling has to do with the SATs. Our own informal analysis of the SAT results from 2006 reveals that four years of high school arts or music classes confer *a 100-point advantage* over the average SAT score, whereas four years of science confer only a 69-point advantage.

James Catterall (2009) has demonstrated that this positive arts effect is not limited to schools in socioeconomically advantaged neighborhoods but is actually strengthened in the poorest neighborhoods. Arts, in short, have the greatest impact of any subject on standardized tests scores, even when those tests have nothing to do with arts-related material. These studies demonstrate loud and clear how important arts-related skills are for learning in general and mathematics in particular.

Moreover, these arts benefits persist beyond high school. In quantitative as well as qualitative fashion, we have observed the effects of adult participation in arts and crafts, as well as continuous participation from childhood into adulthood, on various measures of success among individuals at work in the fields of science, technology, engineering, and mathematics (STEM). Our data show that the more arts and crafts scientists, engineers, and entrepreneurs engage in *across their lifetimes,* the greater their likelihood of achieving important results in the workplace. Not only do the most successful STEM professionals engage in arts and crafts at rates significantly higher than the general population, but the top-performing, most successful members of these groups engage in arts hobbies at rates higher than their peers (Root-Bernstein, Allen, et al., 2008).

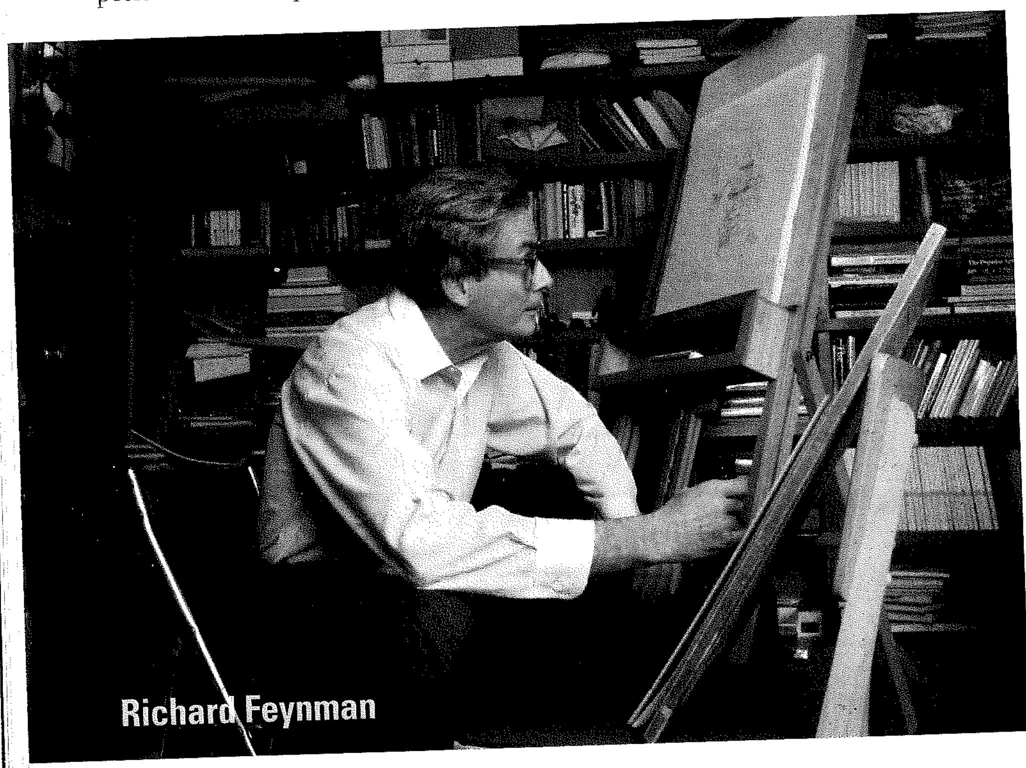
The idea that arts and crafts training enhances scientific ability, first advanced by J. H. van't Hoff (1967), the first Nobel laureate in chemistry, has been substantiated by numerous subsequent studies of eminent individuals in other fields (see Cox, 1926; Cranefield, 1966; Goertzel, Goertzel,& Goertzel, 1978; Milgram, Hong, Shavit, & Peled,1997; White, 1931). Our own study of Nobel Prize winners indicates that these eminent scientists are 15 to 25 times more likely than the average scientist to engage as an adult in fine arts, such as painting, sculpting, and print making; in crafts, such as wood and metalworking; in performance arts, such as acting and dancing; and in creative writing and poetry (Root-Bernstein, Allen, et al., 2008).

In concert with a team of researchers at Michigan State University (MSU), we have also recently studied several populations of engineers, STEM honors graduates, and STEM entrepreneurs and found that in these groups, too, sustained adult arts and crafts participation characterizes top performers (LaMore et al., 2011, Root-Bernstein et al., in press). For instance, MSU Honors College STEM grads are 3 to 10 times more likely to be engaged in arts and crafts than the average American.

Engineers and inventors are also more likely to participate in various arts and crafts, especially photography and music, at higher levels than the public at large. Moreover, as in the case with scientists, individuals in these professions who produce creative capital (for example, who publish papers and books, file copyrights, file and license patents, and establish companies) are much more likely than their peers who do not produce creative capital to be involved in a sustained manner with one or more crafts or arts. This is especially true for avocations in photography, woodwork, mechanics, electronics, and dance. It appears that inventors in the STEM fields enjoy working with mind, body, *and* hands.

We found that measures of family wealth did not correlate with either the presence of childhood arts and crafts hobbies or mature production of creative capital. Rather, arts and crafts participation started in childhood and sustained in maturity looks to be a leveler among individuals from diverse socioeconomic backgrounds. Childhood privilege in and of itself does not give a leg-up on entrepreneurship and innovation. Arts and crafts apparently do.

STEM professionals understand and value the connections between their avocations and their work. Many report that the beneficial exercise of observing, visualizing, manipulating, and dealing with material and aesthetic concerns in arts and crafts hobbies builds creative capacity at work. Eighty-two percent of surveyed scientists and engineers answered *yes* to the question, "Would you recommend arts and crafts education as a useful or even essential background for a scientific innovator?" (LaMore et al., 2011, in press; Root-Bernstein et al., in press).



Richard Feynman

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A Luxury? Think Again

The education of future STEM professionals is, literally, in our hands. Crossover creativity depends on sustained participation in arts or crafts, beginning in childhood and continuing into adulthood. As our data on MSU Honors College graduates in STEM fields suggest, if an individual does not participate in arts and crafts activities as a child, there's only a 5 percent chance, on average, of his or her participating in any art or craft as a mature adult. Put another way, about 25 percent of those who take up an art or craft in childhood sustain that interest and immersion into maturity (LaMore et al., 2011, in press; Root-Bernstein et al., in press).

By igniting in students an early passion for photography or music, woodworking or dance, educators can expect a significant return in lifetimes of creative practice and impact. Arts and crafts are essential investments in STEM research, discovery, and innovation that pay off in decades to come. In addition, as with any set of skills that must cross from one discipline to another, the crossover will be more likely if we emphasize the need for it, provide role models, and study exemplars.

Arts and crafts, in short, are not luxuries that we can dispense—or dispense with—as the mood strikes us. The skills, knowledge, techniques, models, concepts, and inventions that artists and craftspeople develop sculpt the imagination, making new sciences and technologies possible. The best scientists have always known this. Max Planck (1949), a Nobel laureate as well as an extraordinary pianist, wrote in his autobiography, "The creative scientist needs an *artistic* imagination" (p. 14). Santiago Ramon y Cajal, perhaps the greatest neuroanatomist of all time, winner of the 1906 Nobel Prize in physiology or medicine, inventor of modern color photography, and painter of great talent, agreed. He wrote: "The investigator should possess something of this happy combination of attributes: an artistic temperament which impels him to search for, and have the admiration of, the number, beauty, and harmony of things" (1951, pp. 170–171).

It's high time we listened both to what our most creative scientists have to say and to existing data on successful learning and innovative practice. What they show is clear—that the arts add value to the pursuit of science. EL

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