

CREATIVITY AND BIG SCIENCE

The idea of creativity in science is contemporary with the institution of the Nobel Prizes. To excel at today's big science, however, may require a type of creativity different from that rewarded by the early Nobels.

John L. Heilbron

Creativity and big science may sit uneasily together. Creativity is considered good in any amount; I do not recall ever hearing anyone complain of having more of it than he or she wanted. Big science, however, has its detractors. Some fret that it consumes resources better devoted to little science; others, that it routinizes work, bureaucratizes laboratory life and, to say the worst, suppresses creativity.

When and how did "creativity," and its relatives "originality" and "genius," become associated with scientists? What characteristics do big science and big scientists encourage and select? What consequences, if any, result for the reward system of science, especially the institution of the Nobel Prize?

I've divided my very sketchy and preliminary answers to these questions into four parts:

- ▷ a little lexical exercise, to throw some light on the term "creativity"
- ▷ a short inventory of honorifics, to indicate traits apparently prized by physicists
- ▷ a brief characterization of big science, to indicate traits apparently selected by physicists who work on big projects
- ▷ a very modest conclusion, to apply the results to the Nobel Prize in Physics.

The creative scientific genius

The word "creativity" was coined only recently. *The Oxford English Dictionary* dates its first appearance to 1875, in a book on English dramatic literature; it referred to Shakespeare's creative power. Alfred North Whitehead used it in the 1920s about God, and *Webster's*

Third New International Dictionary records an example of its application to an entire people, as in "the creativity of immigrants." Since in English literature Shakespeare is on the same level as God, it appears that up to around the date of the founding of the Nobel Prizes, "creativity" was the business of deities and large populations, not of individuals.

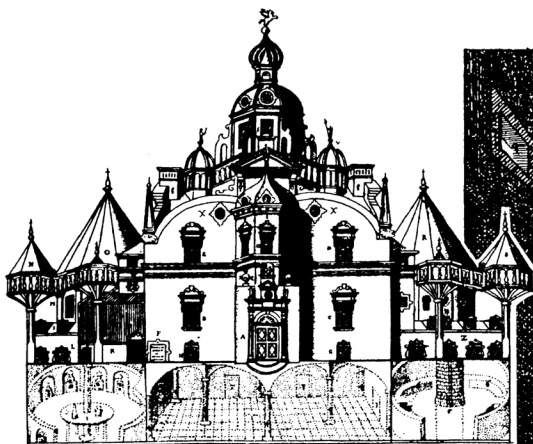
Much the same story can be told about the word "originality." Initially it referred to the authenticity or genuineness of things. The *OED* says it was first applied to an individual in 1787, when it distinguished the power of originating new ideas from mere eccentricity. During the 19th century it came to apply to ideas about nature as well as about poetry.

Some further guidance may be derived from the word "genius," which originally meant the guiding spirit of a place, the guardian angel of a person or the bent of a population. Only toward the end of the 18th century did "genius" take on the additional meaning of an individual who greatly surpassed his or her fellow creatures in brains and sensibility. Like "originality" and "creativity," the new usage at first referred to writers and artists. During the 19th century, the *OED* implies, "genius" in the sense of "native intellectual power of an exalted type" came to be opposed to "talent." The antithesis between creative genius and mere talent may have been an invention of the last century.

"Scientist" also is a word of the 19th century, coined in the 1830s to designate the type of people who attended the meetings of the newly established British Association for the Advancement of Science.¹ The name did not catch on: It sounded too professional, too much like "dentist." The preferred term continued to be "men of science" or "scientific men" until well after the First World War. "Scientist" came into common use in the 1930s, just as big science was taking its first toddler's steps in Ernest Lawrence's Radiation Laboratory.

The timing of this usage is significant. The phrase "a scientist's creativity" could not have been composed before

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Tycho Brahe is depicted at right sitting with his famed mural quadrant at the Uraniborg Observatory (shown above) on the Danish island of Hveen. If big science is defined as a practice involving squads of disciplined teams and instruments so expensive that they appear as line items in national budgets, Tycho's elaborate complex easily qualified.



the late 19th century, and even then something like “the creativity of a scientific man” would have been preferred, to keep the individual’s genius from disappearing into the professional’s expertise. By the 1930s scientists had lost this scruple and accepted their name.

The adjectives “creative” and “original” had been applied to persons long before the 19th century. Their reification into nouns, and their specification to men of science, were authorized by the theory of evolution: It made credible the notion that originality and creativity might be heritable and the human race bred for geniuses. The earliest work on this theme, Francis Galton’s *Hereditary Genius*, appeared in 1869, only ten years after his cousin Charles Darwin’s *Origin of Species*.

Galton set himself the task of determining how many families in England possessed a distinction similar to his own. He assumed that intelligence, like height, distributed along a bell-shaped curve, and he placed the Galtons and Darwins at ten standard deviations from the normal Englishman.

Galton’s spiritual offspring in this line of work was James McKeen Cattell, professor of psychology at Columbia University and founding editor of the reference work *American Men of Science*. Cattell devised a general quantitative way to distinguish genius from talent.² He asked peers to decide the hundred most distinguished men and, on occasion, women in each of the 12 sciences into which he had divided the world of learning.

The total number of entries reached 4000 in 1904 and 20 000 in 1930. As the population of scientists rose, the chance of achieving distinction by peer evaluation declined. According to Cattell’s calculations and prejudices, giants of science did not appear as frequently among American men of science in 1930 as they had before 1900. Some might see in this an indication of the coming of big science.

We arrive at the hypothesis that “creativity” became associated with men and women of science around 1900 by the extension of a term introduced to characterize literary

lions and sublime artists and with the encouragement of the theory of evolution. The man of science liberally endowed with creativity and originality rated as a scientific genius. His exemplar was the inventor of the theory of relativity, in whose originality not a little singularity also figured; some dictionaries allow “einstein,” with a small “e,” as a synonym for “scientific genius.”

Accolades

In early modern times, cultivators of natural science praised their most distinguished fellows not for reified qualities but for comparative attainments. Thus “the new Archimedes,” “Democritus redivivus” and “*philosophorum huius aetatis facile princeps*.” “The Ornament of the World” and “the greatest man who ever lived”—honorifics applied to Newton—took the style as far as it could go. To be sure, Newton was associated with genius, but in the old sense of superhuman spirit. English visitors to Paris in the early 18th century had to assure the mathematician Guillaume-François-Antoine de l’Hôpital that Newton ate and slept like an ordinary man. L’Hôpital had imagined Newton to be “a genius, an intelligence entirely disengaged from matter.”³

During the 18th century the standing secretary of France’s Académie Royale des Sciences had the task of writing eulogies of the academy’s deceased members. The qualities praised in these *éloges* were strength of mind and humility of spirit—“seriousness, simplicity [and] righteousness.”

Here is the preferred type in the words of the academy’s earliest and most influential secretary, Ber-

nard le Bovier de Fontenelle:

The qualities of his heart were even preferable to those of his mind, a rectitude so naive and unpremeditated that it made self-contradiction impossible... a total unfitness in self-advancement except by his works... and consequently a nearly total unfitness in making his fortune.

These may not be the qualities most needed by a successful group leader in high-energy physics, but they were precisely those most useful in persuading the wider public in the 18th century that the cultivation of science ranked with that of letters and did not undermine morality.⁴

Having established their position in society, the Parisian academicians of the 19th century could advertise a new set of essential qualities and try to select for them. Obituary notices of the second half of the century systematically praised the late master for his clarity of thought and elegance of expression. These are preeminently the qualities of the successful teacher, and teaching was the route to science in 19th-century France.

In a far from exhaustive search, only one French necrology of the later 19th century has come to light that mentions the defunct scientist's power of imagination, a trait so bizarre in a solid savant that the obituarist felt obliged to observe that his subject had an English mother. (C. E. Brown-Séquard was the imaginative hybrid; Spencer Weart of the American Institute of Physics drew him to my attention.) At the same time dead British scientists received praise in obituaries for boldness as well as imagination, and also a little credit for eccentricity. No one mentioned creativity or genius.

Something different entered with the age of Einstein: The great theorists of the time did credit one another for creativity and originality, as well as deep sensibilities—that is, precisely the complex of genius qualities that first came together in literary figures and painters. German-speaking theoretical physicists of the early 20th century liked to put themselves forward as artists. It is not logic, Max Planck wrote, but creative imagination “that kindles the first flash of new knowledge in the mind of the researcher who pushes forward into dark regions”; without imagination, “good new ideas do not come.”

Planck praised Hermann Minkowski's “artistically formed nature,” Albert Einstein's special “power of imagination” and Arnold Sommerfeld's “forward-groping imagination.” Einstein in return remarked on Planck's “truly artistic style” and the “artistic compulsion” that drove his creativity.⁵

A quality frequently associated with the artistic genius is a craving for solitude. Despite Einstein's humanitarianism and Planck's sense of religious community, both were loners in their work.

With high-energy physics came a new set of approved qualities. Letters of recommendation put mastery of cyclotroning and ability to work with others as prime desiderata. In a typical evaluation, written in 1946, Lawrence sold a new PhD as “an energetic and effective member of a research team,” specifically not as an original thinker or research director.⁶ Another representative endorsement, from Brookhaven National Laboratory in 1957, runs in its entirety, “His ability for independent research is about average, while his demonstrated ability to work congenially with others is outstanding.”⁷

Cooperativeness, in contrast to creativity, was pre-

cisely the characteristic for which Brookhaven then selected. In 1956 Samuel Goudsmit, who had contributed part of the idea of electron spin to little physics, issued the following bulletin in his capacity as head of physics at Brookhaven National Laboratory:⁸

In this new type of work experimental skill must be supplemented by personality traits which enhance and encourage the much needed cooperative loyalty. Since it is a great privilege to work with the Cosmotron, I feel that we now must deny its use to anyone whose emotional build-up might be detrimental to the cooperative spirit, no matter how good a physicist he is... I shall reserve the right to refuse experimental work in high energy to any member of my staff whom I deem unfit for group collaboration. I must remind you that it is, after all, not you but the machine that creates the particles and events which you are now investigating with such great zeal. The designers and builders of the Cosmotron get little credit for this. That we are favored with the opportunity to use this accelerator is for most of us a mere matter of luck and not of selection or intent, a circumstance which should fill us with humility.

We thus unexpectedly return to a trait recommended by Fontenelle.

The Nobel lectures of two of the participants in this session [see author note on page 42] provide a final datum. Samuel C. C. Ting and Melvin Schwartz (in 1976 and 1988, respectively) used the same words to describe the qualities that make a good physicist—“good taste.” Taste is something quite different from artistry. Taste can be taught, whereas artistry usually signifies something inherent. True artists, we are told, have a feel and sense for their culture; the more penetrating their vision, however, the less likely they will be recognized in their time. In marked contrast, good taste is a social quality, approved and recognized by other connoisseurs. The Nobel lecture delivered in 1990 by the third prizewinner on this program, Jerome Friedman, emphasized the group character of experimental research in high-energy physics.

Big science

Size alone does not define big science or allow us to date its advent. By crude but persuasive measures, “science” has been growing exponentially, with a doubling rate of 15 or 20 years, since the 17th century.

It does not seem profitable to seek a time on this continuous curve before which science was little and after which it was big. The measures that indicate continued exponential growth refer to scientists and their most immediate products: the number of people who worked at science and the number of their publications, journals, institutions and so on. If figures for financial support were available, they too undoubtedly would show exponential increase—and probably with roughly the same doubling time.

The effect of wars on this inexorable march is to displace the growth curve but not to change its index. For example, the number of entries in *Physics Abstracts* doubled every 15 years before World War II; the rate declined during the war, but in 1946–47 growth immediately resumed at the old pace.⁹



Jesuit Society's global reach is depicted on this 17th-century map. In pursuit of their mission to defend and expand the Roman Catholic Church, Jesuits collected, compiled and disseminated a wealth of scientific information.

When does quantitative growth produce qualitative change? What criteria are relevant? Quantity of data, size and cost of instruments, organization of work, self-image of the workers, and relations between science and the wider society come first to mind. Perhaps we should say that the appearance of squads of disciplined teams using instruments so expensive that they appear as line items in national budgets marks the arrival of big science. If so, we would have to date big science to early modern times. Two examples may be persuasive.

In 1576 Tycho Brahe began building his observatory on the Isle of Hveen in the Øresund. Its main building, a palace surrounded by walls five meters high, housed a great brass mural quadrant (see the figure on page 43), a chemical or alchemical laboratory, and living quarters and a game room for many assistants. A fully equipped branch observatory also on the island insured that results would not suffer from systematic errors. Tycho had a dozen assistants, many of them "predocs"—medical students from the University of Copenhagen come to learn the astrology then necessary to the higher practice of their profession. There were other observers, mechanics, assistants and calculators. The last of these were the predecessors of Kepler, who joined Tycho as head of his computing division just after Tycho left Hveen in 1597.¹⁰

Tycho ruled over his staff with an authority more feudal than project leaders enjoy at CERN. He designed the instruments, the buildings, the way of life, the observation protocols and so on. Observations made under these protocols—which amounted to regular, sustained viewing of the Moon and planets—yielded great quantities of data, from which his computing division derived parameters of planetary motion far more reliable than any previously determined. Tycho disseminated his results from his own printing press, which was also part of the big science installation on Hveen.

Tycho relied on the Danish king to finance his empire. He enjoyed the proceeds from farms, ecclesiastical posts, government sinecures and, for a time, customs levied on ships passing through the Øresund. The financing of Hveen was eased by cheap labor supplied unwillingly by the inhabitants of the island, whom Tycho held in feudal thrall: They did the heavy construction, tended his garden

and raised his crops. The organizational effort and refinement required might appropriately be compared with the running of a modern large telescope with its support services.

My second example of big science in early modern times comes from a most unlikely source—the Society of Jesus, which celebrated the 450th anniversary of its founding last year. During the 17th and most of the 18th century, the Jesuits were the schoolmasters of Catholic Europe. Although the theoretical basis of their curriculum was old-fashioned even then, in practice they offered up-to-date information on all respectable subjects. They emphasized mathematics as particularly useful to aristocrats and sons of the upper middle class for use in fortification and commerce, and they compiled great inventories and treatises about the natural world as revealed in voyages of discovery, in sojourns in foreign lands, and in the laboratories and libraries of Europe.¹¹

To keep track of this information, to check it and to extend it, the society maintained seminaries and collections in which members with a special aptitude for science could work. These *scriptores*, as they were called, composed large books and did small experiments; they also conducted extensive correspondence with Jesuit missionaries and scholars. Their great cooperative venture resulted in the education of many students who made their mark in science, of whom the best known is Descartes. A complete inventory of Jesuit-trained savants would include most of the members of the Paris Academy of Sciences during the 17th and 18th centuries and the leading mathematicians of France, Italy and southern Germany.

During the early modern period, the Jesuits possessed a network of scientific collaborators more extensive and numerous than today's international tribe of particle physicists. They concerned themselves with the relationship between pedagogy and study, or teaching and research, much as university administrators do today. And they perfected the argument—the same one that the US Atomic Energy Commission used to justify the multiplication of accelerator laboratories in the 1950s—that they deserved the financial support of the wider society because they trained students in socially useful applications of contemporary learning.

I bring these examples forward not because I consider Tycho's observatory or the Society of Jesus a model for the Lawrence Berkeley Laboratory or for CERN, but because they help to isolate what may be the definitive element in modern big science. In neither ancient case did individuals seek to—or need to—build a reputation apart from the collectivity. Tycho ran Hveen as a private fiefdom: He made the rules, designed the research and published the results. The Jesuit savants did exactly what their superiors told them to do, and their publications redounded to the glory of the society, not to the advancement of the individual. In short, neither system was intended to produce what then did not exist, the career scientist.

In high-energy physics, in contrast, individuals must play for the team while simultaneously distinguishing themselves for leadership and good taste. Achieving the right balance has been difficult, especially for accelerator builders and, more recently, detector builders, who have had fewer chances to call attention to themselves than have experimenters.

In 1956, Mark Oliphant encountered the problem in his homeland of Australia after returning there from Britain at the urging of the Australian prime minister to introduce high-energy physics. A meritorious machine-building colleague was having trouble climbing the academic ladder. Oliphant applied for advice to Lawrence,¹² who answered that the new science required new rules.¹³

For many years I had similar problems here but now it is well understood and appreciated that the design and construction of accelerators and associated instrumentation for nuclear research involves the same high talent and devotion to science that is necessary for the effective utilization of these tools in nuclear investigations.

Lawrence gave the case of a physicist who had recently been made a full professor at Berkeley not on the strength of his publications but “rather because of his outstanding ability and devotion to the cause of advancing science by the development of new facilities for research and in other ways contributing effectively as a member of a team in scientific endeavors.”

The combination of outstanding ability, devotion to the cause, effectiveness in developing new research facilities and teamwork makes up the special endowment, the peculiar creativity, of the big scientist. Or at least that was the opinion of the founding father of big physics.

Inferences drawn from prizes

Alfred Nobel established his prizes to enhance the prestige of scientists. The world would take note of awards of such value and infer the value of science. The Nobel Foundation furthered Nobel's purpose by the pomp and splendor of the award ceremonies, and the Royal Swedish Academy of Sciences kept it green by adopting the rule that no more than three people could share a science prize.¹⁴

These features agreed perfectly with the heroic concepts of creativity and scientific genius current when Wilhelm Röntgen received the first Nobel Prize in Physics 91 years ago. But they do not correspond very well with the practices of big science.

A brief review of two Nobel Prizes given for work done in high-energy physics at the Lawrence Berkeley Laboratory indicates the progressive intensification of the mismatch. The earlier prize, that for 1939, went to Lawrence alone “for the invention and development of the cyclotron and for results obtained with it, especially with regard to artificial radioactive elements.”

This formulation from the official citation suggests that Lawrence himself discovered something important

with his machine. The Nobel Prize committee knew better: Its telegram to Lawrence specified the importance of the cyclotron itself for the production of radioisotopes in great quantities. Most of the nominations Lawrence received likewise praised the cyclotron as a cornucopia, not its inventor as an investigator.

The man who made the first cyclotron that worked, Stanley Livingston, gave the best assessment of Lawrence's claims on a prize: “Lawrence was the first and only one to have enough confidence in [the idea of the cyclotron] to try it out. . . . His optimistic and inspirational attitude was what convinced me it was worth working on. . . . [His] ability as a director and organizer and his inspirational leadership amount almost to genius, but the bulk of the development was done by others.”¹⁵

In choosing Lawrence, the Nobel Prize committee preferred work that resulted in a prolific machine and in the invention of the interdisciplinary accelerator laboratory over a more traditional contribution in the same field. I have in mind the achievement of John Cockcroft and Ernest Walton, who not only built a machine to crack atoms but also succeeded in cracking them and, moreover, had priority over Lawrence in both respects.

But by 1939 the cyclotron had proved its superiority over the Cockcroft–Walton generator in the range and quantity of the radioisotopes it produced. Cockcroft and Walton had to wait until 1951 to receive the prize “for their pioneering work on the transmutation of atomic nuclei by artificially accelerated atomic particles.”

Lawrence's role in big physics was unique. It amounted, as Livingston put it in a phrase reflecting an earlier way of looking at scientific distinction, “almost to genius.” He received his prize for inventing a new way of doing science. Most physicists thought the prize appropriately bestowed.

My second example comes from the late 1950s, the same time that Goudsmit issued his orders about social conformity to the physicists at Brookhaven. The Nobel Prize in Physics in 1959 went to Emilio Segrè and Owen Chamberlain “for their discovery of the antiproton.” Segrè's immediate group included two others—Claude Wiegand, an electronics expert who built much of the experiment's innovative circuitry, and a graduate student who was soon to become an assistant professor, Thomas Ypsilantis.

A critical piece of the detector, a set of quadrupole magnets, was made by the accelerator team, which also built the Bevatron, the machine that made the antiprotons that Segrè's group detected. The head of the accelerator team, Edward Lofgren, also had a small group searching for antiprotons. Adding to the cast of concepts and characters, the experiment depended on measuring the time of flight of particles from one detector to another. According to Oreste Piccioni, then at Brookhaven, he had suggested the time-of-flight method and the associated electronics, and he considered himself a member of Segrè's group. In their announcement of the detection of antiprotons, Segrè and Chamberlain did thank Piccioni for his advice.

In 1972 Piccioni sued Segrè and Chamberlain for theft of intellectual property. To explain his long delay in bringing suit, he said that when he complained to Lawrence in 1955, immediately after Segrè's group first sighted antiprotons, he was told to keep silent if he wished to continue to have access to the accelerators at Berkeley and Brookhaven; in return Lawrence and other leaders of the field would promote Piccioni's career. In his brief of 1972, Piccioni identified the mafia oppressing him as the Nobel Prize winners who had run the wartime Manhattan Project. “The rewards and honors in the scientific



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A mismatch between the traditions of the Nobel Foundation and the practices of emergent high-energy physics was apparent at the field's inception. Ernest Lawrence (left, holding his first cyclotron) was awarded the 1939 Nobel Prize because he had invented a powerful machine and an interdisciplinary science. Most physicists considered the prize appropriate. Ernest Walton and John Cockcroft (left and right below), shown with Ernest Rutherford at the Cavendish Lab, built a machine to crack atoms—and actually cracked them before Lawrence did—but they had to wait until 1951 to be recognized with a Nobel.

UK ATOMIC ENERGY AUTHORITY



community are controlled by the Nobel laureates," he wrote. Piccioni's charges were never considered on their merits. The court dismissed them on the ground that he had taken too long to bring his grievances before the law.

In its commentary on the affair, *Science* magazine observed that threats and promises of the kind that Piccioni alleged were "now considered commonplace in scientific life."¹⁶ (See also *PHYSICS TODAY*, September 1972, page 69.) In confirmation of this allegation, it cited a study of some 200 British high-energy physicists, over a sixth of whom responded that they believed that some of their work had been stolen by coworkers. Half of the American physicists who responded to a similar inquiry said that they would not feel comfortable discussing their ideas with all of their colleagues.

The press traced much of the problem to the competitiveness in a system that gave so much authority and prestige to the very few that made it to the top. The inclusion of Piccioni (if warranted) and also Wiegand, Ypsilantis, Lofgren and perhaps others in a share of the prize would have come closer to acknowledging the effective contributors to the antiproton's detection than did the actual award.

The original Nobel statutes presented no bar to awarding a prize to a group. The relevant statute reads as follows in the official, antiquated translation:

In cases where two or more persons shall have executed a work in conjunction, and that work be awarded a prize, such prize shall be presented to them jointly. . . . It shall fall to the lot of each corporation entitled to adjudicate prizes to determine whether the prize or prizes they have to award might likewise be granted to some institution or society.

The Norwegian Parliament, which awards the Nobel Prize for Peace, has chosen an institution as winner 14 times.

The proposal to return to the letter of the original statute, which would make groups eligible to receive Nobel Prizes in science, can scarcely be fresh. No doubt it has not been adopted for good reasons. Still, in many cases rewarding groups would respond better than the current system to the practices of disciplines like particle physics

and to the special mix of talent and teamwork that supports and constitutes creativity in big science.

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