Invent or Discover

the art of useful science

[Sample Chapter 7: Curiosity]

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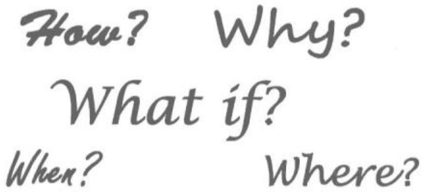

And how will you enquire, Socrates, into that which you do not know? What will you put forth as the subject of enquiry? And if you find what you want, how will you ever know that this is the thing which you did not know?

(Plato)

Curiosity is a strange topic, a puzzling characteristic of humans. Some researchers claim gossip to be the basis of how the human brain became fully differentiated from that of all other animals once we developed language. What is the incentive for gossip other than insatiable curiosity about what our neighbors, friends and colleagues have been getting up to? What then of the type of curiosity that scientists hope is something more highfalutin' and surely is more productive of interest, wonder and better tools. Who possesses scientific curiosity, and why do some people have more than others? These are difficult questions. The psychologist Stephen Pinker, toward the end of a detailed exploration of human nature speculated about our ability to understand scientifically the natural world. We evolved as small groups of people living directly off the land and only settled down to an agricultural means of providing food a few millennia ago. That is too recent for evolution to have changed our brains from their primitive state. So we now continue without evolved faculties for understanding nature intuitively or spontaneously.

Pinker carried on with a list of 200 characteristics of human nature that anthropologists consider to be universal amongst all groups and peoples. Conspicuous by their absence from this list are curiosity, inquisitiveness, investigation or similar characteristics and behaviors of humans. Pinker derived his list from a book by anthropologist Donald Brown about human universals; Brown similarly makes almost no mention of curiosity or similar behavior as a characteristic of humans.

It gets stranger still. Curiosity has been a subject of academic study at a very small scale, compared to a veritable industry of studies on scientific creativity that originated in the paranoia sparked by the launch of Sputnik. Several reviewers have commented on how the subject of curiosity vanished between 1900 and 1950, possibly influenced by Sigmund Freud's wacky ideas about the role of early sexual exploration in the development of human personality. It is possible to read recently published psychological studies on the origins of scientific creativity and genius without finding discussion of curiosity.

Researchers who study animals, from rats to dogs and cats to monkeys, baboons and chimpanzees have little problem in demonstrating curiosity in response to varied test materials such as blocks of wood, pieces of chain or balls. Cows are curious, whales are curious. The explanations offered for this behavior usually involve the adaptive advantage of learning how to search or hunt for food. Sometimes even the tricky, almost taboo, proposition of play for fun is offered. And humans too, if young enough, can respond to tests by psychologists for curiosity.

Curiosity is amoral; the impulse is as indifferent to the consequences as is our urge for speed. The urge to gossip about neighbors and colleagues is almost irresistible despite the moral prohibition against something obviously bad for good community relations and work-place efficiency. Religious teachers with moral and social control systems to maintain are fearful of curiosity because their rules are based on a heavenly authority they claim to be omniscient and thus beyond questioning. So does the problem with curiosity in adult humans derive from the danger it may lead to? 'Ask no questions and you'll be told no lies' is a classical response to unwanted curiosity. The parable of Pandora's Box and the play about Doctor Faustus warn us. Or as Milton in his Paradise Lost passage about the angel Raphael answering questions from Adam and Eve put it: 'Heaven is for thee too high to know what passes there; be lowly wise; think only what concerns thee and thy being; dream not of other worlds.'

Cultural differences between educational systems in the expression of curiosity are well known. In some classes and lecture theatres students are expected just to sit and listen so that they can remember and regurgitate their received knowledge in the exam. The teacher carefully guards his authority against embarrassing questions. Conversely, even in intellectually open and questioning colleges teachers often despair at the difficulty of getting everyone in a group of students to contribute to an interactive tutorial. Too many students feel paralyzed by the thought of asking what they call a silly question, fearing to lose face. Yet another source of distrust of the curiosity of scientists, even amongst people of an openly enquiring mind, is the alienation and fear induced by some aspects of new technological developments: radioactivity, carcinogenic chemicals, cloning, genetic manipulation, and other melancholies about loss of the familiar old ways.

Could science as playful enquiry be part of the reason why curiosity is ignored or treated with suspicion; is curiosity sufficiently serious for the attention of scholarly academics? Many of the researchers who write about the way they work comment on the importance of play as both a motivation and even a deliberate method of research. Scientists, so bound up in their world of apparatus, experiments, facts and theories, talk about their play unselfconsciously. Bankers and lawyers and doctors, with serious professions to attend to, wear dark suits. Scientist turn up to work as if dropping in on their way to the beach. This is not just because they have few fee-paying clients to impress – they really are getting together in the lab for a game of 'bounce this theory back and forth across the net'.

Let some scientists and inventors speak for themselves.
Sydney Brenner: '. . . another thing that is terribly important to creativity is day-dreaming.'
David Bohm & David Peat: 'Play, it appears, is of the very essence of thought.'
Thomas Edison: 'I never did a day's work in my life, it was all fun'.

People looking in on science as it is presented for the public, often by researchers themselves in press releases promoted by their public relations department, get the impression of a robotic scientific method, that once properly applied to a problem will produce the required answers. From that, it follows that industry, commerce or the economy is at fault if the fruits of discovery cannot be deployed as inventions.

This is a myth. As the six stories of this book have shown, there is no such single thing as *the* scientific method. Scientists have methods they use in the laboratory or when collecting facts in the field. They have methods to analyze their facts and experimental results. They have ways of applying these methods and organizing their lives to increase their chances of finding something unexpected and interesting. They cultivate and develop the art of serendipity. There is no single prescriptive route from asking a question to providing any answer, let alone an answer that may lead to an invention.

Necessity obviously is a mother of invention; the list is a long one, starting from a stone axe or similar aid to survival. Chapter 4 mentions batteries invented to meet acute demand without understanding of their chemistry. The invention of the canning process for preserving food was an effective and profitable response to the needs of a more mobile human population working away from farms. Even more necessary was the paired invention for the can, but all we have are numerous less effective gadgets for opening these obstinate things. As the mathematician and philosopher Alfred North Whitehead expressed the matter: 'Necessity is the mother of invention is a silly proverb. Necessity is the mother of futile dodges is much nearer the truth.'

Another way of looking at the matter is to ask, just how necessary is something that will not yield to invention? Obviously a vaccine against HIV is necessary, as is fusion power, but other means of reducing AIDS and providing more electricity are slowly becoming effective. The dichotomy between necessity and curiosity as mothers of invention might appear to parallel that between market pull and technical push. The weakness of necessity is that it only pulls at an often insufficient body of knowledge and understanding, whilst curiosity provides the scientific basis of both push and for responses to much of the pull.

What of scientific creativity and genius: are these the crux of the matter? It is easier to apply the concept of creativity to the arts than sciences. In the arts there is endless scope for creativity, for inventiveness and originality – the essence is in degree of originality. For science, the scope for creativity is confined to theories, and to avoid scorn and rejection they should have some plausibility derived from known facts. Most of these theories must then be discarded when tested by new facts of observation and experiment. Although the natural world has an almost infinite supply of facts, for any one theory there are few that are relevant for testing, and they must be found as natural phenomena, never created.

High creativity, genius, in science is displayed in the use of technique to gather facts, the relevance of the facts to the question, and the usefulness of the theory to further understanding. Is this most easily understood as a function of intelligence? Most researchers would score above average on standard tests of intelligence but there is little evidence that those with exceptionally high scores on standard tests are exceptionally high achievers in science and invention.

Individual differences are interesting. Retrospective calculations of intelligence quotient put mathematicians Gottfried Leibniz at 195 and Isaac Newton at 150. Despite that discrepancy they simultaneously and independently invented infinitesimal calculus. Or compare physicists Richard Feynman and Albert Einstein by their conventional indicators of performance in school, college and professional life. Feynman the star pupil was a young prodigy. Einstein, the auto-didact, dismayed his teachers, he was a dropout. Feynman flashed his brilliance throughout his life, a popular teacher and playful thinker, whilst Einstein was reticent and often brooding. And yet Einstein's contributions to human understanding are accepted as deeper and wider than Feynman's.

Genius is a concept of limited use to analyze how scientists discover and invent. All of the highest talents can be described geniuses because their discoveries and revelation of new understanding are so conspicuous. Does that description inform us about the process of discovery or does it place it in a black box? Is the concept of genius more aligned with hero, or even celebrity? No scientist sets out to be a genius. A member of the National Academy will do fine to improve social contacts. Genius is a quality thrust upon those few scientists who fit that job description by people in search of celebrities to admire.

As for black boxes, how the human brain works remains the largest and toughest challenge to researchers of living things. Progress so far suggests that it will be a long time before concepts such as creativity, intelligence and genius can be explained and defined, or possibly replaced with something more useful.

Philosopher Daniel Dennett explains some of the current thinking on the problem of consciousness and how it might be explained. Start from the brain equipped by evolution for the life of a hunter and gatherer, as described by Pinker, with animal-like capacities developed separately for operating a hunting group, for avoiding predators, recognizing members of the social group, grasping, throwing, picking berries between finger and thumb. Then consider how those abilities are now used in our modern lives for organizing a company, for assessing risk of earthquakes, reading and writing, and performing heart surgery. There is no empirical evidence of any central controller or any single physical component that can confidently be labeled the source of intelligence quotient or genius. The enormous difference between how our brains work for us and those of a chimpanzee are due to cultural inheritance, to the units of social learning and memory mostly through language in speech and writing, that have aptly been named memes by Richard Dawkins and whose social workings have been described in detail by Susan Blackmore.

Where lies curiosity and play within this proposition? The evolved capacity is connected to searching for food, learning to hunt, learning about predators – not just avoiding them but avoiding wasting time and energy by clambering up trees when the risk is too distant. The culturally developed capacity for curiosity is suppressed because it is dangerous to social control. It is also encouraged because it brings understanding that is satisfying and is of economic use. Compare research into suspicious activities of the secret security services with research into the connections between nerves in the human brain. If you cannot find out what the secret security agents are up to, you make jokes about them instead; all the more funny for the fear they elicit.

Rather than genius, surely ordinary curiosity is the place to look for the roots of discovery and invention. If chimpanzees have it then surely we humans all have some of it, and some of us happen to be possessed by intense and insatiable curiosity about the way the world works. All of the researchers in these stories were driven. Why, why, why they asked. And then from each answer come ten more questions. How, why? This searching dominated their lives, consumed all their time and energies. They were in for the long haul, the life's work.

As a consequence, the productivity of these enquirers was high as measured by publication of numbers of papers over time, and separately by the quality of those papers as measured by citation ratings relative to others. A more effective description of the scientists who contributed to these inventions than creativity, intelligence or genius is their ability to channel energy through their work. A handle on how they differ in productivity is how many times other scientists quote, in the reference list of their papers, a particular paper of any other individual scientist. Thus the particular paper soon acquires a citation count, ranging from an embarrassing number that are never cited to some cited by thousands.

The pattern that forms when frequency of papers within categories of citation numbers is plotted on a graph is universal. The data strongly aggregate into a high shoulder alongside the vertical axis at the left, where the biggest category is typically zero to nine citations per paper. Out toward the right of the graph a long tail slopes down to of a few papers with citations going into the thousands per paper. This long tail to the right is where most of the papers published by the researchers in the stories of this book will be found.

This type of distribution has long been described, first by the Italian engineer and economist Vilfredo Pareto, who commented on his findings that eighty percent of the wealth of Italy was held by twenty percent of his countrymen; his observation is now a common theme in business management. The same distribution was analyzed later in terms of energy flow. In our case, the energy flows through a search for resources, where soluble research problems are the resource and scientists do the searching. But the quality, or solubility, of the research problems varies and so the researchers will partition themselves amongst these patches by competing with each other, and also by good chance.

The crux is the rate of energy flow from problem to scientist. There will be a limited number of soluble problems in any one field of research and they will vary in the information they yield. In this context, information is equivalent to energy and the more a researcher can obtain the better she will thrive professionally. This trend will then be amplified by a positive feedback from higher ability of some researchers to solve problems and by the powerful phenomenon that the more a paper is cited the more visible it becomes and thus even more highly cited. Recognition is the scarce resource: scientists crave and need it because high recognition literally translates into energy embodied in the labor of assistants and material equipment purchased with the money awarded because of high recognition.

What of those researchers producing mostly papers that are less recognized? They contribute in multiple ways. They are the students who later improve their productivity and citation ratings; they are the technically adept gathers of the raw data needed by the top theorists. They provide the teaching that economically enables universities to be enduring centers of research, stable for centuries compared to the decades typical of institutes of research. Moreover, these researchers constitute the economic market of sufficient size for the essential specialist equipment and reagents of their trade. Without these ordinary workers those at the top of pyramid would fall.

So where does curiosity fit into this distribution? As the stories of this book have shown, all these people who gained high recognition were possessed and driven by curiosity. That is the craving they got up in the morning to satisfy, and continued working to satisfy through the night, weekends, holidays. Sometimes they ruined their social lives and health, knowing fully that for every answer there would be ten more questions. The biochemical mechanics of how curiosity works in the depths of the brain may remain a mystery for long time, but when the behavior is cultivated, nurtured and given the freest opportunities its results are obvious.

As soon as humans invented axes robust enough to chop down trees into logs, some of those inventors must have wondered whether several logs in a row would permit a big tree trunk to be rolled where it was needed instead of carrying it in many hands. That successful experiment led to Stonehenge and similar monuments to human wealth and need to calibrate the seasons. Thence to the wheel. But logs as rollers inspired an obvious question, something they knew they did not know; a known unknown in need of an experiment. Even more so the wheel: once invented it was obvious that it needed improvement. Make it rounder, larger or lighter, but how? With spokes, with pneumatic tires. So the innovation goes, increment by increment, there is the original tire and the endless minor improvements to it still being made.

Not so with recombinant DNA technique for synthetic protein, for the properties of macromolecules as plastics, for nuclear fission and fusion, for the laser. These were unimagined let alone unknown. As chemist and commentator on how science gets done Henry Bauer put it: 'Most of scientific research deals with the known unknown. Deliberate research into the unknown unknown is more or less impossible by definition, but the unknown unknown is revealed by serendipity and luck, and these come more readily to the prepared and searching mind.' These and many similar inventions are not part of a continuum from the ancient wheel to the many interconnecting wheels in a traditional windmill.

New technologies can proceed without understanding how (batteries) and by many innovations on a theme (wheels) driven by a combination of necessity from customers, need for profits to the inventors and curiosity of the experimenter. What will happen if we fit this windmill with many thin vanes instead of a few wide ones? In contrast, the inventions of this book are examples of inventions from the other side, from the unthought of and the unimagined. They are fantastical and of immense power. There is only one key to open the door onto them: curiosity.

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Bauer, H.H., 1992. *Scientific Literacy and the Myth of the Scientific Method*. University of Illinoi Press, Urbana and Chicago, (Illini Books edition, 1994). [Pg. 74: 'Most of scientific research deals with . . .' **Unknown unknown** is a phrase that unfortunately gained notoriety after Donald Rumsfeld, US Secretary of Defense, during a press conference in 2002, described one aspect of the fog of war in general, and in Iraq at the time. He said: 'There are known knowns. There are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know.' Mr. Rumsfeld made surprising good sense to anyone with the patience to think it through; unlike some newsreaders and comedians. However, the concept was nothing new, it had long been circulating in the Pentagon and was expressed millennia ago by Plato, then publicized by that eminently practical American philosopher Henry Thoreau. See Plato's Dialogue '*The Meno'* for the header quotation.]

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