Profiles in research*

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In this article, addressed to young people, the author attempts to describe the nature of scientific research by narrating several real-life examples of exciting discoveries.

The title of this article was inspired by the non-fiction best-seller entitled '*Profiles in Courage*', written by President John F. Kennedy of the United States. It is a story of challenge, hope, despair and the will to survive and be a winner. These outlines of life have some parallels in the story of scientific research. I would like to narrate this story with the hope that it would spark the imagination of some young people who may develop something new, something that we can be truly proud of, to point to as our contribution to mankind.

The word research is an interesting one to contemplate on, and a study of its etymology can be instructive. Let us start with the dictionary meanings of the noun forms:

- Search – act of searching and examination.
- Research – a careful hunting for facts, or enquiry, probe, investigation.

The meanings of search and research are somewhat similar, i.e. seeking and careful examination We must go back to the French words '*cherche*' and '*recherche*', from where the English equivalents were derived. The prefix 're' means again, anew, once more. The first motivation is one of searching, to discover – *cherche*. This involves an attitude of mind known as the creative instinct, the illumination. After the discovery, there is a second set of distinct actions: process of verification; comparison with natural laws; generalization, possible expansion into other realms The latter frequently requires more patience, time-consuming theoretical probing and experimentation, reworking of old hypotheses and laboratory data – the 're' part of *recherche* (or research). Once in a while, we find people gifted in both types of motivation, but, in general, only few have the inspiration and knack for discovery, leaving the more arduous task to methodical researchers, working often in teams, to provide verification.

Search and discovery

That there is a set of logical steps in the process of discovery is debatable. Obviously, the mind of the discoverer is the focal point. In some cases, the route could involve the following steps: (a) recognition of the problem; (b) incubation and frustration; and (c) illumination. There are, of course, many instances where major discoveries have been made by the flash of genius. Serendipic discovery is often made in a short period of time. The noun '*serendipity*' (or the adjective 'serendipic') has an interesting birth. It was coined by Horace Walpole in 1754 when he discovered a fairy tale from Sri Lanka (then, Ceylon) called *The Three Princes of Serendip*. Their Highnesses travelled a great deal and always made discoveries by accident and/or sagacity of things which they were not at all looking for. For example, one prince deduced that a mule, blind in the right eye, must frequently travel the same road because the grass was eaten only on the left side. The term has been used to describe an ability or acquired trait of recognizing and interpreting interesting and exciting experiences or phenomena in everyday life.

The stimulation of the mind, being the handmaiden of discovery (via the *creative process*), is the most crucial factor. What makes a truly creative person tick? A study by the University of California points why some persons are more creative than the others I quote the following: 'There is no single mould into which all that are creative will fit. The full and complete picture of a creative person will require many images. If, despite this caution, one still insists on asking what most generally characterizes the creative individual as revealed in these studies, it is the high level of effective intelligence, openness to experience, freedom from crippling restraints and impoverished inhibitions, aesthetic sensitivity, cognitive flexibility, independence of thought and action, high level of creative energy, and striving for solutions to the ever-more difficult problems the person constantly sets for himself.' Many of these traits can be recognized at an early age.

The nature of creativity is little understood since it involves primarily the human mind. Psychologists find that the mind can be influenced towards a creative trend with somewhat variable results. Some persons are better than others. However, the net result is positive if the correct attitudes can be instilled and an appropriate environment provided. *What is unfortunate, however, is that in the prevalent educational system, dominated by meaningless examinations, there appears to be single-minded destruction of creativity in the young people.*

A great many persons have the ability for search and discovery but are blocked by poor qualities such as lack of problem visualization, lack of imagination, lack of incentive and emotional or cultural blockages. The last one may have handicapped some of the potentially creative Indians in the past. For example, the curiosity of taking apart mechanical objects and making serendipic discoveries may have been stifled by an abhorrence for dirtying the hands. Much can be done to remove these blockages and to stimulate creativity in people with latent talent. For instance, *the concept of "The Professor" who completely dictates the thoughts and the work of the students and allows no questioning is an example of how not to stimulate creativity in students.* Such domination from parents, teachers and other contacts in life must be avoided from childhood onwards. Remember that imagination (a good measure of creativity) is maximum around the age of 15 years or so and starts falling off later What keeps on increasing with age is judg-

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Verification

Once a discovery is made, it has to be subjected to thorough scrutiny, preferably by the discoverer, if not, certainly by a competitor or a co-worker. Many good ideas have been put forth, left indefinitely in the formative stages and not verified or developed. The ideas are often rediscovered later much to the chagrin of the original discoverer. The proof of the discovery of an idea is frequently more time-consuming and costly than the initial creative step(s). It takes a creative mind to set up an original hypothesis or a good experiment, and an objective mind to examine the results critically. The original discoverer may often require help in the development of the idea.

Research illustrated by example

Research involves the mind of a person and a set of attitudes towards life. These are wholly personal and human. Michael Faraday was probably the greatest experimental scientist that ever lived. Even though he had only three years of schooling, his dedication and excitement for science made it possible for him to discover ever so many new phenomena, new laws, new chemical compounds and new materials properties. He discovered benzene, electricity and the laws of electrolysis. He originated the idea of fields. He could have, by the present-day standards, easily received five or six Nobel prizes for his major discoveries. He wrote around 450 research papers based on the experimental work carried out by himself. One wonders what exactly inspired someone like Faraday. His is a pure case of the inner urge propelling him to do science of such high calibre, so profusely. His performance is unparallelled in experimental science.

Ramanujan, without any university education, did more mathematics than any other single person that one knows. He wrote page after page of equations in notebooks based purely on his own initiative and intuition. Although he often attributed his accomplishments to the grace of his family deity, he clearly had something powerful inside him. I cannot think of any external stimuli that made Ramanujan one of the greatest mathematicians of all time. It was certainly not his educational background either.

I have always wondered how Einstein got to concern himself about the laws governing the Universe. Or how Newton did all that he did in such a short period, writing his remarkable work from his country home during the year of the plague. I have specially admired the prolific discoveries of Linus Pauling during the period 1927–1951, covering chemical bonding, crystallography, molecular structure and molecular biology. I have been equally impressed by the synthetic genius of Robert Woodward and the high level of research productivity of Nevill Mott and Herbert Brown lasting over six decades. It would be really instructive to learn how they generated ideas and what motivated them. We learn much by examining the way ideas are born and by examining the working lives of great scientists.

Let me cite a few examples to illustrate how significant discoveries have been made in the saga of modern science.

A trend-setting chemical discovery in the 19th century with immediate technological benefit: Synthesis of dyes (1856) – William Henry Perkin

Although his father was against a career in chemistry, Perkin studied chemistry by attending lectures during dinner hours at the age of 13. When he was in his second year at college, Perkin became an assistant to his teacher and also set up his own laboratory at home. One of his first pieces of personal research was on a colouring material. He soon discovered an azodye and during the Easter vacation in 1856, synthesized mauve, the first synthetic dyestuff. Perkin was 18 years old at that time. This was followed by other discoveries of dyes. After establishing the effectiveness of his dyes for colouring textiles, Perkin became involved in building a factory for the production of dyes during 1857.

By the year 1873, Perkin had earned enough money through the production of dyestuffs. Perkin then decided to devote himself to organic chemistry research and made many discoveries. One discovery of significance is the synthesis of cinnamic acid from benzaldehyde, which was preceded by the synthesis of coumarin and unsaturated acids. It may be recalled that the Indian production of indigo, which was a plant product, had to be stopped because of Perkin's synthesis.

Perseverance and the urge to succeed: Preparation of aluminium (1886) – Charles Martin Hall

Charles Hall started reading his father's chemistry books at an age when other children probably did not fully know the alphabets. His interest continued in a home-made laboratory which he stocked by borrowing and buying, with his meagre savings, from the storeroom at Oberlin College. He was admitted to this college, where he continued to study chemistry as his major subject. One day, his teacher, Prof. Jewett, told him about a light metal of high strength, aluminium. He remarked to the boy that if only someone could find an economical method of extraction there would be so many everyday applications. Hall was heard saying 'I am going after that metal'.

After graduation, he continued to borrow apparatus from the college for a larger-size laboratory in the shed at the back of his father's parsonage. He started searching for a solvent for aluminium oxide. Within six months, he discovered that cryolite, a mineral of formula Na_3AlF_6, acts as a flux for the oxide and could also carry electric current. This was the beginning of fused-salt electrolysis and the answer to his search. He came into Prof Jewett's office one day in 1886 with a dozen little globules of the shiny metal and held out his hand saying 'Professor, I have got it'. He had accomplished something that had eluded scientific giants like Humphrey Davy. The commercial development took a while longer. The use of aluminium in everyday life and in high technology is proof of the 'going after' that Hall, at the age 19, vowed that he would do.

Observing Nature as a clue to discovery: Raman effect (1928) – Chandrasekara Venkata Raman

C. V. Raman studied physics and obtained the M A degree with distinction at the Presidency College, Madras, at the age of 19. He took a competitive examination for the Indian Finance Service, secured first place, and became an assistant accountant general. Although he spent the next ten years of his life as an officer in the Finance Department, his after-hours were spent in doing experimental research in the laboratory of the Indian Association for the Cultivation of Science. His success attracted much attention and in 1917 he was asked to take the Palit Chair of Physics at Calcutta University Four years later, Raman was on a sea voyage to Europe when his curiosity was aroused. The following extract is taken from his Nobel lecture, in which he tells how the study of molecular scattering was initiated:

'A voyage to Europe in the summer of 1921 gave me the first opportunity of observing the wonderful blue opalescence of the Mediterranean Sea. It seemed not unlikely that the phenomenon owed its origin to the scattering of sunlight by the molecules of the water. To test this explanation, it appeared desirable to ascertain the laws governing the diffusion of light in liquids, and experiments with this object were started immediately on my return to Calcutta in September 1921. It soon became evident, however, that the subject possessed a significance extending far beyond the special purpose for which the work was undertaken, and that it offered unlimited scope for research. The study of light scattering ... (became) the main theme of our activities at Calcutta from that time onwards.'

The success of the work carried out at Calcutta is evidenced by the naming of the scattering phenomenon observed by Raman as the Raman effect. It has proven to be of the greatest importance in the study of molecular structure and a variety of other problems. Yet, it started by a questioning observance of a natural phenomenon – the colour of the sea – by a young enquiring mind

Serendipic discovery: Teflon (1938) – Roy J. Plunkett

Roy J Plunkett discovered Teflon, the chemical- and heat-resistant plastic, only a few years after completing his postgraduate work at the Ohio State University. His assignment at duPont chemical company was to prepare fluorochlorohydrocarbon compounds useful as refrigerants. A need developed for a supply of tetrafluoroethylene, which he synthesized and stored in small gas cylinders for a series of experiments. His discovery of teflon was made shortly thereafter as he tells it.

'On this particular day, soon after the experiment started, my helper called to my attention that the flow of tetrafluoroethylene had stopped. I checked the weight of the cylinder and found that it still contained a sizeable quantity of material which I thought to be tetrafluoroethylene. I opened the valve completely and ran a wire through the valve opening, but no gas escaped. When I shook the cylinder and found there was some solid material inside, I removed the valve and was able to pour the white powder from the cylinder. Finally, with the aid of a hacksaw, the cylinder was opened and a considerably greater quantity of the white powder was obtained. It was obvious to me immediately that the tetrafluoroethylene had polymerized and the white powder was a polymer of tetrafluoroethylene. Following this discovery, I immediately took steps to characterize the white powder and to determine ways and means by which it could be formed.'

Challenging the traditional: Discovery of inert gas compounds (1962) – Neil Bartlett

Chemistry books stated (until recently) that inert gases such as xenon had full electron shells and were, therefore, inert (unreactive). Yost tried to make xenon compounds in an electric discharge in 1933 (under the guidance of Linus Pauling) but was unsuccessful. Another disbeliever in the inertness concept was Neil Bartlett, a chemistry professor at the University of British Columbia. He reasoned that a compound of xenon might result if an electron from the xenon shell could be drawn over into the field of an anion. Experiments using hexafluoroplatinate as the oxidant gave a stable solid with xenon, proving that the traditional concept of inertness of noble gases was not right. This was reported in June 1962. In September of that year, three US chemists from the Argonne National Laboratory synthesized xenon tetrafluoride by simply heating xenon and fluorine at 673 K and 10 atm pressure for one hour. Other compounds of Xe have since been reported.

Research habits

J. O. M. Bockris narrates an interesting story. This story is about a person who wanted to start a research project. 'Arriving at his laboratory at 8. A.M. on the first morning, he found a catalogue and ordered a large and expensive machine. While waiting for delivery, he concerned himself with the instruction manual notes on spare parts, etc After the said large machine was installed and his laboratory built around it, this citizen set to work. He placed ampoules of liquids in the machine, noted and counted its clicks, and marked down many pages of data. For two years he did this, eight hours a day, five days a week, taking two weeks of holiday a year. At the end of the two years, he had filled 100 notebooks with results. Then he said, "Now, what the hell do I do with all this stuff?"

There is a complementary story about another person. This person arrived a few days after his research grant had begun (he had lost the address of his institute), and when finally he entered his near-empty laboratory, he made a cup of tea. Then he went to sleep. Sometime later, when he woke up, he went to the library. He stayed there on and off, for about three months. He then returned to his laboratory and had another cup of tea. Then he went on a six-week vacation. After this he returned to his laboratory, took out a notebook and for some time sat lost in thought. Now and again he jotted things down and made calculations. This he did, on and off, for three months, caring little when he ate something, sleeping little and sometimes sleeping for a sixteen-hour stretch. Then he said, 'Ah'. After this, he got up, went to the shelf, and mixed one liquid with another The mixture was blue. He again said, 'Ah'. After this, he published a short note which changed the entire position in his field '

While there is no simple recommended habit for an aspiring young researcher, it is nice to remember that some daily meditation about one's work is essential to accomplish something worthwhile.

Quest for truth

Research is clearly concerned with the problems of the world, which fall broadly into two categories Some relate to the desire to know and understand Nature, some others aim at finding better and more effective (and even cheaper) ways to accomplish the task at hand (these are practical problems). Many problems defy rigid classification and researchers often shift their emphasis and interest as a free-wheeling discovery suddenly points to fruitful applications Remember that Michael Faraday did not know that electricity would be of any benefit when he discovered it. The main goal of a researcher should be the quest for truth and happiness, despite pressure for the classification of research as pure or applied Only with this goal can creative research become meaningful and exciting. We should also remember that almost all the major discoveries and inventions of recent times, such as lasers, transistors, fullerenes and superconductors, were not 'planned' for. It is, however, useful sometimes to have a major target, such as *man on the moon*, to catch the imagination of a nation.

The weight given to different types of research has varied both with time and with the country. Advanced countries such as the US and Japan applied themselves almost exclusively at first to research with a practical objective. Having achieved an industrialized economy, emphasis towards fundamental research was increased. Countries with older civilizations such as India had remained attached to research only for intellectual gains till the first half of this century. The spread of ideas throughout the world after the Second World War has produced a blending of the practical with the intellectual. The achievement of an optimum balance between these two types of research is of essential importance

Conclusion

In closing, I would like to leave you with the possible flavour of research in the 21st century, say ten years hence. By that time, the working of the brain may well be understood and it may not be necessary to see or hear in order to gain knowledge. Perhaps man will still have the opportunity to develop decisions in his own mind based on the input of information. Let us hope so, or the fun of living will be lost forever. Storage and retrieval of a vast body of knowledge larger than can be held within one mind would have been fully developed by means of miniature electronic components housed on a large space station orbiting the earth A literature search may simply involve a message communicated to a satellite station on the idea to be developed. An analysis of the idea would be immediately returned, which would include an up-to-date survey of all the related literature, what work is going on throughout the world and may even provide a weighted opinion on whether or not to proceed and along which lines. Equally fantastic would be the methods used to proceed with this research. I will leave that to your own imagination.

'The world is so full of a number of things,
I'm sure we shall all be as happy as kings'

– Robert Louis Stevenson

Come, my friends,
'Tis not too late to seek a newer world,
Push off, and sitting well in order smite
The sounding furrows; for my purpose holds
To sail beyond the sunset, and the baths
Of all the western stars, until I die
It may be that the gulfs shall wash us down
It may be we shall touch the Happy Isles,
And see the great Achilles, whom we knew
Though much is taken, much abides, and though
We are not now that strength which in old days
Moved earth and heaven, that which we are
One equal temper of heroic hearts,
Made weak by time and fate, but strong in will

– Alfred Tennyson

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