Burning Questions and their Power to Kindle a Fire

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The current status of science and mathematics education is pathetic, especially in elementary to high schools. This has been caused in part by unenthusiastic teaching, which has repelled some students from these subjects, while others have been lured to more lucrative jobs, even before acquiring a university degree, such as call center jobs. Even students who may have pursued a career in science have often been turned away, either by a monotonous teaching style or by prevailing myths of alternative lucrative career paths. All of these have contributed to an alarming exodus of students from pursuing scientific and innovative research disciplines. What has gone wrong with our science and mathematics education? Is it possible to carry out cutting edge innovations in science and technology without basic foundations in science and mathematics? What can we do to keep young minds excited about scientific and technological innovations? These are indeed very complex and perplexing questions that do not have simple answers. One approach to address these questions is to simply ask what excited some scientists to pursue science and research and see how to introduce some of those excitements into the curriculum, and kindle interest in science, at a very early stage.

Many famous and accomplished scientists have often derived their inspirations to pursue research and innovations by asking a mind-boggling question, for which, until they found the answer, they could never rest. It is as if they are obsessed. This may explain the famous notion of an absent-minded professor; indeed it is not that an absent-minded professor's mind is “absent”, rather the professor's attention and brain energy are so focused on that question and the quest to find the answer to the unknown, that the professor becomes oblivious to the immediate surroundings and happenings. Science and research are, in a way, an obsession - it is a perpetual drive of enormous energy to find an answer to the unknown and until the answer is found, the obsession continues. Until we can get our students to this obsessive state of enthusiasm, it seems that we may often lose some very creative minds. Nobel Laureates Richard Feynman, Albert Einstein, C. V. Raman, S. Chandrasekhar and many others have had this thirst to understand the beauty of nature through questioning why things in nature are the way they are. Einstein is famously attributed to having said that imagination is more important than knowledge. Had Raman not asked a question as to why the sky and the sea have the same blue color on a clear day, we would not know today the Nobel-prize-winning Raman effect and Raman spectroscopy. In the same way, when Einstein questioned his teacher, who asserted that the speed of a light flashing from a moving train would be different from that of a light pulse emanating from a stationary train, his quest for a satisfactory answer to that question culminated in what is today known as the Special Theory of Relativity. This visual power to understand something in nature that we call the beauty of nature is what leads to great innovations in science. It is, therefore, extremely important to cultivate the power of imagination and the quest for answers in our students.

In trying to seek answers to what would excite a student to pursue science and research, I have asked myself the same question. I have attempted to draw some very exciting personal examples and anecdotes that attracted me to science. My very first scientific excitement was ignited by a science fair that my sister and her friends organized in Pachaiyappa's College, Chennai. I was about 13 when we went to this science exhibition where I saw a man mix two chemicals in a dark room and the whole room glowed with a luminescent blue color. The next thing I knew was that I was busy trying to understand why these two chemicals produced this beautiful luminescent blue color. On another day, when I was about 14, I saw my mother mixing turmeric water with white *choona*, (also known as *sunnambu* in Tamil; quick lime/white wash, etc. in English), and the immediate result was that the yellow-colored solution turned blood red. In many of the Hindu ceremonies, one of the traditional practices is to perform *aarathi* and the ladies prepare the *aarathi* by mixing yellow turmeric solution with the white alkaline *choona*-like substance that is predominantly composed of calcium hydroxide. Why does this yellow color of turmeric change to red? This question sparked my early interest in science, and my quest to understand this took me along a path of understanding the beauty of nature. Recently, we have tried to use a variety of household chemicals to create a kaleidoscope of colors from turmeric that are shown in Fig. 1.

Fig. 1 Turmeric in neutral solution at center surrounded by its colors in various chemicals: clockwise starting from yellow(vinegar), quick lime or choona ($Ca(OH)_2$), Ammonia, hair & grease remover, and oven cleaner.

Although the question took me on a scientific path that culminates in quantum mechanics and spectroscopy, the fact is that it was this question that resulted in a never-ending pursuit of knowledge and innovative research. In retrospect, I feel that the question was far more important than the answer itself. It is the question and that never-ending quest, or what one may call an obsession to find the answer, which lured me to science and scientific research. Asking fundamental questions, no matter how simple or how complex they may be, is the most critical path to innovation.

My mother was making *Mysore pak* one day and *rosagulla* on another day, and I saw how milk was getting separated into a solid state when she added lemon juice to milk. Why is it that milk separates into two distinct phases of solid and liquid upon the addition of lime juice? Here again, asking a question was the key to my pursuit of science. Is it the acid in lime that is responsible for this or is some other substance the cause? What is really the state of milk? Questions like this can take one on the path of understanding hydrogen bonding and structures of proteins, but it is important to ask questions, whether or not the answers are obvious. Likewise, I often asked: "Why is it that most substances turn from solid into liquid when you heat them, but egg yolk turns into a solid from a liquid state when you boil it?" Again the answer, that it is caused by the breaking of the hydrogen bonds, resulting in denatured state of proteins in egg yolk, is not as critical as the question itself. The question was what engaged and attracted me to science. While making a number of sweets, often solid sugar is mixed with water and heated, to bring the solution to different states, either a "string state (*kambi paagu* in Tamil)" or a "spherical state (*urundai paagu*)", depending on which kind of dessert is being made. If one asked questions based on these observations and the different states of the solution thereof, one would travel to the world of states of matter and phase diagrams! There is so much that happens around us, that we often take for granted or never have the opportunity to stop and wonder about.

My interest in science was further fueled by more questions that I asked. This often challenged my school teachers, as they started finding me intimidating because of the perplexing questions that I asked. In one of the chemistry classes, I was asked to balance a chemical equation, which is tantamount to placing coefficients in front of the chemicals so that the total number of different atoms is the same, on both sides of the reaction. For a somewhat complicated reaction, I arrived at two different solutions, such that one is not a multiple of the other. For those who are eager to know the reaction, it was a reaction between $KClO_4$ and HCl. The trouble is that we were taught that there is a unique solution to balance a chemical reaction, or otherwise reactants will not react in definite proportions. Yet, my question to the teacher was, which one of the two solutions is then correct? He was baffled and did not provide me with a satisfactory answer to my question. So my quest continued. When I went on to Birla Institute of Technology and Science (BITS), Pilani, I continued to ask the same question to some of my chemistry teachers, but could not get satisfactory answers. It was not until I took a course in linear algebra and matrix theory that I was able to come up with a satisfactory answer to my quest on balancing chemical reactions. From linear algebra's rank-nullity theorem, I could indeed establish that for the $KClO_4$ + HCl reaction there are not merely 2 independent solutions but infinite solutions. Indeed it turned out that more chemical information, such as from chemical thermodynamics, is needed to isolate the correct solution or split the reaction. The trouble with our education is that teachers often segregate their knowledge and understanding to narrow disciplines, when in fact, the majority of the real world problems are inter-disciplinary. The questions pertaining to nature do not have the power to know if they are mathematical, chemical or biological! For example, flower petal patterns and cactus thorns are arranged in mathematical sequences called Fibonacci numbers, where one finds harmony of mathematics, biology and nature's way of space optimization. This results in Fibonacci patterns. It seems that as a teacher, one often needs to develop an understanding of multi-disciplinary concepts, rather than segregating knowledge into a given discipline.

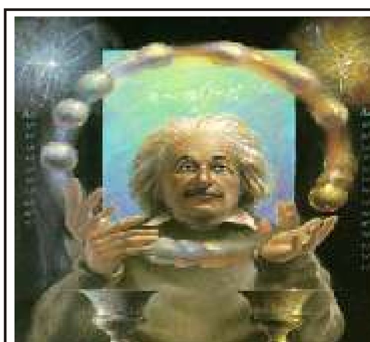
When I was a student at BITS, Pilani, the then Director of the Institute, Dr. C. R. Mitra, asked me and my classmate, Subhash Gupta, to take up the challenge of developing and teaching a course on “Concepts in Science”, to all incoming freshmen students. (A few pages of this book may be accessed through the link: http://www.mcs.csuhayward.edu/~kbalasub/reprints/1.pdf). This was indeed a great innovation in teaching, for me, as it provided an opportunity to experience the joy of teaching while I was still a third year student at BITS. We designed the course based on an innovative method of learning concepts by asking questions and subsequently, seeking answers to them. Although this style was particularly challenging for the teacher, it had considerable merit. As part of the course, each student was asked to come up with a science project which was simply to “stop and stare” at something around and explain the observation using the concepts of science. One exciting project was related to an observation of trees on the side path of Vyas Bhawan hostel at BITS. The project was on explaining why trees along the side path, at times, oozed out fluid under high pressure, through the bark openings. The explanation drew concepts from capillary action to hydrodynamics; but once again, it was simply the question that was important. The question may take the person on any path; it could be simple capillary action to more sophisticated hydrodynamic equations, but it is the question that leads to knowledge and excitement. Sanjib R. Mishra, a student in my class, simply asked the question: Why does a stream of water, passing through a wash basin sink, create a type of turbulent current, especially when the last bit of water passes through the sink? This question led Sanjib to the path of fluid dynamics and Navier-Stokes equation, at an early stage and as a freshman student. Most importantly, the course and the experiment kindled a spark of excitement for science in Sanjib, which culminated in his obtaining a Ph.D. from Columbia University and finally, a professorship in Physics at Harvard University, researching in high energy Physics. This course fascinated Sanjib and another student, Rattan Nath, so much that we jointly taught the course again, when I was in my fourth year at BITS. This resulted in us bringing out a 700-page book titled, “Concepts in Science”. In a sense, our obsession was never-ending and we put in enormous time and effort to writing this book, without feeling any pain whatsoever. While I was a National Science Talent summer student at Indian Institute of Chemical

Technology (IICT), Hyderabad, my friends and I were walking around the campus of Osmania University and were intrigued by the seeds that had fallen from a tree on the campus. The seed had a hard shell that looked like the shell of almond seeds, but we were warned by the local people that the seed was not edible. Intrigued by the questions that I asked about the seed, my summer project at IICT was on the extraction and analysis of the oil extracted from the seed, which I subsequently learned was *Pongammia Pinata*, commonly called the *pongu* seed. Again, it is this question on the seed that took me to a new area of research on natural product chemistry, chemical extraction and spectroscopic analysis of the oil, using a variety of techniques. It turns out that the oil has a number of medicinal properties and is used in herbal medicine. My quest for answers to a particular question often led me to different disciplines from mathematics to physics to chemistry to biology and thus, not restricting me to segregate my understanding to one discipline alone. My interest in learning the connection between mathematics and chemical isomerism resulted in me carrying out my master's thesis with Professor V. Krishnamurthy, a mathematician by training, although I belonged to the department of chemistry.

Life histories of many famous scientists and mathematicians clearly point to a unifying theme that science evolved by asking questions and the subsequent obsession to finding answers to those questions. Teachers should try to inculcate this culture into their teaching style and the curriculum, and encourage students to actively participate in the fundamental quest for answers to the unknown. It is equally important that a number of practical and interesting demonstrations of scientific principles are included in teaching. It makes it far more interesting to point out the various applications, relationships, and reasons as to why we are learning something, at the very outset, as opposed to introducing text book material without providing adequate motivation to understand the same. For example, sequences of numbers, like arithmetic progression, geometric progression, or Fibonacci sequences can be introduced with motivating and anecdotal examples, such as how Gauss discovered the technique of finding the sum of natural numbers when he was merely in elementary school. The story goes that an elementary school teacher asked the students to add the first 100 numbers, hoping that the task would keep the students busy for quite some time. But Gauss came up with an answer very quickly by discovering that if he wrote the same numbers in the reverse order below the numbers, the sum of each column becomes the same (as shown below), thus finding the answer instantaneously.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	...	99	100
	100	99	98	97	96	95	94	93	92	91	90	89	88	87	....	2	1
Total	101	101	101	101	101	101	101	101	101	101	101	101	101	101	....	101	101

We can make science really exciting by visual demonstrations, anecdotes, historical perspectives, applications, and by simply asking questions and seeking answers. Indeed, asking a question turns out to be far more important than the answer itself, as the path of seeking answers to these riddles introduces students to the fun of experimenting with science.



"Eternal Mystery of this Universe is its Comprehensibility"

- Albert Einstein

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