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Notes on Engineering Research & Development

NERD

National Engineers' Day

Ancient Indian Science and Civilization

Michel Danino

Interview with Prof. K Muralidhar

SOARING HIGH

IIT-K students win AHS Design Competition

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The background is an edited version of image of infront of library shot by Prasoon Suchandra

The front cover page central image has been taken from Vikas Trivedi's (Y6) article 'The Re-Discovery of India' of Volume 2 Number 2 of NERD

Editorial

Welcome you all to the fourth year of publication of NERD! As the co-founders of NERD, we thank you for your valuable comments and suggestions throughout the past three years; and sincerely hope that you all continue to play your role in making NERD reach new heights.

Many activities that started under the umbrella of NERD in the past three years are now evolving, all aimed at motivating students for at least dirtying their hands once in science and technology, before they get enchanted to itch for lucrative careers light years away from science, as science journalist Angela Saini, in her book 'Geek Nation', points out –"The only reason students come to IITs is to get better salary package than their fathers."

SCoPE, the lecture series where we invited eminent professional science communicators of the likes of Mr. Arvind Gupta (famous science toymaker), Mr. K P Madhu (Producer, Turning Point) and Mr. Pallava Bagla (Science Editor, NDTV and Senior Correspondent, *Science* Magazine) witnessed active participation from the campus and taught us important lessons in communicating science to our readers. Competitions like science poetry, science fiction writing and scientoon making explored new avenues of conveying science to peers. Workshops on science communication and journalism were designed and conducted at other IITs and IISERs to emphasize upon the significance of good communication in science - be it popular or professional. Last but not the least, the discussion group of young science and technology enthusiasts lured many untainted minds to share their excitement in reading and discussing about what they wanted to.

Recently, there have been too many activities in the campus to motivate you all to look towards science, and that left us in a fix to choose which articles to include in the issue that's in your hands. The lecture series on ancient Indian science and civilization by eminent historian Michel Danino, that had jam-packed L16 with the enthralled audience and the discussion that followed regarding a 'History of Science' course being offered in our curriculum, was undoubtedly the best choice for the cover story; along with an exclusive detailed interview with him. Two undergraduate students recently won the 'Best new entry' award of the AHS (American Helicopter Society) Design Competition – how can we dare not include it! To increase your awareness about Indian science itself, we have a piece on National Engineers' Day. Not to mention, there were many other high esteem stories too, but we secure them for our next issues!

This issue also marks the start of two new regular genres to the magazine – one related to STS (Science, Technology and Society) and philosophy of science and the other from projects that students make in the clubs of Science & Technology Council. We hope you enjoy these new arrivals.

Interview with faculty members has been the most regular feature of NERD. We talk to Prof. K. Muralidhar, the former Dean, R & D; under whose guidance and support NERD started in 2008. We express our gratitude to him not only for trusting a completely student-led initiative, but also guiding us in the right direction at all times, thus helping NERD grow better. We also have an interview with Dr. Suchitra Mathur, the Gopal Das Bhandari Memorial Awardee 2010 for Outstanding Teacher; as a teacher, a researcher and an active member of IITK community.

Move on with the issue and fill our mailboxes with your feedback! We'd be grateful. 'Create, Communicate, Contribute!' remains our mantra.

Cheers!
Editors, NERD

IITs and the future Indian research scenario

Interview with Prof. K. Muralidhar

Mohit Kumar Jolly

Prof. K. Muralidhar served as the Dean, Research and Development, IIT Kanpur from January 2008 to January 2011. An eminent researcher in experimental fluid mechanics and a Fellow of Indian Academy of Engineering, he has been a faculty member in Mechanical Engineering Department since 1987. He has also served as Head of the Department and Chairman, GATE among others. Here are excerpts of the interview NERD team had with him on role of IITs in the future Indian research scene:

NERD: You have been in this institute for more than two decades now. What, in your opinion, is the most distinguishing feature of this institute?

Prof. Muralidhar: We have a heterogeneous mix of students, staff and faculty, and hence a mix of ideas, viewpoints, outlook and working style. These reflect in the way we offer courses, the academic programs, research topics we work on, and our publications. To a great extent, we find that faculty members work in areas they are excited and passionate about. They may work on their own or collaborate with colleagues within the institute and across the world. Faculty would like to be seen as leaders in certain areas, but the defining point is that they are really excited and interested in their field of work. Indeed, they work hard in their chosen disciplines for long years, perhaps decades. Accordingly, you would see that an enormous amount of expertise is available within the institute in certain areas, which in turn is well-recognized internationally because of this depth of knowledge and contributions to the literature.

NERD: You just completed your term as Dean, Research and Development. What was your vision when you joined in 2008 and how far, do you think, did you achieve it?

Prof. Muralidhar: The role of a Dean is clearly defined within the institute - it is to assist the Director in chosen realms. When I took over, the Director told me that he would like to support new initiatives and fulfil the dreams of the faculty. I assumed my role was to provide the link between the potential that exists with the faculty and their performance. Having said that, I felt that there were emerging areas in technology vital to the Institute and the country, such as solar energy. When I found that there were groups available within the campus to work on these subjects, I encouraged them as much as possible. I pushed them to write large proposals and insisted that they work collectively.

NERD: IITs were established to provide technical manpower and strengthen the base of science and technology in the country. In the past 50 years, do you think we have realized this vision?

Prof. Muralidhar: The contribution of IITs cannot be assessed purely by numbers. Moreover, I am not sure if IITs have been set up purely in the national context. The goal has been to train engineers to be the best they can be. To that extent, our students have excelled both as specialists as well as entrepreneurs. In numerical terms, we would not have trained as many people as we would have liked, but I believe that we have succeeded in terms of quality to produce the best engineers who have done very well both within and outside the country. Of course, by engineers, I include those who have specialised in basic sciences as well. Nationally, the contribution of our students has been limited, but globally it has been very good and our training program has been uniformly hailed in various quarters.

NERD: Coming to the role of IITs in the future of Indian research scenario; what, in your opinion, are the major reasons that are holding the Indian research scenario to bloom currently?

Prof. Muralidhar: This is a fairly difficult question to answer. In a nutshell, it is the complexity of the subject domain itself. Consider the fact that the demand for superior technology in our daily life has become quite acute; say an audio system or a computer has to be of really high quality today. Engine emissions must be truly benign. Microscopes need to be super-specialty and oscilloscopes, of the greatest speed. Apart from using

these gadgets, engineers are the ones to develop these tools as well. We need to work for novel materials, new processes and innovative ideas. In addition to intellectual sophistication, it calls for a huge investment in research and development - both in academia and in industry. These acute quality benchmarks are a defining requirement of the current times that was not present earlier.

I must also point out that the expertise in technology development has become very distributive. People have to work together; no one person can do it all. Individualistic approach will not lead us further anymore in achieving quality or performance. This is a new revelation. For instance, medical technology needs surgeons, mechanical engineers, electrical engineers, computer scientists and biomedical and biotechnology scientists to collaborate and work together to produce a superior product, for example a surgical robot.

"Indian graduate students are not really articulate, they may not show-off their excitement as American students do – that's our personality."

In short, quality specifications have shot up and the nature of the demand is multi-disciplinary. Only those researchers who function with this mindset are likely to succeed in the future.

NERD: An article in the journal 'Science, Technology and Society' and one in Current Science state that the issues that are stagnating the growth of the Indian research are more related to the motivation and dynamics of students and faculty involved than the infrastructure issues. How far do you agree with this?

Prof. Muralidhar: I see the issue differently. Mobility in research, of course, requires positive attitude as a pre-requisite of success. Jointly, research requires *strategy* in the sense that a right balance needs to be maintained between depth and breadth. The defining criteria would be the speed with which improved products are delivered to the customer, goals of the society are fulfilled, while meeting constraints of cost, time, and demand. On the other hand, a certain dependable minimum infrastructure that improves with time is also needed to facilitate research. The absence of strategy is a weakness in our system.

"Quality specifications have shot up and the nature of the demand is multi-disciplinary. Only those researchers who function with this mindset are likely to succeed in the future."

Speaking of students, my experience is the following. I have seen students work tremendously hard over a period of time. One also has to keep in mind the fact that Indian graduate students are not really articulate, they may not show-off their excitement as American students do – that's our personality. They quietly look around, observe things and at some point, a glow fills their eyes; that is their passion for the subject. I have seen that glow very often among students at all levels- undergraduates, masters and certainly at the doctoral level. I have seen doctoral students become very passionate about their subject. Some choose to work in a given area throughout their lives, but they have not been eloquent about it. I would say, look for the spark in the eyes of students rather than any exclamation or outburst of sound from them.

Also, there is a slight diffidence among students since they may not see their work being relevant or getting implemented in everyday life. Suppose a student is working on laser imaging of fluid flow, where would he/she find his/her work in action? This plants doubt in one's minds, you see them confused but ultimately, over a period of time, students gain confidence.

NERD: Based on personal communication with a faculty member, he told me that the only reason he would like to conduct research so that he can get promoted to the next level, where he would get a house that his wife likes. Do you think that this lack of accountability on the part of faculty members is holding our research output, because everything is so permanent in the government setup at IITs?

Prof. Muralidhar: Within IIT Kanpur, a very large number of faculty members are self-motivated. Three decades ago, publishing a paper was not considered as important as going to the class and giving your best effort and energy to the students. Compared to grooming students, publication was given less importance. Over a period of time, it is now clearly stated that everybody has to publish, so I would say that a large majority of faculty members are publishing in good journals. Even those who never published earlier are now getting into it. Undoubtedly, the research performance is certainly going up.

Even though we are under the government mindset that everything is permanent, still there is something called as peer pressure, and this is what is driving most of our colleagues. We should also keep in mind that in every organisation, around 10% of the individuals would be non-performing for various reasons, so we should give that allowance. Quite a few faculty members at IIT Kanpur work on technology demonstrators, developing infrastructure for the institute, or for the welfare of students as wardens, so their time is put to use very productively.

If you want my opinion on a major weakness among faculty members of IIT Kanpur, I would say that our inter-personal relationships are not as healthy and professional as they should be**.** There are conflicts, both major and minor and when such conflicts exceed a certain level, they can get personalised. Other weakness that I feel among faculty members here are that we are not effective in managing our time.

Speaking of output, we have to start viewing ourselves as a corporate entity rather than a university if we hope to convert the financial investment into productivity. The structure we function in is more like a corporate body, but we need to adapt our mindset too in that direction. There are weaknesses, but, with greater clarity of our roles and expectations, I am sure that the faculty performance will really explode in the future, because a high degree of motivation and competence is available.

NERD: Coming to research ethics, recently many cases of scientific misconduct came up in different IITs and also abroad by many Indians specifically.
What, do you think, is special with this Indian attitude that is calling this scientific misconduct?

Prof. Muralidhar: Misconduct has been noticed at several stages. Let's start with the research projects that students do. We tend to give extremely ambitious projects to students - projects that are way beyond their normal level of competence. Later, we expect superlative presentations within a couple of weeks while the student has not been nourished properly on that topic. Under these conditions, quite a few students adopt the short-cut of downloading material, including presentations, from the internet and present it as their own. Something similar happens with some faculty too. They try to work in cutting edge areas even if they lack necessary preparation for it. They have a mindset for aiming for a breakthrough because that's what gives them the most recognition. Some may think that slogging out for thirty years on a topic is not really exciting, but very routine. So, this expectation of breakthrough without adequate preparation, understanding and effort leads to considerable embarrassment. Running faster than your natural speed is probably the reason for these very unfortunate incidents.

"Scientific misconduct happens because people try to run faster than their natural speed."

NERD: One of the most common scientific misconduct has been the communication of science. On one hand, it's told that we should be very innovative in communication, and on the other hand, right from class sixth, if you write the definition of friction even one word that is different from the book, students shall not be given marks. Right from the school education, we have been trained to copy and paste things. Don't you think this is a contradiction?

Prof. Muralidhar: Again, this is a very difficult question for me to answer. I find that this school mentality of forcing the students to write exactly as per the text book is because we are in the system of mass education. The class sizes are very large. The teacher has to grade the answer sheets in a short period of time, so the person looks for extremely conventional answers that are visible in either one book or a collection of books. Any new idea can simply not be valued because the teacher does not have time. Probably students should be counselled to reveal their creativity outside the classroom rather than within the classroom, for example, NERD is a very good paradigm where students having strengths in certain domains can flourish. Similarly we have a student group called PoWER (Promotion of Work Experience and Research) where students take on challenges from the industry and try solving them.

"A major weakness among faculty members of IIT Kanpur is that their inter-personal relationships are not as healthy and professional as they should be."

I suggest that students should look for avenues outside the classroom for innovation. Of course, I should point out that research is about creativity, because every publication has to be unique. A student, as an individual, can grow a lot while being involved in research.

NERD: As it's said, "Just as the twig is bent, so is the tree inclined", so what is your suggestion to promote undergraduate research at IITs and other institutes to have a better future scenario?
Prof. Muralidhar: Research has become more of a necessity. New diseases are getting revealed every other day; it means that we come up with medicines faster than the rate at which diseases are being discovered. It is true with product quality. Your simple mobile has been evolving on a monthly basis - we want more and more features in the mobile, all within the same space and cost. All that would demand a heavy amount of research. Designing was considered a prime activity for engineers. This has changed and I feel that engineers and scientists have to lead the life of a researcher as an everyday activity. They have to conduct research a lot more aggressively than in the past. It follows that original thinking and research should be promoted from the first day of undergraduate studies. Thinking out of the box, doing new things, thinking of ways and means of problem solving - all these would soon be normal. Research has become an essential part of the engineering profession, therefore, it has to be brought early on in the curriculum of undergraduate students.

NERD: We have been hearing that private as well as government funding for IITs and research has been raised. In the increasing arena of infrastructure support, what other limitations do you see as a hurdle for the future Indian research scenario?
Prof. Muralidhar: The answer is very simple. Research is time consuming, so faculty members and students need to generate a lot of time to do research. In our institute, that would mean less meetings, less committee work and paperwork at every level, so that a faculty member can spend at least 6-7 hours per day on research and students, probably 8-10 hours. Faculty, students and the staff will have to just focus on doing creative work. This will highly impact the quality and quantity of research that is done and it would be justice done to the heavy investment of the government into our institutes. So, time, I would say is the essence.

NERD: Coming towards the end of the interview, so how would you describe Prof. K. Muralidhar in one line?
Prof. Muralidhar: Motivated and interested in life.

NERD: And what is the final message for the students?
Prof. Muralidhar: Believe that each person can make a huge difference.

NERD: Thank you Prof. Muralidhar for the interview and the insights you have given!

This interview is the transcript of an audio interview with Prof. Muralidhar, taken for IIT K 90.4 FM. It was transcribed by Pankaj Prateek.

Mohit Kumar Jolly (mkjolly@iitk.ac.in) is an M Tech student in the Department of Biological Sciences and Bioengineering at IIT Kanpur. He is interested in science communication and co-founded NERD, the campus science and technology magazine, in 2008.

Workshop on effective scientific communication for PhD students

Can scientists just sit in isolation, talking to their microscopes? No. Communication is central to science—be it in reading and writing papers, giving and listening to talks, or discussing with students or collaborators. You can not NOT communicate, being a scientist!

A workshop on scientific communication was organized for 25 doctoral students across all departments during the mid-semester recess, from March 21-25, 2011 by Dr. Geoff Hyde, the scientific communication coordinator at National Centre for Biological Sciences (NCBS) Bangalore.

The workshop aimed to improving students' skills in both forms of scientific communication - writing scientific manuscripts, and giving research seminars. The workshop started with an introductory talk by Dr. Hyde where he introduced the concept of treating the presentation of scientific research as a story, using the example of movie *Lagaan* and a hypothetical study on tree frogs. The participants had to explain their research in a five minutes to their colleagues coming from different departments. This was followed by detailed exercises for 5 days on the philosophy of storytelling as an effective method of scientific communication. The participants both enjoyed and learnt during the workshop very much and were sensitized to the fact that effective communication leads to clarity of thought in their minds about their own work too. For more details and opportunities to participate in future such workshops, contact Mohit Kumar Jolly (mkjolly@iitk.ac.in).

Soaring High

IITK students win American Helicopter Student Design Competition

Puneet Singh and G. Sriram

Two dual degree students in Aerospace Engineering, Puneet Singh and G. Sriram, recently won the best new entry in the American Helicopter Society Student Design Competition 2011, with their reconfigurable compound helicopter 'RC2'. Let's have a look at their design that has won applaud for the institute:

The Contest

The American Helicopter Society (AHS) International is a professional technical society for the advancement of vertical flight. A major driving force behind the rotorcraft industry since the 1940s, it has been conducting a Student Design Competition since 1984 – an extremely challenging competition with fierce competition among universities considered to be hubs of helicopter and vertical flight research. Past competitions have involved designing sport helicopters, one man rotary racers, tilt rotors, heavy lift helicopters, UAVs, firefighting vehicles, Mars rotorcrafts, urban disaster helicopter, high altitude rescue vehicle, non conventional drive system, control surface designs and many more. The competition is based on a RFP (Request for Proposal), developed by the sponsoring company, which details requirements for a challenging vertical flight technology.

Fig 1: RC2 helicopter

The 2011 competition, sponsored by Bell Helicopter Textron, had the problem statement of designing a multi mission vertical lift system that optimally blends the competing requirements of three very different missions:

Search and Rescue:
The vehicle had to have a payload of six passengers or carry two litters (medical stretchers) with two medical personnel plus equipment for a radius of 225 nautical miles (nearly 415 km) Also, there is a concept of a 'Golden Hour'. In rescue operations, critically injured patients have the highest chance of surviving if they are provided with medical treatment within an hour of being injured. This puts an extreme constraint on the speed of the helicopter, requiring up to 225 knots (nautical miles per hour).

Insertion:
The vehicle was required to carry six persons plus equipment totaling a minimum payload of 4000 pounds (1815 kg), for a minimum one way distance of 250 nautical miles (463 km). This was a test on the payload capacity of the vehicle.
Resupply: 3000 pounds of payload was to be delivered till 250 nautical miles (463 km) and exchanged for a similar payload for the return journey.

The motive behind such a vehicle is that in addition to the multiple areas of use, it reduces inventory and maintenance costs due to commonality of parts. The vehicle had to have a crew of four, and had to be able to perform 'out of ground effect' hover at 6000ft (1.83 km), at a ground temperature of 95 Fahrenheit (35 degree Celsius). The RFP called for the vehicle to be reconfigurable (within one hour) for the different missions. Also certification noise requirements and a representative engine technology were specified. Fourteen teams participated in this contest with six of them dropping out later.

The Configuration

The IIT Kanpur team, consisting of two undergraduate students of Aerospace Engineering Department, proposed a vertical lift system named 'Re-Configurable Rotor Craft (RC2)' (Fig.1) for this RFP and captured the prize in the 'New Entrant Category'.

We started the design by considering various existing vehicles and configurations which came closest to meeting the requirements, and found only a few of them technically possible with the capability of hovering. Let us give a brief outline about different rotorcrafts.

Apart from the conventional helicopter (with one

main rotor and a tail rotor), there are coaxial rotors, tilt rotors, tandem rotors and jet rotors. Coaxial rotors do not have a tail rotor which consumes power, but they have a large rotor hub creating significant drag during forward flight. Tilt rotors (like those side by side vehicles seen in the movie 'Avatar') are fast and have a high operating ceiling, but their payload capacity is small and they have complex moving and rotating wings, rotors, and a propulsion system. Tandem rotors (like seen on the Chinook) have a heavy lift capability but are slow sluggish machines. Jet rotors use a high speed jet of air ejected from the tips of the helicopter rotor to rotate them. There are no commercially produced jet rotor helicopters because of a lack of a good control system and complexity of propulsion.

Compound Helicopters

Helicopters that have a wing and/or an auxiliary thrust system are known as compound helicopters. There have been many prototypes of these helicopters made till date, but none have ever reached the production stage. These have been able to reach very high speeds with the record being held by the Sikorsky X2 of 250 knots (463 km/h). There are two reasons behind this ability. First, at high speeds, much of the lifting force is taken over by the wing, and the rotor is unloaded. Secondly, in conventional helicopters, the rotor has to tilt forward so that there is a horizontal component of the rotor thrust which pulls the helicopter forward. (Fig 3) Tilting causes a decrease in the upward component for balancing the weight of the vehicle. This has to be compensated for by the pilot increasing the blade angles. Having an augmented thrust removes the need of tilting the rotor forward, and can provide much higher forward thrust for the helicopter.

Design Challenges and Trade offs

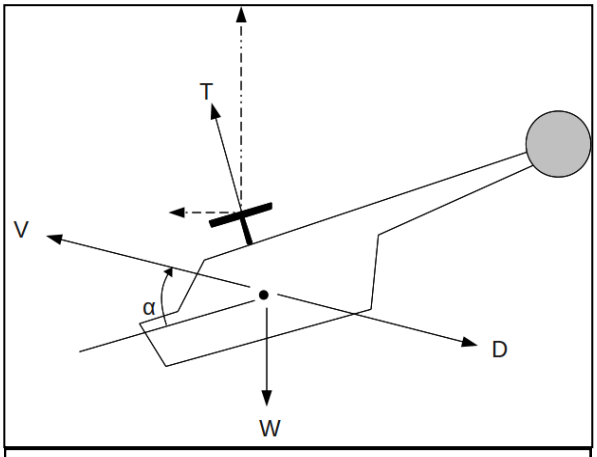

Fig 3

Fig 2: (From top to bottom) Conventional rotor, Coaxial rotor, Tandem rotor and Tilt rotor.

Restrictions on high speed:

Conventional helicopters are restricted from high speeds because of two effects. The first is the advancing blade compressibility effect. Assume that the blades are rotating in a counterclockwise direction when viewed from above, and the helicopter is moving forward. On the right side, the blades are moving forward (advancing side) in the direction of the helicopter's velocity, and on the other they are moving in the backward direction (retreating side). The relative velocity on the advancing blade is much higher than the free stream velocity and the flow approaches the speed of sound there. The formation of shock waves can completely damage the flow, and cause unacceptable loads on the blade.

The second restriction on high speed is due to

retreating blade stall. On the retreating side of the rotor, the relative velocities are much slower. This causes the angle of attack on the retreating blade to increase, since it is inversely proportional to the horizontal velocity. Airfoils can produce lift only for a small range of angles, and above them the flow separates and the airfoil stalls. So if the advance ratio, which is the forward velocity divided by the tip speed of the rotor, is high (in the range of 0.4 - 0.5), portions of the retreating side of the rotor stall and the thrust required to keep the helicopter in the air is lost.
Due to these reasons no conventional helicopter has been able to break the speed record set by the Westland Lynx, which used a specially designed blade tip to reach 216.4 knots (400 km/h). However the compound helicopters have been able to go much beyond this limit due to the help of the wing and augmented thrust as explained above.

Rotor Design:
The first major element of the rotor system is its tip speed. The compressibility effect during forward flight, the noise levels and the retreating blade stall set the tip speed at 644 ft/s (196m/s). The number of blades impacts the vibration, noise, drag and power. We incorporated five blades in order to reduce the intense noise and vibration at high forward speeds. But a larger number of blades also have a disadvantage of higher weight and cost. We obtained the radius of the rotor blades from our hover ceiling condition and the available power from the engines, and showed that a 21.325 ft (6.5m) radius rotor was ideal for our mission. We kept the aspect ratio of the blades at 10.825 for aerodynamic efficiency as well as restricting the modes of vibration.

The blade airfoil was kept different over the root, middle and tip of the blades for optimizing the speed and hover capability; and the tip as reconfigurable for the three different missions. Finally, to delay the compressibility effects, we varied the tip speed, airfoil and shape.

Wing Design
The major challenges in the wing design were the selection of wing plan form (shape and layout), geometry, airfoil and location of the wing on the helicopter. We extensively studied previous helicopters for the merits and demerits of using a variable incidence wing, flaps and spoilers. Selecting wing area and aspect ratio was a trade off between hover capability of the helicopter and the induced drag of the wing, whereas the location of the wing was decided by giving consideration to rotor wing interference, ground clearance and longitudinal stability characteristics. We did not use the variable incidence wing considering structural complexity of the design and inability to build in components such as undercarriage and fuel storage into the wing, although it provides the ability to optimize the wing lift ratio and re-

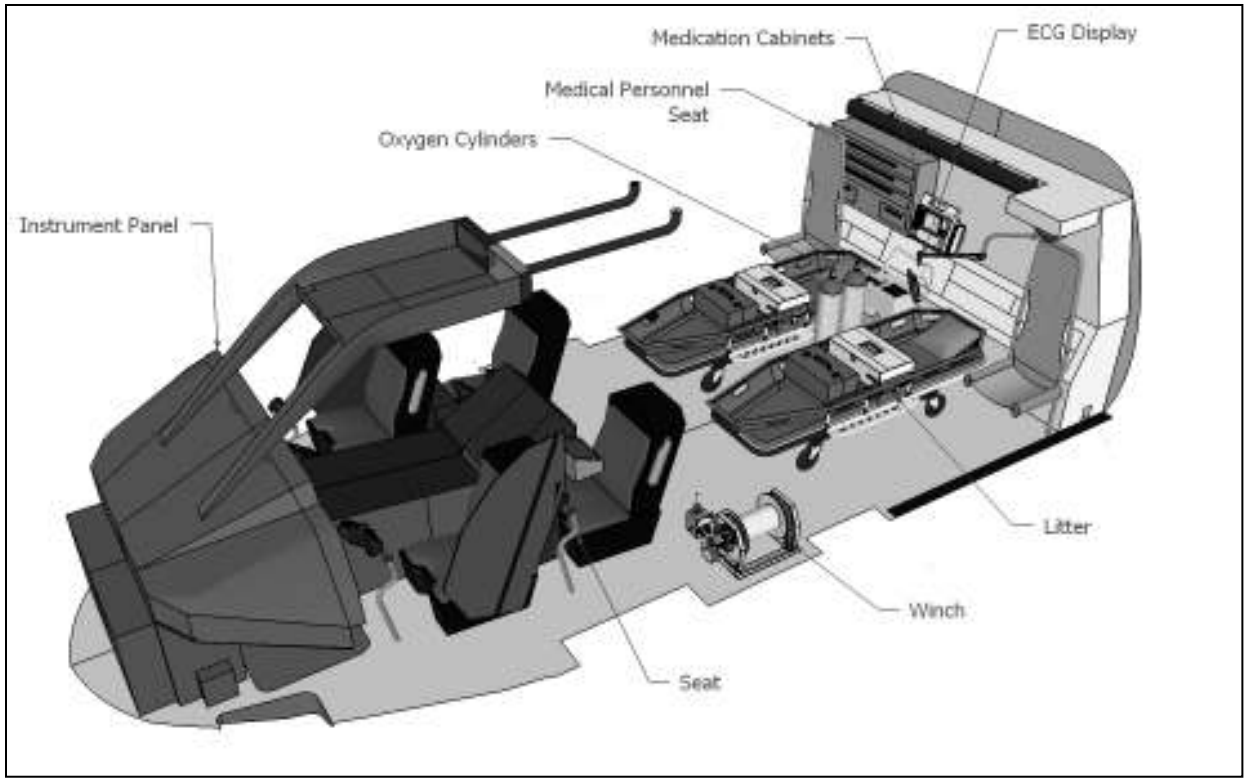

Fig. 4

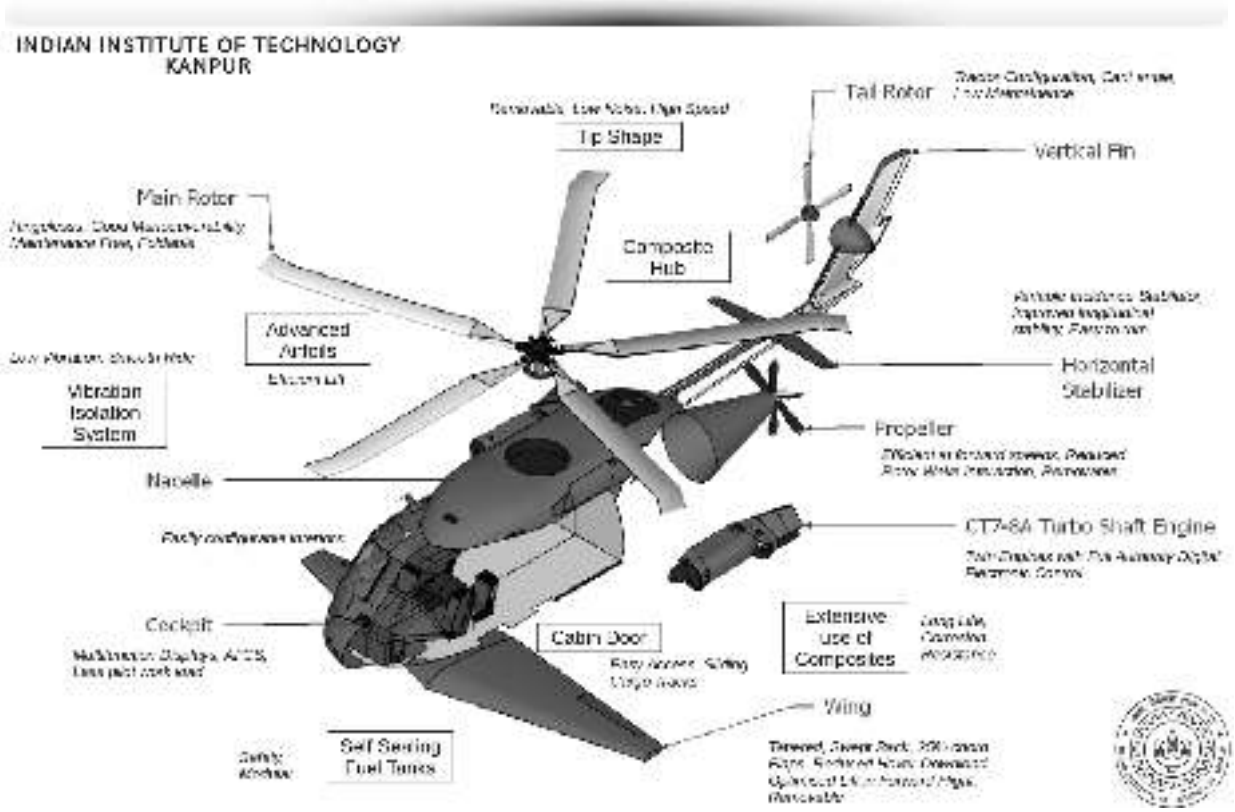

Fig. 5

duce hover download. A trade off which allows the wing lift to be controlled to a greater degree while not impairing the structural simplicity is the use of flaps and this was incorporated into the wing design.

Auxiliary Propulsion System:
We considered various propulsion systems - such as turbojet engines, turbofan engines, propeller and ducted fan arrangements- to find an efficient one that optimizes cost, weight and noise. The propeller complied with most of the mission requirements and provided a lighter, less noisy and a reliable source of auxiliary thrust for a sustained flight.

The propeller was not only easy to install and remove during reconfiguration, but also provided greater fuel efficiency as compared to turbofan and turbojet engines, which is critical in missions involving high power requirements. Also, it had reduced mechanical complexity and separation losses as compared to the fan-in-fin ducted fan concept.

Transmission:
A hard nut to crack in designing a compound helicopter is effective power transmission to both the rotor and the auxiliary propulsion and varying the power transmission ratio between them. We chose the variable-cycle engine transmission mechanism to avoid power redundancy and reduce the weight penalty of the transmission. This engine can be controlled to provide both shaft power and thrust, or two different shaft power outputs where the power can be continuously varied.

Final Design
The design was of a conventional helicopter with a five blade main rotor, and a tail rotor. The helicopter was reconfigurable with a wing and an augmented propeller thrust system, for the high speed mission of search and rescue. The maximum take off weight was of 12484 lbs (5660 kg). Speeds of 192 knots were feasible. For the insertion and resupply, the wing and augmented thrust was removed for more space and fuel capacity. The best range speed in these missions was 120 knots, and the vehicle weighed at takeoff 13600 lbs (6170kg) , and 12900 lbs (5851 kg) respectively.

We designed the rotor to have reduced vibrations and noise apart from being able to operate at high altitudes and hover. The wing was designed such that it does not interfere with the rotor wake. The controls also were configured such that the helicopter remains stable and in equilibrium in its flight path, with and without a wing. The helicopter was powered by two GE T700 turbo shaft engines which allowed the helicopter to operate

safely and with enough power for all missions. The high speed mission especially required higher power to both the augmented thrust and the rotor. Studies showed that the available power was sufficient enough even for emergencies or an engine failure. Interior reconfiguration (Fig. 6) allowed standard air ambulance equipment arrangements and fast easy changeover due to modular design. Cargo was stored according to the International Air Transport Association container specifications.

Finally, the cost analysis showed that the cost of the helicopter including development and manufacturing costs to be around $6 million. The operational differences between the missions could be appreciated by the variation in the direct operating costs for different missions, $320/hr for the Search and Rescue mission, $160/hr for the Insertion mission and $120/hr for the Resupply mission.

Notes from the authors

The design challenge was an exercise that gave us an idea of the real world challenges in building a vehicle. It taught the nuances of the design process, giving consideration to manufacturing, costs and flying quality apart from the enormous technical challenges in keeping tonnes of payload hovering in the air. The complete proposal can be viewed at http://www.vtol.org/awards/sdcomp.html. The work would not have been possible without the splendid teaching of Dr. C. Venkatesan during the course AE686 (Helicopter Theory: Dynamics and Aeroelasticity) at IIT Kanpur. We also graciously acknowledge the help by Rohin Kumar, a doctoral student in the department. Mr. Angel Moore kindly gave us permission to modify his UH-60A Blackhawk 3D model for our modeling purposes.

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Together, they spend their time plotting to make India a self reliant aerospace superpower.

National Engineer's Day: Why, When, in whose memory?

What is common between Dr. Abdul Kalam, Dr. C V Raman and Sir M Visvesvaraya? These are the only three Indian scientists or engineers who have been awarded the highest civilian award of the nation- Bharat Ratna, and September 15, the birthday of Sir M. Visvesvaraya, is celebrated as National Engineers' Day.

So what 'public service of the highest order' did Sir Visvesvaraya render? A great visionary who believed in industrialization as the panacea for the country's poverty, he was passionate about optimal usage of water resources and was the most eminent engineer India has ever seen. He contributed to the greatest common good in terms of irrigation, industries, infrastructure, waterworks, dams and roads. He was not only an engineer par excellence – but also a social transformer.

Sir Mokshagundam Visvesvaraya was born on September 15, 1860 at Muddenahaali, a village at the foothills of Nandi hills near Bangalore. He was the architect of the Krishnarajasagara (KRS) dam across Cauvery river – one of the biggest dams in India which irrigates a hundred and twenty thousand acres of land. He also set up Mysore Iron & Steel works in 1918 – the plant that used to export pig-iron to USA in those pre-independence days of India. The famous tank duo of Secunderabad-Hyderabad cities that he designed saved Hyderabad from the devastating floods of Musi river, and ensured good water supply to the city. The concept of rotation of supply of water to prevent its misuse and maximize benefits for agriculture, introduced by him, completely revamped the Deccan canal system.

Rightly called as the 'Father of modern Mysore state' (now Karnataka), he transformed the departments of industrial and economic development. He established Mysore University and introduced compulsory education in the State of Mysore, which later got enshrined as a fundamental right in the Constitution of independent India. State Bank of Mysore (then the Bank of Mysore), a reputed financial institution, was also his brainchild. The only aircraft factory in India today– National Aeronautics Laboratory in Bangalore – came through his consistent efforts. He set up Mysore soap factory, Mysore oil factory, and later served as the Diwan of Mysore from 1912 to 1919.

His life was disciplined and replete with significant contributions to the public good. He passed away on April 14, 1962, at the age of 101 years. He was the Knight Commander of the order of Indian Empire (KCIE) in 1915, and was honored with the membership of Institution of Civil Engineers (based in London) for a period of 50 years. He was conferred Bharat Ratna in 1955.

Several institutions, including Visvesaraya National Institute of Technology (VNIT) Nagpur, have been named in his honor. A beautiful memorial of Sir MV (as he was sometimes called) is located on the family-owned land at Muddenahalli. An IIT is also proposed to come up at Muddenahalli by 2012, to pay a tribute to his birthplace.

Let's pay respect to this personification of 'Simple living and high thinking' today, and express our gratitude for his unparalleled contribution to the society as citizens of the country.

Hitchhiking on the edge of thought

Part One: Sneaky Assumptions

V Gopi Krishna

Author's Note on the Series

*A look at **The Structure of Scientific Revolutions** by Thomas Samuel Kuhn provides us the stages of scientific investigations, and shows us that although science has been successful in making predictions within the theories, the prediction of the next new theory has been more difficult, and scale of the new theories have consistently come as a surprise. No one anticipated the revolution in thought brought by Newton, or Copernicus, Einstein or Dirac. If science is a prediction of the unknown from the known, what can Science predict about Science itself?*

*This series is dedicated to crossing the barriers that thoughts enforce on us. This series will ask, and try to answer, the questions: **Why didn't we think of it before? How can one anticipate and create the next revolution?** With an understanding of perspectives, and how they change across time, this is an attempt to make our perceptions flexible enough to grasp the nature of this horizon, without sacrificing reality or logic. To that end, this would be a no-holds-barred investigation of various viewpoints about science, including some obscure ones. Let the integration begin.*

Editor's Note: The Structure of Scientific Revolution

*Widely regarded as one of the most influential works since the Second World War, **The Structure of Scientific Revolution** is an examination of how science evolves with time. Written by Thomas Samuel Kuhn, an American historian and philosopher of science, the book was first published in 1962. The book introduced ideas that have since been used beyond history and philosophy of science. Kuhn put his point across by using examples from the history of science; his approach reminiscent of the case study method in social sciences. The book sparked several debates which are still going on in academic circles encompassing scientific enterprise and fields beyond that. It inspired several other works, often with elements critical of the ideas propounded by Kuhn. To state the obvious, the Wikipedia page about this book is an excellent introduction to the central body of ideas propounded by Kuhn.*

Today we have an appreciable scientific body of thought built up, with questions addressed right from the microscopic to the macroscopic world. There is a massive industry which is running its course every day, with thousands of papers published in various disciplines, and huge amounts of money being poured into certain fields for the purpose of research. The **scientific method** is the prevailing agreed upon method of approaching the truth of the world. How does one know if the scientific method provides us with the true perception of reality? Well, technically, we do not know that, but it is possible to subject that idea to the self-same test of scientific validity. What will be attempted hereon will be to highlight the approach by means of encountering certain facts, in a more or less haphazard order, and then work towards the conclusions.

With that in mind, let us make ONE single assumption right away, regarding the approach which one is using — that the World or Universe of our experience can be understood via a rational approach, and it is possible to obtain a true perception of the world being led by facts, to the limits of accuracy to which we are able to perceive them. Although assumptions by definition do not require previous reasoning, I think we can postulate this general statement simply because rationality is the essential feature of the scientific method which we will here set out to examine, and to the best of our knowledge, experience is a good indicator of reality. Note that the core of the statement is the principle of rationality, coupled to experiential facts. Also note that **setting out to examine** itself embodies the same principle, so we are consistent.

A second concept which is largely called upon to verify the truth of phenomena is proof. This is largely the requirement for mathematical treatment, where a certain relation among magnitudes, with the assumptions of mathematics being used, brings out a certain other relation among magnitudes as an inherent necessity. Let us allow certain facts to throw some light on this requirement of truth.

Rewind the clock a hundred years back, towards the latter decades of the 1800's. It was well-known *then* that the only **minor problem** with physics for example, was with respect to a blowing up of the UV spectrum predicted for a blackbody, as well as certain **small** (note that keyword) corrections being required to account for the movement of Mercury around the sun. A look at theories of later time shows that two offshoots have been derived from those apparently innocuous discrepancies. The blackbody radiation problem led to the concept of the quantum, and thereby to quantum mechanics and the discrepancies in Mercury's movement paved the way to relativity.

We will not concern ourselves with whether or not the above theories are correct, and to what extent, because the point to be noted is with regard to the mathematics. The mathematical assumptions were changed, at quite a profound level, introducing Lorentzian metrics and for the first time ever, *complex* numbers to describe the physics of *real* quantities (as a preliminary look at the Schrödinger equation reveals). This means that no one who had not made the connection with this sort of mathematics, in the years preceding this, could ever PROVE that the existing set of laws are inadequate, and not just in a minor way but to quite a large extent (in retrospect). One has to restrict oneself to the existing set of mathematical assumptions in order to even set out to prove something to the scientist of the day. Also note that from the point of view of that particular time, the scientist would be attempting what would be seen as a wholesale revision of existing concepts merely to account for some **small** discrepancies. I shall come back to this point in a later article.

What can we take away from this idea? We can take away the fact that **proof** is valid only for the mathematical aspect of a theory, and NOT for the coupling of experience with the mathematics. Since mathematics does not require the adherence to reality or experience, but science does, it follows that one cannot disprove a scientific theory on mathematical grounds, unless, of course there is a mistake in the mathematics itself. At that point the laws of mathematical necessity are enough to demolish the theory. A contradiction is all it takes. What this means is that no one can prove, for example, that Newton's theory is wrong mathematically.

This means that in order to examine the scientific validity of science, we are to direct our sights elsewhere, out of the domain of proof. That is quite a big step, so let me reiterate, it is NOT necessary beforehand that one is able to PROVE that a particular theory or view of the world is wrong, in order to bring forward changes into the worldview. And the more massive a paradigm shift, the tougher it is to prove the previous worldview as being inadequate. Absence of disproof is NOT a test of scientific validity.

So how then are we to judge the validity of our

scientific examination of science? It has to be from experience, and the coupling of mathematical ideas to experience must reveal whether or not we are on the right track. It is here that we approach another turning point: how much of the mathematical treatment must adhere to experience? What is the connection between the two?

Let me illustrate this with an example. It is commonly known, that in Newtonian dynamics, physics does not change under time reversal. What does this mean? This is actually a mathematical statement which means that if we flip the sign on the term having time from **+t** to **–t**, the dynamics is essentially unchanging, or as it is generally called, invariant. This represents that instead of going from initial to final conditions, one can easily think of going from the final to the initial conditions, with essentially the same physics coming into play. Hence **dynamics** is closely connected here with our perception of time. In a general representation, going from **–t** to **+t** represents time moving forwards or events presented in a forward manner, and going from **+t** to**–t** represents time moving backwards or events rewound as if a video were reversed.

Pause. There is another explanation. When we look at time, as represented by **t**, is just a count. It is a number that counts a periodic occurrence. Since this count is linear, we are at perfect liberty to be notoriously pessimistic and choose to count BACKWARDS. Let us assume that instead of time starting from (for example) 1 AD and going to 2010 AD, it instead starts at what we mark as 2010 AD counting DOWN to 1 AD. In that sense, the future would go towards negative numbers! It is entirely up to us whether we count it by adding an increment, or subtracting an increment, as long as we do it periodically. But what happens in the case of ($t_{final} - t_{initial}$) in the case that the counting is backwards? It turns out to be negative. The number line mathematically offers us this freedom, and it is the same freedom that is reflected in the change of sign. The only conclusion that can be drawn in that case is that in classical mechanics, time enters as a linear quantity.

However, note the connection generally made in physics, with **-t** and time flowing from future to the past. Here, a physical perception (or mental qualitative perception, if you will, both being valid in our examination) of time is allowed to go totally reverse, and is then taken as reality and applied to concepts such as causality, its violation, et cetera. There is absolutely NO evidence of time ever 'flowing' backward, and about that, all the scientists naturally agree. Not just that, quite apart from the absence of evidence, it offers a way to understand that there are various ways to couple mathematics to reality. Hence, the coupling of mathematics with experience here is vital to re-examine, as it offers the ONLY corrective factor any theory has. Mathematics says time can be counted backwards. That stands to experience. The reversal of time, or processes, or any of our experiences, is not subject to the same law.

As you have seen, a simple argument such as the above has far-reaching consequences. What about causality then? What about the second law of thermodynamics? How about time reversal symmetries in recent theories? And so on. We'll examine the process of these questions in the next article, but here we note that this happens because it deals with the basis of the sciences, which is the area from where the revolutions in thought generally come about. It is indeed encouraging that there is an avenue open for each one of us to explore independently, where we connect the mathematics to the outer world.

To summarize, the criteria we apply on science is that it must explain things rationally, quantitatively for the time being. In view of that quantitative aspect, it is seen that in shift of viewpoints, it is generally the relation between mathematics and reality that is remolded, and hence disproof of an existing theory is not a good criteria. At this point we necessarily reach the question: How do we overcome the limits of human perception? We cannot obviously perceive electricity in the same way as we do light, and we are pretty far from experiencing any nuclear force, which nevertheless offers considerable explanation to physical phenomena. We must be able to decide scientifically, the amount of leeway we offer to mathematics when it comes to our perceptions and intuitions, and hence put them **on hold** when we make our calculations.

We shall consider that in the coming article(s) in this series .

This article is the first part of the series of 7 articles the author, Gopi Krishna, has written for NERD; on topics related to philosophy of science and science and society. Reach out for next issues of NERD to read the following articles of the series.

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Civil Engineering Education and Construction Practices:

How to Bridge the Gap Between the Two

Kaustubh Dasgupta

Editor's Note

This article was awarded the first prize in the national-level essay competition on "Civil Engineering Education and Construction Practices: How to Bridge the Gap Between the Two" organized by the Indian Chapter of American Concrete Institute, Mumbai, during December 2004. Seven years later, this article is still relevant. It has been reproduced without any editorial changes. Instead, updates to the article have been provided at the end and have been referred to from within the text of the article. The views expressed in this article are those of the author and do not necessarily represent the views of, and should not be attributed to, the NERD Magazine and its team.

Introduction

Civil Engineering (CE) is the oldest engineering discipline. The earlier days of engineering consisted of military engineering and civilian engineering services only. Since then, challenging projects in the development of infrastructural facilities of the country have been the testimonies to the glory of the profession. In a project, the execution stage poses the biggest challenge; the preceding planning and design stages revolve around the adopted construction method. The true romance of the Civil Engineering comes out in the construction stage.

Thus the basic CE education should prepare the budding engineers in tackling the challenges in construction. Many a times the construction practices do not comply with what is taught in CE courses. This needs a detailed investigation.

Challenges Before Construction Industry

In India, the construction industry is the second largest industry after agriculture. Its impact on the national economy is such that, investment in this sector contributes 6.5% of the growth of Gross Domestic Product [1]. With the undertaking of several mega-projects in various infrastructural sectors, a severe demand on the human and material resources has been created. New materials, improvised equipment and technologies have entered the construction practices. But the industry is facing a dearth of qualified technical manpower. The alarm bells have been already sounded in the 14th Engineering Congress on Human Capital Development in January 2002 that "*in time to come, India will not have sufficient quality civil engineers even to undertake basic infrastructure work*".

Creating this pool of specialized people for the construction industry poses the biggest challenge to the human resource development sector. The engineering education system needs to play a dual role, namely (a) building the pool of construction professionals, and (b) developing a continuing education system for the professionals. The build-up of human resource pool will be wasteful if the imparted training is out-of-sync with the construction practices.

Civil Engineering Education: Current Scenario

Among the educational institutions offering CE courses, there are very few universities offering undergraduate (UG) programs in construction engineering. These institutes offer theoretical courses covering the whole gamut of construction methods and practices. But the practical aspects are overlooked in many cases.

Postgraduate (PG) programs on construction management and project management are offered in some institutes, e.g., National Institute of Construction Management and Research, Jaipuria Institute of Management etc. But the number of such institutes is ridiculously small as compared to the huge requirement of trained manpower. Also, these institutes impart specialized managerial skills to the students, not the nitty-gritties of the prevalent construction practices.

Most of the CE faculty members in the engineering colleges have no or very little work experience in construction industry. So they are not able to highlight the relevant site problems during the classroom teaching. For example, unless the difficulties faced in the construction of a dam are discussed in a course on dams, the overall picture is not complete. Surely the tricks-of-trade can be learnt only with experience. But the students should be aware of the concerned issues and the

challenges faced at site.

During the UG program, the vocational training period of two months (*if not less*) is hardly utilized by the students. Sometimes the students lack motivation to visit the working site; they seem to be happier indulging in "lucrative" career building options. Sometimes the site supervisor of the student is himself so demotivated and frustrated with his job that he discourages the willing-to-learn-but not-so-eager student in his endeavors of learning construction practices. Thus in many cases, the vocational training doesn't help in shaping up the student's career.

So, in a few words, the current CE UG curriculum does not train the students sufficiently to face the construction world.

Construction Practices – Rift Created

The construction industry in our country has been in the forefront of the development of the infrastructural facilities. The toils of thousands of people in building the nation have brought glory and international recognition to this industry. Paeans sung, there remain a few issues of concern.

Currently, the codes of practice (prescribed by the Bureau of Indian Standard) and the guidelines for construction are not adhered to, many a time, during actual construction. Strict monitoring by the responsible statutory bodies is not being done due to resource crunch. Also in rural India and the slums of urban India, there are "non-engineered" structures for which there are no code requirements or any regulatory bodies to oversee such construction work. These loopholes in the practices are exploited to the hilt.

With the construction industry playing a major role in shaping the economy, the codes of practice and guidelines should reflect the state-of-the-art construction methods. But these documents are not revised and updated regularly, *e.g.*, the Indian code for seismic design of structures, namely IS:1893, was revised after eighteen years (5th revision of the code came in 2002 after 1984) [2]. Also, many codes do not have elaborate explanations of their provisions and this leads to ambiguities during their implementation.

Another major malady afflicting the construction industry is the low compensation and salaries. A civil engineer draws a very low salary as compared to an engineer in the Information Technology, electrical, mechanical or allied field. To compensate for this, the contractor and client get into shady deals and this, in turn, breeds corruption. Coupled with the absence of accountability of the concerned people, improper construction practices are followed at the site to make illegal profits. Once a newcomer in the construction industry enters this vicious circle, his focus shifts towards making money. The quality of construction suffers at site.

With the above-mentioned scenario in the construction sector, the wide rift between the actual work profile at site and the education system becomes obvious. *First of all*, the four-year CE curriculum grooms the student in a theoretical mode with little emphasis on vocational training. *Secondly*, the codal provisions and construction guidelines get violated due to various factors. *Thirdly*, the four-year UG program in CE gives very limited scope to students to think about the subjects they study. As the students do not develop the habit of thinking, sometimes they tend to blindly follow the wrong construction practices. Applying a bit of engineering sense might bring out the flaw in an adopted method. But that does not happen!!! Thus, the knowledge gained in the four-year course remains back in the class-notes and the construction practice shapes up in its own way.

Changes in the Education System

In order to bridge the gap between the education system and the construction practices, a few changes are necessary in the education system.

Firstly, the duration of the UG CE program needs to be at least five years. About six to eight months of the extra year should be spent by the students getting trained at site. During the rest of the time, the student should attend classroom lectures by faculty members or professionals having site experience.

Secondly, the course curriculum should encourage students to pursue a career in the construction industry. Students should do hands-on small-scale construction project work as part of the curriculum with incentives being awarded as encouragement. The designs and details should conform to the standard codes of practice and guidelines. Simultaneously, the students should be made aware about the actual on-site difficulties at every step. Supplementary site visits supervised by experienced engineers are also desirable.

Thirdly, industry-academia interactions need to be arranged on a regular basis. A novel initiative was the Summer Camp 2001 [3] held at the Indian Institute of Technology Kanpur. In that camp a select group of second year UG CE students were exposed to the challenges and opportunities

in CE through various activities. Such interactions during the proposed five-year UG program will definitely motivate the students entering the construction industry, and proper construction practices will be adopted honestly by them.

Fourthly, students should cultivate the habit of thinking during the vocational training and the proposed hands-on project work. This will help them develop the insight and engineering sense for devising efficient construction methods.

Last of all, the UG engineering education should cover the applications of IT and process automation. An integrated course on construction practices, IT and the automated processes will be helpful with supplementary site visits to see the applications.

Educating Construction Professionals

The educational institutions need to conduct separate continuing education programs and short courses on a few relevant topics, namely (a) the explanations of the code-specified construction practices, and (b) state-of-the-art construction methods and international practices. Apart from site engineers and contractors, structural design engineers should also participate in these programs. The interactive discussions will enable all the concerned parties to adopt proper construction methods.

There should be two types of professional training programs, namely (a) multi-disciplinary training, and (b) specialist training programs. Under the first category, the courses should cover the architectural, engineering and surveying aspects. Also, a civil engineer should know the basics of mechanical, electrical and instrumentation engineering for his complete understanding. Under the second category, visiting practitioners should conduct the courses for imparting special skills and knowledge.

Construction Industry: Things To Be Done

The issues of low compensation and salary of an engineer need to be addressed urgently and comprehensively. The current trend of underbidding adds to the misery. If the projects are awarded to the contractors based on their competence rather than the lowest fees, then definitely it will not be demotivating for the professionals involved in the project. With a balanced education system for the professionals, the unfair construction practices can be definitely avoided. Also, the system of professional liability and accountability needs to be implemented among the practicing professionals.

Every construction company should have a division of research and development. Although this aspect is generally overlooked, this is imperative for devising efficient construction methods and employing state-of-the-art practices. Professionals with specialized skills should be employed in these sections.

Concluding Remarks

In any subject, teaching and learning materials should match and respond to the ever-changing needs of the professions and society. Construction industry is no exception to that. The need of the hour is the interaction between construction professionals and the CE academia on various issues of construction practices and the ways of improving them. Then only the construction industry can reach its pinnacle of glorious achievements in the time ahead.

Updates to the article

[1] Contribution of Construction Industry

As of First Quarter of 2011, as per the Central Statistics Office of Ministry of Statistics and Programme Implementation (http://mospi.nic.in/), Government of India, construction industry contributed nearly 8% to the growth of Gross Domestic Product of India.

[2] IS:1893

As per the Bureau of Indian Standards, the governing body responsible for maintaining and upgrading various standards in India, a portion (Part 4) of the Indian code for seismic design of structures, IS:1893, was updated again in 2005. However this upgrade deals only with industrial structures. An appropriate search within http://www.bis.org.in/ will give the reader a complete picture of the frequency of upgradation of various Indian standards by the Bureau.

[3] Civil Engineering Summer Camp at IIT Kanpur

Summer Camp for Civil Engineering at IIT Kanpur was first organized in 2001. The mission of the camp, as stated on its website is "to provide exposure to second year civil engineering students from engineering colleges across India, to the challenges and opportunities in Civil Engineering, towards building a stronger nation for tomorrow." Since its inception in 2001, the Summer Camp was organized annually with great success till 2010. The 2011 edition of the camp had to be called off due to unavoidable circumstances (as stated on the Camp Website: http://www.iitk.ac.in/summercamp/).

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Indian science, civilization and culture: past and future

Lecture series by Michel Danino and a detailed interview with him

Mohd. Suhail Rizvi and Mohit Kumar Jolly

Eminent Indian civilization historian, conservationist and author **Michel Danino** delivered a ten-lecture series on **'Science and Technology in Early and Classical India'** in February and March 2011. Michel has been a student of Indian civilization since he came to India from France in 1977 at the age of 21. He has authored many papers and lectured extensively across the country on India's scientific heritage, Indus Civilization and problems faced by Indian culture today. He has authored landmark books such as *The Invasion that Never Was* (2000), *The Lost River: On the trail of Sarasvati* (2010) and *Indian Culture and India's Future* (2011). He also convened International Forum for India's Heritage (IFIH) in 2001 to promote the essential values of India's heritage in daily lives.

Fig 1: Michel Danino during one of his lectures in L-16, IIT Kanpur

The lectures followed a chronological development of science and technology from ancient to pre-modern India, using specific case studies and the social environment of science in India in those days; and concluded with asking the pertinent question why Indian science and mathematics failed to move on to 'modern science'. Following is the summary of the series of lectures given by him.

There are generally two extremes views of India's contribution to science and mathematics. The first, taken by some western authors, considers Indian contributions to be limited to the decimal place-value system of numeral notation, and thus give only half a page to India in a book on history of science or mathematics. The other stand is taken by some over-enthusiasts who claim that ancient Indians were omniscient – they knew it all from theory of relativity to quantum mechanics and from genetic manipulations to nuclear weapons. The truth lies somewhere in between these extremes. Unfortunately, the ancient Indian tradition of knowledge transfer, being primarily oral, does not provide many written accounts. The biggest sorrow is the dilapidation of the existing ancient Indian literature and evidences in India itself. Only 7% of around 11,000 existing ancient manuscripts of texts of science preserved in Kerala and Tamil Nadu have been examined and read. Comparing this with China, which has had some enthusiastic scholars like Joseph Needham whose works have culminated into the voluminous series *Science and Civilization in China*, Indian science has not yet found its Needham.

Science, as it is defined today, is a modern concept; the ancient Indian mind did not apply this definition to study the nature. In ancient India, nature was studied by means of poetry, mythology and philosophy; and the religious and social practices were deeply intertwined with science and its developments. For example, *Jyotisha*, primarily a combination of astronomy and mathematics, was developed to keep the calendars, fix the dates for seasonal sacrifices or predict the occurrences of eclipses. The *Shulba Sutras*, treatises of sacred geometry, were instruction manu-

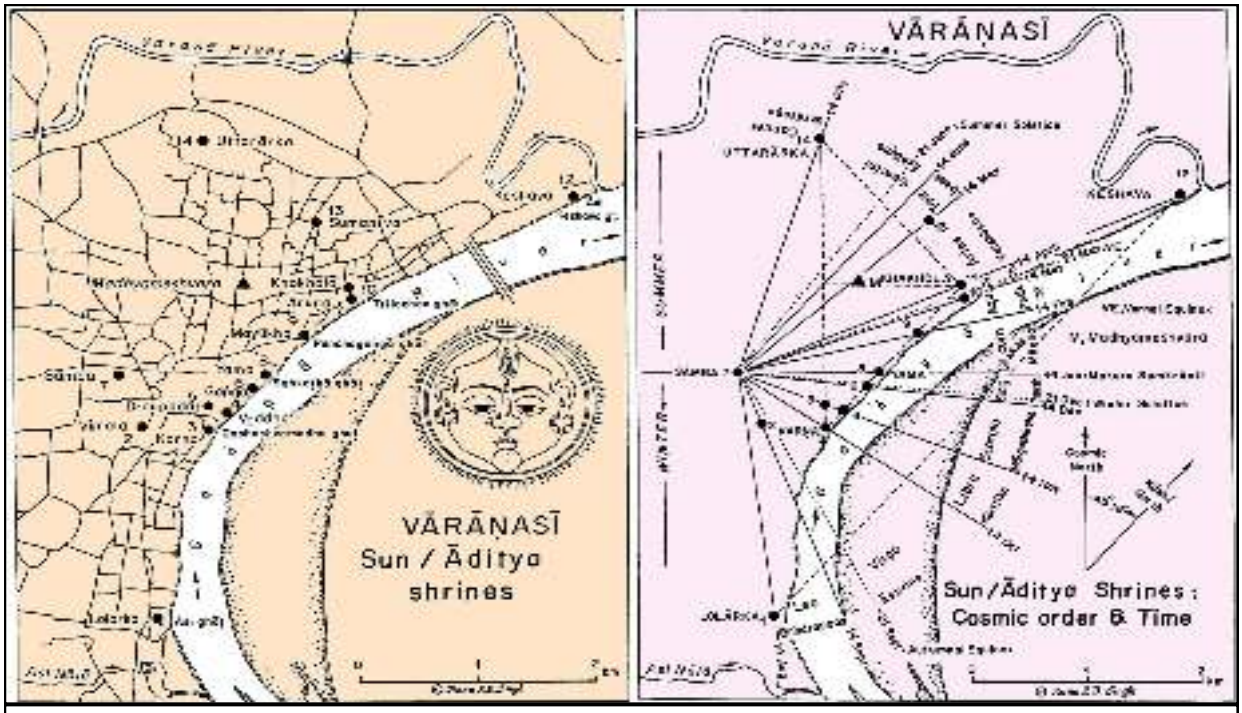


Fig 2: Layout of Varanasi (left) as based on astronomical alignments (right) embedded in the city design

als for the construction of *vedic* altars (*vedi*) as they describe complex geometrical construction with bricks of various sizes and shapes. One of such *sutras* gives the value of square root of two as 577/408 or 1.414215 which is correct to fifth decimal place. *Vastu Shastra*, the science of architecture, describes the design of temples and cities as representations of the cosmos. Studies performed by German archaeologist Holger Wanzke on Mohenjo-daro's town planning and U.S. astrophysicist J. McKim Malville on the layout of ancient Indian cities (including Chitrakut and Varanasi) highlight the importance of astronomical alignments embedded in city as well as temple layouts (Fig 2).

Unlike the Greeks who were interested in absolute laws/ rules or in axiomatic foundations of science, the approach adopted in ancient India was highly holistic and application-oriented. This attitude of doing 'science' gave rise to interest in pragmatic methods such as efficient formulas and algorithms. A few instances of the outcomes of such interests include accurate astronomical calculations, *Shulba Sutra Prameya* (Fig 3, also known as Pythagorus theorem) by Baudhayana, geometrical constructions (without compass and scale), estimation of the value of pi, the cyclic method of Bhaskaracharya (*chakravala*) for the shortest integer solution of a quadratic equation, and the units of weight and length. A notion of rationale or proof (*upapatti*) also exists in the works of some ancient Indian mathematicians. Not only was the decimal place-value numeral notation discovered in India, but also these numbers were often denoted with names having mythological meaning related to a particular number, instead of numerals, thus depicting the confluence of religious and scientific mind. Georges Ifrah, in his book *The Universal History of Numbers*, gives a detailed account of India's contribution to the decimal numeral notation and notes that *"A thousand years ahead of Europeans Indian savants knew that zero and infinity were mutually inverse notions"*.

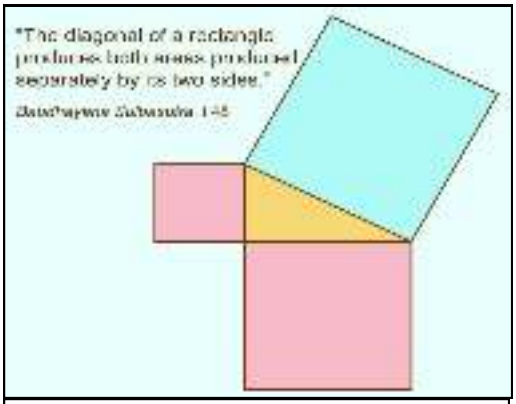


Fig 3: Baudhayana calculation of the Pythagorus theorem

Mathematical concepts are also found in the background of purely religious texts. The *Avatamsaka Sutra,* a Buddhist text, depicts a network of pearls placed in heaven by *Indra* in a way that in each pearl one can see the reflection of all others. (Fig 4) A recent mathematical study has demonstrated that these pearls follow the arrangement of circles in a Schottky group. Similarly, a

comment on a hymn of *Rigveda* (1.50.4) by Sayana, a fourteenth-century Vedic commentator records:

tatha ca smaryate yojnanam
sahasre dve dve sate dve ca yojane
ekena nimisardhena kramamana

"Thus it is remembered:
[O Surya] you who traverse
2,202 *yojana* in half a *nimesa.*"

With a *yojana* of 13.6 km (which is defined as 8000 average human heights of 1.7m) and a *nimesa* of 16/75th of a second, this accounts to 280,755 km/s which is only 6% short from the speed of light as known today.

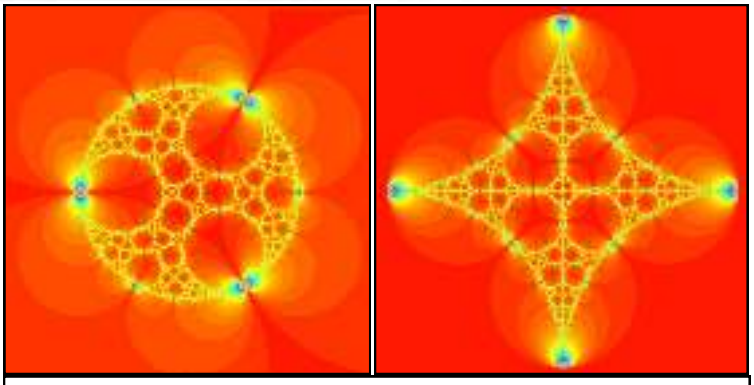


Fig 4: Indra's Pearls

In India, there were two parallel traditions for the sustenance of scientific knowledge: *Shastra* (theory) and *Loka-parampara* (practice). This created an enriching interface between theory and practical knowledge and thus sciences like Ayurveda gained knowledge from folk traditions such as bone-setting and herbal preparations. Even today, much traditional knowledge has been documented from rural and tribal communities. For instance, in Kerala some healers of snake bites can cure a patient by getting two villagers, after chewing medicinal herbs, to blow into the ears of the patient. The All-India Coordinated Research Project on Ethnobiology (AICRPE), a committee appointed by the Government of India, reported that tribals are familiar with about 9500 species of plants including 7500 medicinal ones.

India's fascination with large numbers is beautifully illustrated in the Persian and Arabic story of Sessa, a clever *brahmana* who designed the game of *chaturanga* (chess). The king was so pleased with the demonstration of the game that he told Sessa to ask for any reward. Sessa humbly requested one grain of wheat on the first square of the board, two on the second, four on the third and so on. In order to calculate the total number of grains, the king had to call mathematicians from neighbouring kingdom. They worked out the number to be $2^{64} - 1$ (Fig 5). The embarrassed king was saved by a clever minister who asked Sessa to go to the granary and count the grains himself. In addition to advances in large numbers, efficient mathematical algorithms and accurate astronomical calculations were devised by Indian mathematicians long before occidentals. Historian of mathematics A. Seidenberg compared Greek and Babylonian geometry with the *Shulba Sutras* and found that the latter's geometry cannot be derived from Greek or Babylonian geometry, but Greek and Babylonian geometry have a common origin from 2000 BCE which is very much like the geometry of the *Shulba Sutras*.

On the technological front, many metallurgical and chemical advances like fabrication of wootz steel (which was prized all over the Greek and Roman world), methods for extraction of oils for medicinal and perfumery purposes, iron-smelting techniques, corrosion-resistant metals (Delhi Iron Pillar is a famous example) and water management technologies bewilder the modern scientific mind. Sushruta, probably the world's first plastic surgeon, lists 220 surgical instruments in his *Sushruta Samhita*. The notion of *Dashavatar* (Fig 6, ten incarnations of the divine consciousness) holds some intuitive idea of the concept of biological evolution: the first *avatar* has the body of a fish, the second an amphibian, the third a mammal, the fourth a half-man half-animal, the fifth a short man. Later stages represent a spiritual evolution.

Despite these advances, Indian science and technology could not produce a 'scientific revolution'.

Fig 5: Chess (*Chaturanga*)

The reasons for this are complex, but they include the destruction of centers of learning and libraries in north India, a consequent disruption of mechanisms of transmission of knowledge and manuscripts among savants, a lack of patronage of mathematicians and astronomers by kings (if we compare with the patronage given to the arts), and the absence of a desire to conquer and colonize other parts of the earth, which would have required further technological advances. In any case, India's scientific progress slowed down in medieval age. Under the British colonial rule, 'Western' science gradually replaced India's traditional disciplines. At the same time, Indian philosophy and spirituality travelled to the West, and we see, for instance Swami Vivekananda discussing Vedantic ideas with Nikola Tesla and influencing Kelvin and Helmholtz. Later, Erwin Schrödinger and Werner Heisenberg acknowledged their debt to Indian thoughts and concepts.

Fig 6: *Dashavatar* (ten incarnations of the divine consciousness)

NERD team had a detailed interview with Michel and his partner Nicole after the lectures, on his work related to ancient Indian science and civilization and his views on the future of Indian culture. Some excerpts:

NERD: What was your motivation behind your decision to come to India at the age of 21 and then study here?
Michel: My initial motivation was to come and live in Auroville, an international township in Tamil Nadu located close to Pondicherry. It was founded on the ideas of Sri Aurobindo and the Mother. Sri Aurobindo was a spiritual master well known for his role in the revolutionary movement in the first decade of the twentieth century. The kind of experiment Auroville was — human beings coming from all over the globe and attempting something together — fascinated me. I had been in touch with it for some years while in France, and I decided to take the plunge. This is what initially drew me there — and then I stayed on.

NERD: Please share with us some intercultural experiences you had in the first few years.
Michel: The major experience was that I felt perfectly at home here in India. I had never really felt quite at home in France for reasons I cannot explain; but I felt completely myself and absorbed in Auroville. This feeling of being at home cannot be decided and described on an intellectual basis.

NERD: After settling in Auroville, what was the first study you undertook?
Michel: In those days, various communities in Auroville were attempting different ways of controlling soil erosion, which was the major problem in the Auroville terrain then. I tried to document those attempts in eco-restoration; besides, I helped to bring out a bilingual magazine in English and French. Very soon, I developed an inclination towards books and publications related to Sri Aurobindo and the Mother. This kept us (me and Nicole) busy together. In 1982, when we were called to a small institution in the Nilgiris, we dedicated ourselves to this work much more intensively. It is through Sri Aurobindo that I developed interest in the study of ancient Indian civilization, its history, archaeology etc., because he was interested not just in spirituality, but in making sense of the Indian civilization. He wrote an extraordinary book called *The Foundations of Indian Culture* in which he tried to bring out various features that have made India stick together

in every aspect of life through all these ages. That was a starting point for me; I wanted to see how that would be updated, since Sri Aurobindo's book was written almost a century ago.

NERD: Coming to your work now, you wrote a book, *The Invasion That Never Was,* in 2000 in which you criticized the Aryan invasion theory emphasizing that they were indigenous to India. What did you base your criticism on and how was it received?

Michel: The book actually first came out in a shorter edition in 1996, and then in a much enlarged one in 2000, which ran out of print in 2003. The grounds for criticizing the theory are not really mine but they have been highlighted by many scholars beginning with Swami Vivekananda, Sri Aurobindo, Dr. Ambedkar, besides Western anthropologists, archaeologists and even biologists.

"The Aryan invasion is not required to explain the evolution of Indian civilization."

There were two reasons behind the Aryan invasion theory: one was to explain the linguistic connection between the European languages and Sanskrit, which became obvious once the European scholars were able to read Sanskrit sometime in the late eighteenth century. To explain this connection in those days, in the absence of today's more complex models, the only explanation envisaged was that of migration; that is to say, if two languages were somewhat related, then one had to imagine a migration from A to B or B to A, or from C to A and B. This is known as the 'migrationist model'. Today it is well understood that languages can travel without people having to migrate; for example, Sanskrit migrated to many parts of Asia through an increased interest in Sanskrit texts, not through a migration of Indian people.

The second reason was the colonial context: the British colonial powers tried to divide Indian society by propagating a theory portraying the upper castes as descended from the Aryans, and the lower castes as descendants of the indigenous people whom the Aryans subdued. Another divide-and-rule strategy was the division between North Indians and South Indians: the Aryans invading from the North drove the indigenous Dravidians southward where they eventually settled, although one finds no evidence of this in Indian literature or protohistory.

I tried to bring out in my study that there was no archaeological trace of the arrival of the Aryans in the 2nd millennium BCE: such a migration would have involved the emergence of new types of artefacts — new weapons, vehicles, handicrafts, art forms, etc. — and it's well established now that no such evidence has been found in the second millennium BCE. In fact, some archaeologists now are proposing that the Indus Civilization gradually evolved to the classical Gangetic Civilization of the first millennium BCE. The Aryan invasion or migration is not required to explain the evolution of Indian civilization. Also, the *Rig Veda*, India's most ancient text which is supposed to have been composed by the mythical Aryans soon after their arrival, makes no mention of their arrival. It would be natural for the Aryans to feel nostalgic for their land of origin, but there is not a word to that effect in the entire *Rig Veda*. Instead, they clearly belong to the *Saptasindhu*, which is Punjab, Haryana, Rajasthan and Pakistan today, as if the incoming Aryans had got struck with amnesia and forgotten all about their long migration to India. Correspondingly, in south India's Sangam literature, which goes back to the second or third century BCE, we find no recollection of a traumatic invasion or cultural clash with invading Aryans.

NERD: In your book *The Lost River: On the Trail of the Sarasvati* (Penguin Books, 2010), you present evidence that the river Sarasvati was present in what is Haryana and Rajasthan today, but the currently held belief is that Sarasvati is one of the rivers that meet at the Triveni Sangam in Allahabad. What, in your opinion, is the reason behind this common belief?

Michel: The Sarasvati joining the Ganga and Yamuna at Prayag (Allahabad) is a recent tradition which you will not find anywhere in the Vedas. The *Rig Veda* clearly states that the Sarasvati flowed westward between Yamuna and Sutlej. Even the *Mahabharata* records the Sarasvati as flowing through Kurukshetra (in Haryana) all the way to Prabhas in Gujarat; this is the only Sarasvati the *Mahabharata* knows. Sarasvati at Prayag

"This is the way the Indian mind functions — the memory should be preserved and the worship should continue, while the geographic details and accuracy are a minor consideration."

is a tradition which comes later on, in the Puranas, and, in fact, there are many more Sarasvatis in India: two in Gujarat, two in Haryana, one in Rajasthan, among others. My proposition has been that after the westward-flowing Sarasvati dried up around 2000 BCE, the hundreds of Harappan settlements that had flourished along its banks (they have been identified on the ground) had to be abandoned; some of the Late Harappans migrated into the Gangetic plains, but so as not to forget that river, they conjured up Sarasvati's presence at Prayag. It is curious that the only river to be given the status of a goddess in the *Rig Veda* was the Sarasvati, so the Harappans were apparently quite attached to it (or her, rather!) and were keen to multiply her on the landscape so that they would remember her. This is the way the Indian mind functions: the memory should be preserved and the worship should continue, while the geographic details and accuracy are a minor consideration. Hence, the Harappans created an 'invisible' Sarasvati which people later on embellished with the story of a river flowing underground.

"Indian civilization is the only ancient civilization persisting till today. The two great epics – Ramayana and Mahabharata – gave India its cultural unity and integration."

NERD: Moving on from ancient to current India now. You have written a book *Indian Culture and India's Future*, in which you say that the essential values of the Indian civilization and culture remain indispensable in today's critical phase of global deculturalization and dehumanization. Please elaborate on what those values are.

Michel: You can figure them out easily if you consider a single fact — the persistence of the Indian civilization. With the partial exception of China, there is no known ancient civilization surviving today. Today's Greek has no contact with Plato or Socrates and today's Egyptian has no contact with the Pyramids, but in India, the antiquity of the culture has persisted, and it has persisted because of certain highly effective mechanisms within the society, especially a certain cultural integration creating a sense of unity across India's geography. How was that worked out?

The consensus among the scholars is that more than the Vedas or the Upanishads, it was the two great Epics — the *Ramayana* and the *Mahabharata* — that were widely adopted across India, freely adopted and transformed from region to region. You will be hard pressed to find a place in India where Rama or the Pandavas or some Rishi did not come by. The Epics created a sense of belonging among the people so successfully that they even spread beyond India. The whole of Southeast Asia was mesmerized by them. Even the walls of the Angkor Wat temple in Cambodia depict some of their stories in a grand manner. They continue to be re-enacted in Indonesia, a Muslim nation, as part of its cultural heritage. I believe that such cultural integration gives people a sense of belonging, and that's why this kind of unification of different communities, castes and social levels has been very successful in keeping the whole land together for long. Today, Western countries are talking of multiculturalism, especially in Europe, but their leaders have admitted that their models have failed, because they were trying to keep people together without any real integration. Cultural integration is something which the West could perhaps learn from India — for it can be done only on the basis of certain deep values.

NERD: You also started the International Forum for India's Heritage in 2001. Please tell us about the ethos of this forum and some of the initiatives you have taken.

Michel: It is a network of scholars and we have done a few projects like interviewing 11,000 school children across India about their views on Indian education (that project was sponsored by the NCERT). We have been feeling that there is no valid reason why India's cultural heritage should be kept out of the schooling system. In France, students are obliged to know about French literature, thinkers and philosophy, so that after twelve years of schooling they will have some notion of French culture; but in India, students develop no intelligent understanding of the country's unifying culture. That was one of our motivations behind the creation of this forum.

But it is not enough to just point shortcomings, so we are trying to create educational material on Indian culture and heritage. We cannot give students scholarly material for every branch of ancient Indian knowledge, so we are working towards a series of interactive multimedia educational DVDs. The first of them will be on science and technology in ancient India, which was the theme of my lectures here at IIT Kanpur. In a few months, we will see how this initiative is received.

NERD: Coming to your lectures on Indian science at IIT Kanpur, do you think it is valid to examine

the knowledge of those sciences against the current 'infallible' science? The current scientific setup raises questions about some other points such as treatment of snake bites.

Michel: I brought in some examples to point out that modern science can hardly be regarded as complete, let alone infallible. Any honest scientist will tell you that so many things still defy explanation. Science does not claim completeness, but scientists are very attached to the scientific method. It includes tests for falsifiability, a valid concept in my opinion, but we need to be careful to see how far it can test ancient ways of functioning. For example, in the case of snake bites, if you saw the video clip showing a traditional method administered to a krait bite (in which two people blow into the ears of the patient after chewing medicinal plants), the method would make no sense to a modern doctor. The only way he/she can assess such a methodology is to look at the statistics as to how many people with lethal bites got cured this way. The explanation of this process is as tough as the explanation of Ayurveda, because, in spite of being internally consistent, Ayurveda defies modern explanation through present-day medical science. You may say that the three *doshas* — *vata*, *pitta* and *kapha* — are not scientific entities that can be seen under the microscope, yet Ayurveda works. So, in India's traditional knowledge systems, there are things which science can assess and things it cannot.

Fig 7: LateProf. Balasubramaniam hugging Delhi Iron Pillar

I believe that scientists have to be open-minded, but honest assessments can be made and some groups in India are working towards that — testing ancient technologies to see how far they could be of use to advanced technologies in the fields of metallurgy, agriculture, medicine and other areas. For example, here at IIT Kanpur, (Late) Prof. R. Balasubramaniam worked out the precise metallurgical technology used to create rustless iron pillars (such as the famous one in New Delhi's Qutub Minar complex– Fig 7) and other artefacts; in short this ancient iron had a high phosphorous content, and he found that there was scope for applying the same techniques to stop or slow down the rusting of iron used for rails or in concrete structures. We need this kind of open-mindedness rather than rush to declare everything in the past as ignorant or superstitious.

NERD: Most of us see our traditions as a set of superstitions and talk of spreading a scientific temper. Where and how, do you think, some stories in our history evolve into superstitions; for example we should change our way if a black cat crosses the path?

Michel: The original spirit of rituals is to connect us to the universe, but somewhere along the way they degenerate and people start sacrificing for tangible results —wealth, a son, fame... To avoid this, traditions should evolve with time, otherwise, we get stuck with meaningless rituals that can result in superstition, since their original spirit and hence their intrinsic value are lost. If the original meaning is revived and people are happy with that, I see no problem with it.

NERD: Coming to science education in schools, the way science is taught in India creates an impression in young minds that science is something that is done overseas. Do you think that this leads to a lack of pride in Indian science and hence in our culture?

Michel: For various reasons which I would not go into in this interview, the Indian education system has kept Indian heritage out of sight of the student. This creates an impression, as you say, that all knowledge comes from the West and therefore a subconscious thought that India never generated any worthwhile knowledge. It is a skewed perspective that Indian education imprints on young Indian minds. Students are told that the numerals taught in school are 'Arabic numerals', but it is an accepted fact by all historians of science that they originated in India in the Brahmi script. Why can't the teachers explain this? When students learn to count with the decimal system of numeral notation, why can't it be introduced for what it is — an Indian creation (Fig 8)? Ironically, one of the best histories on the decimal system of numeral notation was written by a French scholar (Georges Ifrah), who praised Indian savants for this achievement. It is natural to know what our country has contributed in terms of knowledge.

"The Indian education system has kept Indian heritage out of sight of the student."

So we are proposing that India's contribution to science should be integrated in the educational system and teachers should tell students about them. Let me repeat that what we call 'science' is not 'Western science': modern science has had important inputs from India, China, Mesopotamia and other parts of the world, and these inputs are now more and more acknowledged.

NERD: Coming to an even more basic question, why do we need to study at all the history of science?

Michel: It is like asking why we need to know about the evolution of ideas. At a very crude level, to get a degree and a job, you don't need it; but to understand a bit more about the country you live in, to answer the question who you are (because it is related to what is India about), you need to know something of what ancient Indian thinkers, astronomers, mathematicians, chemists, physicians really achieved. The limited availability of genuine material has led to many spurious, exaggerated claims that ancient Indians had *vimanas* flying through the skies, nuclear power, etc. We have to fill the void with genuine information so that those who are interested can pursue them.

"If you just want to get a degree and job, you don't need to know the history of science; but to understand a bit more about the country you live in, you need to know it."

History of science is a recognized academic discipline in the West; you can do a masters and a PhD in it. The problem is that it is multidisciplinary: it integrates not only science but also fields like history, anthropology and archaeology, and is therefore quite demanding. It has not been able to find a home in the Indian academic scenario which is very compartmentalized. I hope the situation will evolve as the need to study this valuable discipline gains recognition.

NERD: Coming to the establishment of history of science as an academic discipline, not many elite science institutes in the country expose their students to it and the humanities department is just considered a service department. What is your opinion about exposing science students at both graduate and undergraduate level to these important aspects?

Michel: I believe that if it is done in a creative way, most students would love it. Generally, the final result is given to a student of mathematics to be swallowed; but if it were given to him or her as an evolutionary process — to understand what Newton and Leibnitz and then Lagrange and Laplace did before reaching the final form of the expression — it would be easier to approach. As a student of science in France, I was also given clues towards the history of science to understand how this knowledge took shape. Most students would be excited to know that so many great minds all over the world toiled for so long, often getting it wrong.

The problem is that in India, history is taught the wrong way. It's all about dates and wars and dynasties and hence meaningless and boring. The student is not able to relate to the history. I have not come across many students of history showing real interest in their subject. That is very unfortunate. We should change drastically the pedagogy for history and the way we look at it — because it is a part of us. It helps you to understand yourself and hence your identity. History should be a fascinating topic taught creatively through plays, research and visits to local sites. I have always said that you should start from local history and geography and build it up from there.

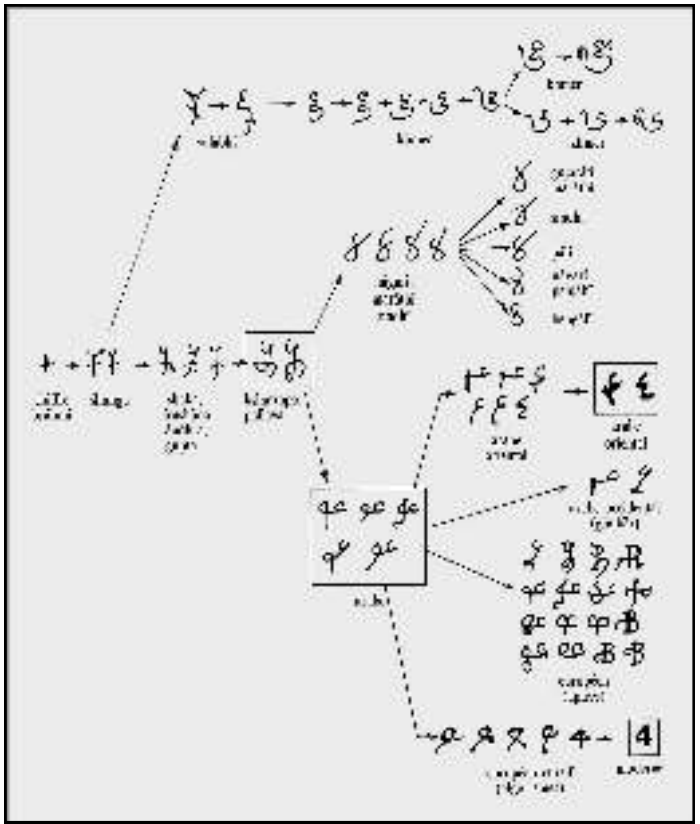


Fig 8: Evolution of numeral 4

NERD: Let's talk about the attitude of Indians. *Yog* has been practised by Indian Yogis for long but today's Indian did not practice *Yog* till it was appreciated by the West and returned to India as *Yoga*. What, according to you, is responsible for this blind following attitude of Indians?

Michel: *Yog* is a Hindi word and *Yoga* is its Sanskrit equivalent. But I understand your question. It is true in a certain class of the Indian population but mostly in the urbanized class. The fact that the West adopted Yoga in such a big way had a ripple effect back home, but not with the mass of the population. I have come across people in rural Tamil Nadu practising asanas and pranayama, and it is a part of their culture somehow. They have no clue what happens in America. Hence, you are partly right that the 'educated' Indian is hypnotized by the West, but the 'uneducated' Indian knows what it means to be Indian and the significance of his traditions. Ironically, the problem comes with Indian education. It is a reflection of the colonial hangover, as our education system has never really been overhauled and reformed after Independence.

"The 'uneducated' Indian knows what it means to be Indian and the significance of his traditions. Ironically, the problem comes with Indian education."

NERD: In your book *India's Culture and India's Future*, you refer to the angry young Indian. How do you define such a person and what is your message to him/her?

Michel: The angry young Indian is the one who is upset to see the state of things: having to bribe one's way around, to pay so much to be educated, etc. This is what puts off many who have aspirations and ideas, and it is absolutely natural. Then they start idealizing the West, thinking that there is no corruption there. That of course is valid to an extent, since there are areas where the West scores above India, such as pollution control and civic discipline, but there are also social tensions in the West that are ever increasing. Some young Indians, yearning to go to the West once, get dissatisfied especially with the concept of consumerism which is the main driving force in Western society. India tried to answer those questions long back by giving a deeper meaning to life, which is what causes many Westerners to turn to India. She also insisted on the art of being happy with little, whereas the West wants us to be unhappy with much. My only message to young Indians would be to explore the meaning of being Indian and India's contributions to knowledge.

"Explore the meaning of being an Indian and India's contributions to knowledge."

NERD: You have been giving lectures on Indian civilization and people have been very open to your ideas. Do you think you would have been received in the same way had you been an Indian?

Michel: First of all, I am an Indian as I took Indian citizenship some years back. To rephrase the question and include skin colour, I think the answer would be yes and no. It may have initially helped as people wondered how someone with a fair skin has probed Indian culture to such depth. At the same time, if I were talking rubbish, the novelty would soon wear off! I have to make sure that I bring something of substance. My approach has been basically to be objective and bring out genuine material, presenting the entire picture in as neutral a manner as possible.

NERD: Shifting to Nicole, please tell us about your journey with Michel in the past years.

Nicole: I came to India a few years before Michel and it was the same love for India that kept us together. We both felt at home here. We felt intimate with the land and the people. Whenever we would go abroad on a visit, we would yearn to come back. We would like to do something for Indian culture in India but the most important thing is the gift of the connection with the divine that India gives us.

NERD: Thank you Michel and Nicole for the detailed interview!

Mohd. Suhail Rizvi (suhailr@iitk.ac.in) is a PhD student in the Department of Biological Sciences and Bioengineering at IIT Kanpur. His interests include biomechanics, long trip cycling and studying about Indian history.

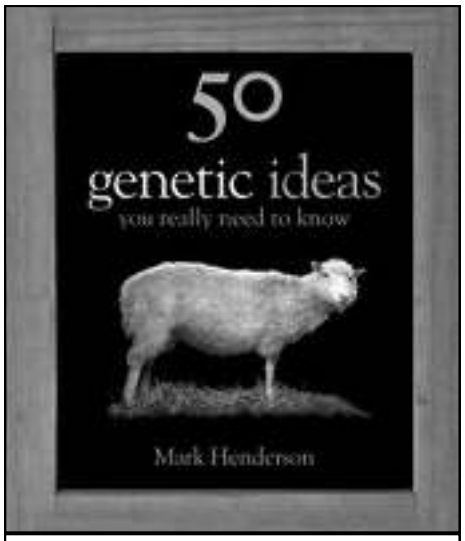
Mohit Kumar Jolly (mkjolly@iitk.ac.in) is an M Tech student in the Department of Biological Sciences and Bioengineering at IIT Kanpur. He is interested in science communication and started the campus science and technology magazine, NERD, in 2008.

This interview is the transcript of an audio interview with Michel and Nicole, taken for IIT K 90.4 FM. It was transcribed by Sayak Dasgupta.

DOG – EARED: Book review

50 Genetics Ideas You Really Need to Know

Anjaney Kothari



ISBN: 978-1-84724-671-4
Publisher: Quercus
Author: Mark Henderson
Binding: Hardback with Jacket
Publishing Year: 2008
Number of Pages: 208
Language: English
Price: INR 324 (on Flipkart.com)
Book Club Availability: 0 (on website)

The author, in the introduction to the book, says: "Without genetics...we would look at life with one eye. We are lucky enough to live at a time when humanity can finally watch with two."

In a time when some or the other word related to one of the most important life sciences, Genetics, is conspicuous in everybody's vocabulary, Mark Henderson has written a book which discusses it all, in a fashion that would increase anyone's inclination towards the wonderful world of biology. Commencing from the genetics of evolution, this book tracks the evolution of genetics from genes to gene patenting, from cancer to 'designer' babies, from Mendelian inheritance to epigenetics, from genetic determinism to artificial life. Commenting meticulously on many such topics, the author has made this book sprawl beautifully across the past, present and future of Genetics. Controversial topics like homosexuality, races and intelligence of human beings have been discussed from the science perspective, serving as an eye opener against many stereotypes on these issues.

Each chapter has been enriched with a timeline of events related to the ideas, discoveries or experiments discussed in the chapter. The 'condensed idea' that the author wishes to convey to the readers through each chapter is highlighted at the end of each chapter in crisp and clear words. At the end, a glossary of the biology jargon used in the book has been presented, which makes the ideas expressed in the book very clear. Many obscure quotes by scientists appear constantly which may spoil the fun a bit for some like they did for this reviewer. Nevertheless, a bit more icing on the cake does not spoil the entire feast.

If one were to encourage people who are not too enthusiastic about biology to read this book, (s)he would say that this book owes all its readers a wonderful realization, that how painstaking serendipity could be and yet how serendipitous painstaking could be, in science. In short, the author has discoursed giant genetics ideas with incredible lucidity, which makes '50 Genetics Ideas You Really Need to Know' a book you really need to read.

About the Author: Mark Henderson

Mark Henderson, a graduate in modern history from the Oxford University, is the science editor of *The Times*. He lives in London and finds genetics, reproductive medicine and regenerative medicine (including stem cell research) quite interesting. He has won several coveted awards in science journalism.

Anjaney Kothari (anjaney@iitk.ac.in) is a second year Undergraduate Student in the Department of Biological Sciences and Bioengineering at IIT Kanpur. His academic interests are genetics, artificial life synthesis and linguistics. When he is not thinking of growing peas like Mendel, he likes to read Agatha Christie novels, write stories and poems and paint.

BOOK REVIEW IN THE NEXT ISSUE (V4 N2): Find the review of the book 'Genome: An autobiography of a species in 23 Chapters' published in 1999, by eminent popular science author Matt Ridley. Watch out for this section in V4N2 of NERD to see what Sashank Pisupati thinks of this book which was described as 'lucid and exhilarating' by the co-discoverer of DNA, James Watson!

From dialogue to learning

Interview with Dr. Suchitra Mathur

Mohit Kumar Jolly and Swapnika Reddy

Dr. Suchitra Mathur has been a faculty member in the Humanities and Social Sciences department since 2000. Well known among the student community for her interesting classes in HSS I and II level courses, she has also been very active in various student activities and festivals. She also received the Gopal Das Bhandari Memorial Outstanding Teacher Award 2011 – an annual award given to a faculty member chosen by the graduating undergraduate batch. NERD team members had the privilege of an exclusive interview with her regarding her experiences as a teacher, researcher and a member of the IIT Kanpur community. Here are some excerpts:

NERD: You have been a faculty member in this institute for more than a decade now. What is the most distinguishing feature you feel about the institute?

Dr. Mathur: I would like to answer that question in two ways. Looking from a historical perspective, what has always attracted me to IIT Kanpur as an institute and what I hope to see continuing is its democratic traditions. The model of self governance in faculty as well as the student body has been that of democratic functioning. What I mean here is not only election of representatives but also the spirit of debate and engagement with everything around oneself. But over the past few years, I have felt that this spirit has been endangered by a variety of factors, primarily by the apathy of the people involved; and I am hoping against hope that those traditions will be revived.

Another distinguishing feature of IIT Kanpur for me has been the enormous amount of innovation and energy brought in by the students. Be it awards won by students in innovation-based competitions, the enthusiasm brought to various socio-cultural activities, the very existence of NERD itself being a prime example - I have always marvelled at it in all fields.

"A distinguishing feature of IIT Kanpur has been the enormous amount of innovation and energy brought in by the students."

NERD: A faculty member in the Humanities and Social Sciences department in an engineering institute – what made you choose such a unique post?

Dr. Mathur: I was teaching in the US and wanted to move back to India. IIT Kanpur has always held a very special place in my heart because I grew up on this campus as a faculty kid, so I applied to IIT Kanpur as well. Honestly, I really did not know then what I, as an English teacher, would do in an IIT. But it took me just one semester to figure out that this was where I wanted to be. All thanks to the students I taught in that first semester here! I was lucky enough to be teaching a level II HSS course and I interacted extensively with third and fourth year students. I realized that I would not find that level of interest in literature and the kind of engagement with it among students anywhere else.

NERD: Students respect you for the way you have taken many HSS I and II level courses, and you recently received the Gopal Das Bhandari Memorial Award. What pedagogical techniques adopted by you make you so different?

Dr. Mathur: I am very honoured to receive the award and would like to thank the outgoing batch for it. Frankly, I am not so sure about the idea of being different. The teaching culture in this institute is another distinguishing feature of IIT Kanpur and fortunately, there are many excellent teachers on the campus in all departments. I have learnt from the pedagogical techniques used by various faculty members and the informal feedback by students in the class.

I think of the classroom as a place where learning takes place. That may sound obvious, but I want to distinguish it from teaching taking place, because I think of teaching as more of a one way activity where it is assumed that somehow

knowledge can be delivered by an individual standing at one end of the classroom to a bunch of students sitting at the other end. I am not denying that this happens – it can happen effectively. I got educated in that system, but I have felt over time that a more interactive classroom where teachers and students are engaged in learning in an active fashion as a mutual enterprise is more exciting. I believe that learning takes place through active participation; and I have tried to implement this in my courses as far as possible.

NERD: Please tell us about some of your most interesting experiences in the classroom.

Dr. Mathur: Classroom experience for me is defined by interaction with students, and I would divide these into rewarding on the one hand and stimulating on the other. Rewarding is where an experience of learning takes place – the excitement you see in students is immensely gratifying. For instance, in a course I teach on feminist theory, many a times the students have had the sudden realization as 'Oh! This is what is meant by gender issues in our everyday lives' and thus linked up what is being learnt in a course with their own lives. Examples of stimulating experiences have been from courses in which I have looked at science fiction, and we have had the most exciting discussions on how we define science and what qualifies as science etc. I have learnt so much from my students through such discussions.

"I think of the classroom as a place where learning takes place, and this is different from teaching taking place."

NERD: Coming to your research areas, can you please explain what is popular culture studies all about and what have you been working on?

Dr. Mathur: Popular cultural studies is a specific subset of cultural studies. In humanities and social sciences, we generally look at society and culture through specific lenses, say the sociological lens, the psychological lens, the literary lens etc. Cultural Studies tends to bring it all together to examine the way in which we live, and tries to give a definition of culture and its function in society through an interdisciplinary perspective to understand why we do what we do. Cultural Studies, in this sense, becomes the study of the everyday, of things that we take completely for granted. Let me give you a concrete example. On our campus between 7 and 9pm, you will see many people out on the street 'taking a walk'. Now this common everyday practice is also a cultural activity. Asking questions like what are the antecedents of this activity, how is it culturally specific, what are the differences in the idea of an 'evening walk' and 'walking as an exercise', how does it really relate to the socio-economic context within which we live and act – this would be a cultural studies project.

Now within this field, popular culture is defined in two very different ways. One is in terms of mass consumption - such as studying the music industry, film industry or the comic-book industry. The other way is its link to folk culture. Folk culture and its study has a longer tradition in India and abroad, but mass culture studies is relatively new and is facing challenges in getting established as an academic discipline because things for mass consumption are assumed to be too banal to be worthy of study. We have the idea of 'high culture' and 'low culture'; but popular culture studies intervenes in this by saying that so -called 'low' or popular culture is also worthy of study, with a different perspective though. When I study high culture, say classical music, it is with the idea of understanding and developing an appreciation for it, but is it the same with, say Hindi cinema? Probably not, but I can understand it in terms of the effects it has and the role it plays in shaping Indian society. So, popular cinema starts being treated as a product here – an example of a cultural commodity; and popular culture studies understands how cultural commodities circulate in a society.

Recently, I have become involved with Indian science fiction being written in English - looking at what is being produced and how it engages with the definition of science especially within the Indian context. Again, things like science fiction are not considered 'high literature' often; hence it falls into popular culture. One reads Asimov and doesn't think of it as reading literature. One reads 'Literature' when one reads Shakespeare! <Smiles>

NERD: You have also been active in science fiction, and you organized a summer workshop related to the same in 2009. How did you get interested in science fiction?

Dr. Mathur: Completely because of my students here. I enjoyed science fiction, but I have never been a huge fan. I grew up reading Asimov, I was a Star Trek fan; but I never, in my remotest dreams, thought of it as a field of study until I came to this campus and started interacting with students. Occasionally, a science fiction book

would become a part of the literary discussion group and the kind of discussion it evoked was very exciting to me. That's partly how I got into it. Also, I felt science fiction to be a way of connecting with a student body that is so deeply rooted in a science culture.

NERD: Fiction is a manifestation of storytelling or narrative. What are your views on fiction as a medium for popular communication of science? How can the teachers of science at different levels incorporate the feature of narrative in their lectures?

Dr. Mathur: Narrative is very fundamental to the way in which we think and function. Fiction is a very small part of narrative. If I ask you a question as simple as how was your day, the answer you would give will be a narrative, a story. You will organise the events in a certain order and tell them in a certain fashion. That's what narrative is – an arrangement of events in a certain sequence to convey a certain meaning. Hence it can be used for absolutely any kind of activity. It is one of our most fundamental human instincts to tell stories. Therefore, if it is included in pedagogy, it will be very exciting because we have all grown up listening to stories, and it is something that interests us. Thus, it can make teaching much more meaningful to everybody; and I think it can be done quite easily. In fact, many students have taught me science through storytelling and I have found it very exciting. Recently, my twelve year old nephew was visiting me and I used the word 'fractal' in some context. He asked me what that was, and I found myself repeating a story definition of fractal which a student had once given me. That is how deep an impact narrative makes on our memory and understanding.

NERD: Which science fiction works (books or movies) would you recommend students to follow?

Dr. Mathur: Actually, it has been mostly other way round. Students have recommended science fiction movies and books to me. One science fiction author I do admire a lot is Ursula Le Guin. She writes what I would call speculative fiction rather than pure science fiction. When we think of science fiction; we mostly think of space travel, aliens or artificial intelligence, but what has attracted me to science fiction is the speculative tendency in it, i.e. giving new ideas about the world we live in. For example, had the force of gravity been six times stronger, how would society have restructured itself. I am very fond of such speculative fiction which gives a broader meaning to what science is. One of my favourite stories is about a woman who uses a snake to cure patients exactly as you would use an injection. Among Indian authors, I admire Amitav Ghosh's 'Calcutta Chromosome', and the work of Manjula Padmanabhan.

NERD: Please tell us about the initiative you have been leading - Literary Discussion Group.

Dr. Mathur: The Literary Discussion Group started in the very first semester I was here. Three students came up to me after the class and suggested forming a group where they could just sit and discuss books; and that is how it began as we started discussing books over weekends. It remained a completely informal group, never becoming part of any Gymkhana club. We realized the need for funding only when we wanted to invite an author from Delhi for a talk. Then we approached the Centre for Creative Writing and Publication (CCWP), which has since then been an official sponsor of LDG. What amazes me is that it has continued for such a long time. It has given me a great deal of satisfaction because of its informality as it is a forum where the entire campus community can get together over shared literary interests.

NERD: CP Snow, the famous British novelist and surgeon, in 1959, said "People belonging to science and humanities are mutually incomprehensible". Has your experience at IIT Kanpur been of a similar kind?

Dr. Mathur: No. These are very stereotypical notions and of course, occasionally you may find people with similar notions on this campus as well, but I have had no such experience. Although some may ask why we have an HSS department at all, in the Institute our department functions not as an adjunct department having second class citizenship, but as one which is central to the institute. Also, students often take HSS courses voluntarily as open electives and do projects with HSS faculty members too.

Also, I believe that mutual incomprehensibility has less to do with specific disciplines than with how one thinks of one's discipline. If I discuss literature in a highly specialised manner and a person from philosophy talks exclusively in the specialised vocabulary of philosophy, we can be mutually incomprehensible much more so than I would be to a biologist; hence it has more to do with how rigid the boundaries are which one draws around one's discipline.

NERD: We have been hearing about various attempts for a course on communication skills for students. Being a member of Academic Review Committee (ARC), please inform us of some previ-

ous and proposed attempts to teach communication skills to students.

Dr. Mathur: I have a very difficult and complicated relation with the term 'communication skills'. During my eleven years at IIT, there was one attempt to teach 'communication skills' here - COM 200 and it survived for four years. It was a semester long course in the third semester to teach various kinds of communication skills. I don't think anybody was really happy with it – students, faculty or the administration. The fact that it's no longer running speaks for itself.

"Reducing communication skills to the ability to converse fluently in English is a very reductionist approach."

When discussions happened in ARC, it was felt that communication skills are something important that our students lack and hence a sub committee was formed to look into this idea. The subcommittee report is available to all, so I would not comment further on that. But in my individual capacity, as someone who has taught the COM 200 course and has been engaged with the problem of 'communication skills', I will say that I find it difficult to accept communication being reduced to a skill, thus implying that one can get a toolbox which one can just mechanically put to use. I believe that this is a wrong approach to communication. First, we have to figure out what kind of problems one faces with regard to communication. Reducing communication skills to the ability to converse fluently in English is a very reductionist approach.

NERD: As you rightly pointed out that communication skills are often confused with English speaking abilities. What, in your opinion, is the reason behind this narrow thought among students, faculty and parents?

"I think it is inexcusable that a science and technology institute offers no course on the history of science."

Dr. Mathur: Cultural cache. If you speak English fluently, you are seen as a more 'cultured' person, as someone with a 'good personality', and this, of course, has to do with our colonial background. People believe that the language of power is English, so if they want power (which usually translates into earning capacity), they have to be fluent in English. It is simply a way to get oneself into a powerful moneymaking position, especially in the corporate world, and, unfortunately, for a lot of people, that is the only focus.

NERD: You are also a visiting faculty at IIT Gandhinagar. Coming from an institute that has a history of HSS since its inception, what suggestions would you give to upcoming science and technology institutes in setting up their HSS departments?

Dr. Mathur: I believe that HSS departments set up at any science and technology institute have to be thought of in a more integrative fashion. I really wish that they would not be called HSS departments because this name itself carries the idea of compartmentalized disciplines along with it. I think new institutes should adopt the approach of what might be called cultural studies, i.e. recognizing that the disciplines function very much in conversation with one another, so that science and technology are integrated with humanities and social sciences to form a truly interdisciplinary curriculum. For example, I think it is inexcusable that a science and technology institute offers no course on the history of science. Does science function in a vacuum without any connection to history or society? It does not and hence inculcating such an idea is nothing short of academic negligence.

NERD: You have been very active in student activities and festivals, and hence in close connection with the student body. What changes have you observed in the student-faculty interaction over the last ten years?

Dr. Mathur: Student-faculty interaction has suffered a huge loss and this is very sad. It spells disaster for the institute. Efforts should be made from both sides in every way possible to bridge these gaps. We need to have repeated conversations amongst ourselves within the two groups, with each other, and be honest in trying to pinpoint the causes and come up with solutions.

NERD: You have been actively involved with the effort to ensure payment of minimum wages and other fronts related to labour rights. What motivates you to work for that section of the society?

Dr. Mathur: The institute has three pillars - students, faculty and staff - but they are not equally weighted. The place would not function for an hour without the workers. Starting from the construction of the lovely building we inhabit to equipment management to maintaining the greenery of the campus and so on, it is the workers who make everything we do possible, and to

ignore them is criminal negligence. So, my decision to be involved goes back to my firm belief in democratic traditions. If I am living in a community, I cannot turn a blind eye to any part of the community, especially a part that is so absolutely essential to my survival.

NERD: How would you describe Dr Suchitra Mathur in one line?
Dr. Mathur: Shouldn't that be left to others? Honestly, I can't give you that one word or line! It depends on my mood and relationship with myself which keeps changing with time! <Laughs>

NERD: What final message you have for the students?
Dr. Mathur: I have a problem with the whole idea of 'giving messages'. How about leaving it at the idea, the hope, that we keep having such conversations? Such dialogue and interaction are what make the campus what it is and allow learning to take place.

Mohit Kumar Jolly (mkjolly@iitk.ac.in) is an M Tech student in the Department of Biological Sciences and Bioengineering at IIT Kanpur. He is interested in science communication and co-founded NERD, the campus science and technology magazine, in 2008.

Swapnika Reddy R (swapnika@iitk.ac.in) is a third year undergraduate student of Economics. She is passionate to learn a lot about Applied Microeconomics, Strategic Interaction and Behavioral Economics. Her other interests are classical music and reading History.

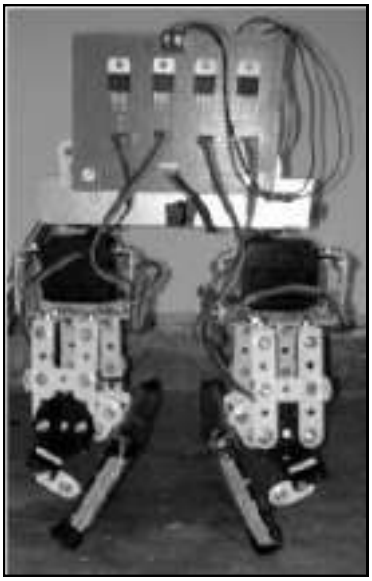
This interview is the transcript of an audio interview with Dr. Mathur, taken for IIT K 90.4 FM. It was transcribed by Swapnika Reddy R and Sayak Dasgupta.

Note from the General Secretary, Science and Technology Council
Through the following three articles— Bipedal Bot, Cracking the Rubik Cube and Rubik's Cube Solver Bot– we give you a glimpse of the projects done in various clubs of the Science and Technology Council. We, at the council, try to innovate and implement your wildest ideas by supporting you with funds and technical help. A reflection of this can be seen in the projects done by students (mostly from the 1st year) in summer vacations where they fabricate their dream projects. "I don't believe, I find out" is the spirit we encourage! See you all with more projects to enthuse you in coming issues of NERD.

Bipedal Bot

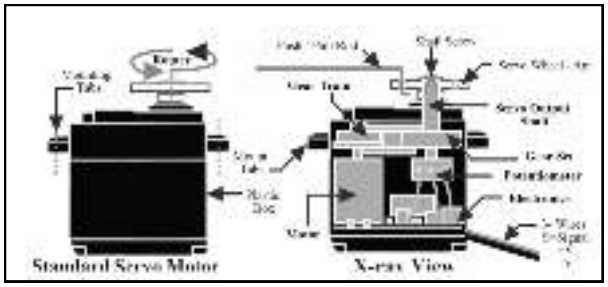
Aditya Prasad

Introduction
You must have seen the movie 'Star Wars' where robots moved just like human beings, i.e. on two feet. Such robots that can walk on two legs without any external support for balancing are known as bipedal robots. Let me talk to you about a robot we made. Our robot has two degrees of freedom of movement per leg – it cannot bend on its knees, i.e. its vertical motion is limited; but it can move and turn easily.



What is the main aspect of producing a "stand-and-walk-on-two-legs" phenomenon? Maintaining balance - be it walking on a slippery surface or an uneven terrain. Our robot can balance itself just like a human being (except bending on knees) and is hence much more versatile as compared to other usual wheel based bots because its base level is not fixed – it can raise itself on a higher terrain (Just as you peep above the wall!) by raising its ankle. But, balancing gets much more complex involving gyroscopes, accelerometers, etc. if the robot has to be designed to run as well, hence we avoided it.

Each leg of our bipedal has the hip joint and the ankle joint but not the knee joint, thus the robot can rotate its each leg about the hip joint with an axis passing vertically along its body, and also about the ankle joint with an axis perpendicular to its length and going into its plane.
This setup allows our robot to lean on one leg through the ankle joint and then rotate the other half of its body in forward direction. This sequence is symmetrically repeated by the other leg to complete one step of forward motion of the robot.



Why did we design a bipedal at all? To achieve the motion of a joint through the use of servo motors; by developing the electronic circuit, building the mechanical structure and programming the ATmega16 microcontroller and synchronizing the motion of the two legs.

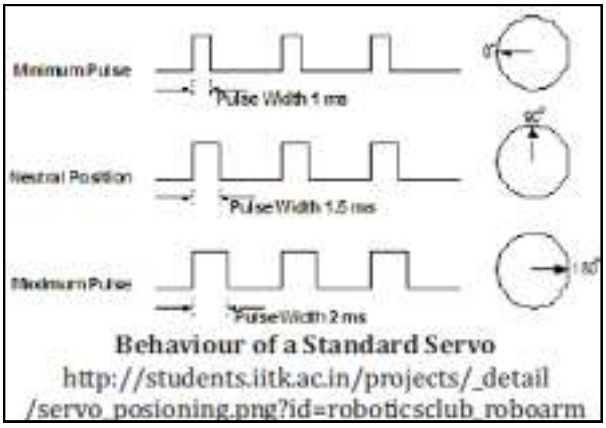
As most of you may know, ATmega16, the brain of a robot, is a microcontroller which has the same role in a robot just as that of Intel microprocessors in our personal computers. We used ATmega16 to control servo motors.

Basics of servo control

Now, let me take you through the basics of servo control. A servo motor is used to get precise rotation in terms of angle. It can align its shaft accurately to any angle between its minimum and maximum value (usually -90 degree and +90 degree respectively). It uses error-sensing negative feedback to correct the performance of a mechanism. It contains a DC motor linked to a position feedback potentiometer, gearbox, electronic feedback control loop circuitry and motor drive electronic circuit.

A servo motor has a speed, torque and power as its attributes. Servo speed is defined as the time (in seconds) in which a servo arm attached to the output shaft will move from 0 to 60 degrees. Servo Torque, measured in kg-cm, is the total push/pull power a servo can apply on a 1cm arm when moving; and servo power is defined as the amount of DC voltage needed to operate a servo without damage.

Each servo motor comes with a three pin connector - first pin for VCC (Positive terminal), second

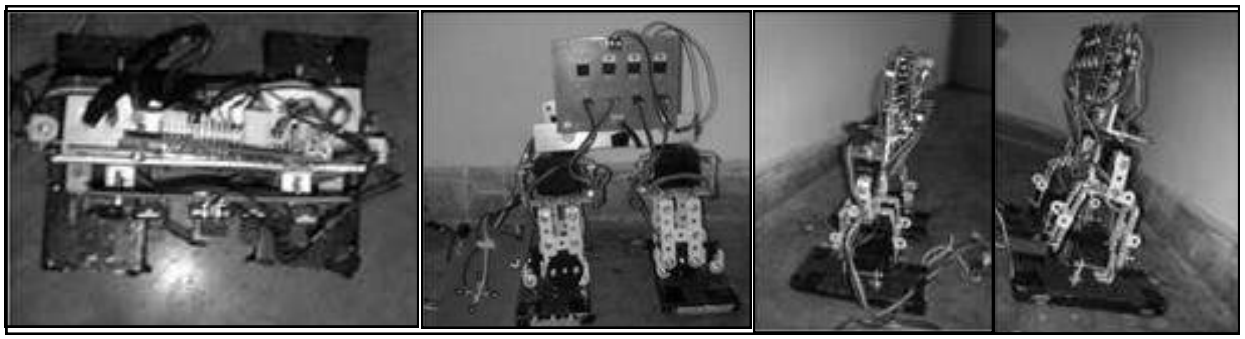


Behaviour of a Standard Servo

http://students.iitk.ac.in/projects/_detail/servo_posioning.png?id=roboticsclub_roboarm

pin for GND (Ground terminal) and the third one for a PWM (Pulse Width Modulation) signal, which is the input for the orientation of the servo shaft.A PWM signal is a clock signal of a fixed frequency but variable duty cycle (ratio of duration of positive amplitude of the wave to its time period). The standard DC servo we used in this project had the clock frequency of 50Hz (i.e., time period of the clock = 20ms), and duty cyclebetween 5% and 10% (5% for -90degree and 10% for +90degree).

Here comes the role of ATmega16 which produces clock signals of different frequencies. The PWM signal we required could have been produced using 'Timer-1' (16bit) of ATmega16 in 'Fast PWM modetop=ICR1', but we had to control4 servo motors simultaneously; and the fast PWM mode can control only one motor at a time. Hence, we would have required 4 microcontrollers and synchronization among them – that would have been very complex and impractical. We solved this problem by producing custom made timer derived from Timer-0 of the microcontroller. We set the timer-0 to the frequency of 20 kHz and enabled the interrupts. An output pin was used to produce the clock signal by counting the number of interrupts and changing the logical state at required intervals. Theoretically, this configuration should give an angular least count of 9 degree for the servo motor. But, when the above



Top View	Front View	Profile Views

setup was put to application, the servo deviated from its predicted behavior about the duty cycle, and its least count decreased to 4.5 degrees. Thus, this method of servo control (by using custom made derived clocks) proved to be very efficient for us. In fact, it can control upto 31 servo motors simultaneously using the Timer-0 of a single ATmega16 microcontroller.

Electrical and Mechanical Parts

We used printed development board for ATmega16 and STK500 programmer. The servos were given power using 7806 IC because the servo provided more torque when operated on 6V instead of 5V. The only problem faced we faced was that the current requirement of the circuit exceeded 5A which is usually the limit of general power supplies. We solved it easily by using ATX Power Supply that provided 10A current and 12V voltage which was perfect for us. The mechanical structure was built mainly by using readymade parts like angles and hinges from the game set of 'MECHANIX'.

Synchronizing the motion of the legs

Here we implemented the theoretical programming into practical motion of the robot. The actual code for the forward, left and right motion was very different from what we theoretically predicted. The motion of the bot was very sensitive to the nature of the surface and to any change in the angle of inclination of the thigh servo (the motor that controlled the hip joint) in both the legs. So, the thigh servos were set to an optimum angle and a final code was prepared using experimentation, by observing the motion through different codes.

But either leg was not able to instantaneously lift the other one while moving. To solve this, we decreased the speed of servo but it did not help the cause completely. So, we changed the code and now instead of lifting the leg, we relied on leaning on one leg and dragging the other one. Due to some possible asymmetry in the two legs, the left and right turns were not similar. So, different codes were used to implement both turns. This worked well and the only problem remaining was the different speeds for the turns. You can see the final statistics about the robot we made as given below:-

Speed of forward motion :1"per forward sequence
Speed of left turn : 3 cycles for 90 degree turn.
Speed of right turn : 4-5 cycles for 90 degree turn.

Useful Links

http://students.iitk.ac.in/projects/roboticsclub/bipedal
http://www.youtube.com/watch?v=hdOxSISoV3o

About the author

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Cracking the Rubik's Cube

Only the most hardcore puzzle-solvers ever go beyond the standard 3x3x3 Rubik's cube, attempting much larger ones such as those pictured on the right. Now an algorithm has been developed that can solve a Rubik's cube of any size. It might offer clues to humans trying to deal with these tricky beasts.

Last year, a team led by programmer Tomas Rokicki of Palo Alto, California, showed that even the most scrambled standard Rubik's cube can be solved in 20 moves or less. That feat is a big deal: the figure has been dubbed 'God's number', the assumption being that the Almighty couldn't solve it faster. But it didn't shed light on the monster cubes. So Erik Demaine, a computer scientist at MIT, set out to find a general algorithm for solving a cube with any side-length – of n squares. He started by looking at a method Rubik's cube enthusiasts commonly use to quickly solve the puzzle. Essentially, you try to move a single square, or 'cubie', into the desired position while leaving the rest of the cube as unchanged as possible, but some other cubies, of course, get disturbed. Thus, this method is time-consuming, requiring a number of moves that is proportional to n^2. But there is a short-cut based on 'cubie paths'. Each cubie has a particular path that will place it in the correct position. Demaine's algorithm looks for cubies that all need to go in the same direction, then moves them at the same time. Instead of solving one cubie at a time, it solves several of them. Grouping cubies with similar paths reduces the number of moves required by a factor of around log n. This means that the maximum number of moves that will be required for a cube of side n now become proportional to $n^2/\log n$.

Figuring out a single cubie's path without a computer is no easy task, let alone doing it for the whole cube, so it's unlikely that humans will be able to directly apply this formula. But Demaine reckons it could offer cube-solvers a few tips. It's possible that some of the techniques behind the algorithm could be applied to speeding up other problems that involve searching or sorting through sets of data with a similar mathematical structure to the cube.

So has the Rubik's cube given up all of its secrets? No. The algorithm only gives an approximate value for the number of moves required. Another puzzle remains to be cracked as well. The current algorithm only finds the most efficient way to solve a cube if it is in the most scrambled state possible. Does an algorithm exist for finding the number of moves required by less-scrambled cubes? Suppose I take a solved 20x20x20 Rubik's cube and make five moves - can you figure out [from that scrambled state] what those five moves were? In other words, can you solve it in five moves? It is suspected that it can't be done but this is yet to be proven.

The next task is to find an algorithm that can solve any 4x4x4 cube in the fewest possible moves. "It would probably take more CPU time to solve a single random 4x4x4 position than we used to prove God's number for the 3x3x3."

If you are keen on learning more about cubes and their eccentricity, we welcome you to the Rubik's Cube Hobby Group (RCHG) - a student group under the S&T Council which conduct workshops in the institute on various cube related puzzles.

Rubik's Cube Solver Bot

Anuj Agrawal and Deepak Pathak

"It was wonderful, to see how, after only a few turns, the colors became mixed, apparently in random fashion. It was tremendously satisfying to watch this color parade. Like after a nice walk when you have seen many lovely sights you decide to go home, after a while I decided it was time to go home, let us put the cubes back in order. And it was at that moment that I came face to face with the Big Challenge: What is the way home?" - Erno Rubik

Introduction

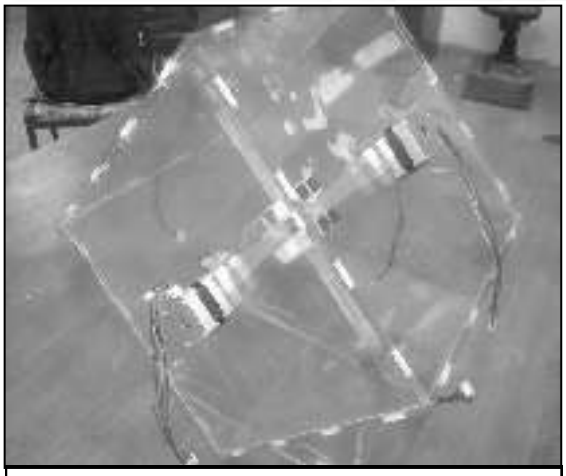
One eighth of the world's population has laid hands on 'The Cube', the most popular puzzle in history and the colorful brainchild of Erno Rubik. Erno Rubik was born in Budapest, Hungary during World War II. His mother was a poet, his father an aircraft engineer. Rubik studied sculpture in college, but after graduating, he went back to learn architecture at Academy of Applied Arts and Design.

Erno Rubik

Rubik's initial attraction to inventing the Cube was not in producing the best selling toy puzzle in history. He was interested in the structural design problem- "How could the blocks move independently without falling apart?" Rubik's Cube is made of twenty-six individual little cubes or cubies. Each layer of nine cubies can twist and the layers can overlap. Rubik's initial attempt to use elastic bands failed, his solution was to have the blocks hold themselves together by their shape. Rubik hand carved, assembled the little cubies together, and started twisting. That was how the Cube as a puzzle, was invented in the spring of 1974, when the twenty-nine year old Rubik discovered it was not so easy to realign the colors to match on all six sides. He was not sure he would ever be able to return his invention to its original position. He began working out a solution, starting with aligning the eight corner cubies and within a month, he had the puzzle solved and an amazing journey lay ahead.

Stepper Motor

We've all tried solving a Rubik's Cube and a few of us may have solved it at least once in our lifetime. All of us know how hard it can get to solve it. After all there's just 1 correct solution and 43 quintillion wrong ones for a Rubik's Cube, or 'Magic Cube'! For humans it may be a tough job but certainly not for computers. Well, if you are thinking of brute forcing all those 43 quintillion possible permutations with a computer - that is not the answer. Thanks to some wonderful recent research, any given permutation of a Rubik's cube can be solved within just 20 steps! And it's the God's algorithm that solves the puzzle in the least number of moves.



The final mechanical structure

We present to you our endeavor in designing and implementing an autonomous machine capable of solving a Rubik's cube given in any possible state. Our idea was to design a mechanical setup on which six stepper motors (electromechanical devices that convert electrical pulses into discrete mechanical movements) can be mounted, each of which would be connected to the centre of the six faces of a Rubik's cube, thus allowing all the six faces to rotate independently. The mechanical setup contains an unsolved Rubik's cube. We used a camera to take the input of the colors of a scrambled cube and then feed the information to a computer program that analyzes it and generates the sequence of steps required to solve the cube. The sequence is then sent to a microcontroller that drives the steppers accordingly with the help of motor driver ICs and hence, the cube is solved.

Shaft alignment and attachment

Design

The work done during the project can be categorized under three sections-

- *Mechanical Design*
- *Programming*
- *Electronics*

Mechanical Design

Mechanical part was undoubtedly the most demanding aspect of the bot. We needed precise 90° rotations of the faces of the Cube, for which we used high torque stepper motors. The biggest mechanical problem we faced was in the alignment of the six shafts of the motors. Successful operation of the robot required the opposite shafts to be in a straight line, at an angle of 180°; but this level of precision was hard to maintain owing to the manual mounting of motors and shafts and the constant need to dissemble the outer acrylic cube to solve the inner Rubik's cube while testing process. The non-uniform force and torque distribution generated on all sides due to this improper alignment hindered the rotation of faces; sometimes preventing precise 90° turns. In a sequence of, say, 200 steps of rotations, even if one step to make a precise 90° turn fails, the orientation of the cube gets distorted, thus preventing any further steps. The problem has not yet been solved but we are working on it.

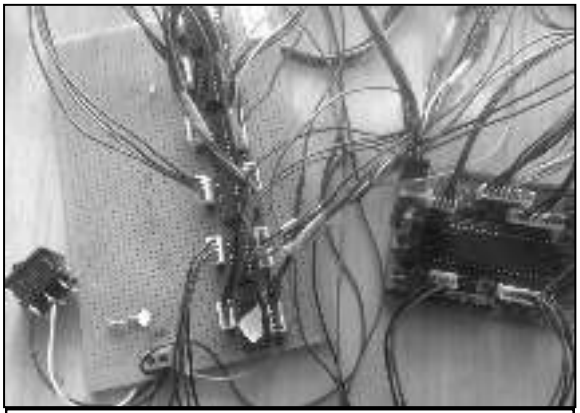
We made our outer frame and the shafts of the motors of acrylic sheet. We prepared AutoCAD drawings for all the parts of the mechanical structure and got them fabricated using the 4I Lab. The final picture of the completed mechanical structure is shown below.

Programming

Programming part was like the backbone of the project. It was basically divided into two parts.

Image Processing- We used a simple web camera to take snapshots of the six faces of the scrambled cube, processed the images using Open CV, and stored them in the RGB (Red, Green and Blue) format. We then analyzed the content of Red, Green and Blue color in the pictures, thus determining the nine colors on each face of the cube. So, the colors of all cubies of the Cube get recorded and stored in an array.

Solving Algorithm - There are hundreds of algo-



Atmega 32 connection with motor driver

rithms available on the internet for solving a Rubik's cube. The faster an algorithm is, the more difficult it will be. As of now, we have been able to implement a method used by blind solvers, the Pochmann Algorithm, which takes about 200 steps to solve a cube. We take the array generated in the previous step as an input to this program and the program outputs another array containing a sequence of characters R,L,F,B,T,D,1,2,3,4,5,6. This denotes the order in which the motors have to be driven. R stands for a 90° turn of the right motor clockwise and similarly for others. Numbers stand for anti clockwise turns. This code runs on a laptop, and this array is then transferred to the microcontroller, the brain of the robot.

Electronics

Controlling the stepper motors, the microcontroller and the communication between computer and microcontroller were the three major tasks of the electronics aspect. We used the microcontroller ATmega32 as it was sufficient to drive six stepper motors simultaneously. It was programmed through STK500 Serial programmer.

We used the stepper motor because they can be accurately controlled in an open loop system, i.e. no feedback information about the current position is needed. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

There are three types of stepper motors based on construction – Variable Reluctance motor, Permanent Magnet motor and Hybrid motor. We used the Permanent Magnet motor, whose rotor has no teeth but is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity thereby higher torque.

Based on the design and working, stepper motors can be bipolar or unipolar. The bipolar motor needs current to be driven in both directions through the windings, and a full bridge driver. But the unipolar has a center tap on each winding that allows a simpler driving circuit limiting the current flow to one direction. The main drawback with the unipolar motor is its limited capability to energize all windings at any time, resulting in a lower torque as compared to the bipolar motor. Unipolar stepper motor can be used as a bipolar motor by disconnecting the center tap. We used unipolar motors for our project.

A stepper mode can be driven by three most common drive modes - Wave Drive (1 phase on), Full Step Drive (2 phases on) and Half Step Drive (1 & 2 phases on). We implemented the half wave drive in our motors in order to get exact 90° rotation. It took around 13 loops of the half wave drive in attaining one fourth i.e. 90° rotation.

Future Scope

A lot needs to be worked upon still! Currently, our robot is not as efficient as we would have wanted. The mechanical flaws can be worked upon thus lowering the probability of lock-ups while turning the cube. The Pochmann Algorithm takes too many steps to solve the cube. Using better algorithms especially designed for cube solving by computers like Thistlewait's Algo(52 steps max) or Kociemba's Algo(22 steps max) will reduce the number of steps thus making the robot work fast. Stepper motors can also be controlled more easily and efficiently by changing the motor driver. Last but not the least, a better quality Rubik's cube, probably a Lingyun Dayan, maybe installed in the bot. These cubes have better edge cutting properties and rotate very smoothly.

Team Members

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We feel privileged to be given a chance by the Robotics Club, IIT Kanpur to take up this interesting summer project. Working during the summers not only enhanced our technical skills but also taught us the importance of team effort. We thank the Co-ordinators of the Club for their constant guidance, and special thanks for Subhash Sir at the 4i-Lab, who patiently worked with us on the Water-Jet machine for hours to get our parts fabricated.

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Are you game for a, nay, for THE RACE?

Updates from IIT Kanpur Motorsports

There could not be better news for an automobile enthusiast in campus! This year IITK Motorsports team is all set to design, build and race an open-wheeled formula race car for the FSAE-2012 competition to be held at Silverstone Racing Circuit, UK. FSAE or Formula Society of Automobile Engineers is a part of the collegiate design series created by the Society of Automotive Engineers (SAE) in 1978. It is one of the most challenging and hotly contested international engineering competitions at undergraduate level and is held every year at a different venue. This will be the FIRST time for IITK to be a part of FSAE competition!

What is the FSAE Challenge exactly?

(1) Based on a strict guidelines set by SAE, a team is required to design the fastest, most effective racing machine possible while keeping the costs minimal, maximizing the reliability, and utilizing the latest technologies in racing today.
(2) The team required to qualifying engineering events during the competition.
(3) It also has to make Cost Report and Sales Presentation and market the car to a panel of prospective buyers. An aspect of engineering often overlooked by us students: serve the consumers too!

Our Design Goals

(1) Design and build an open wheel, open cockpit formula style race car with high performance in acceleration, braking and turning around a corner (cornering).
(2) Keep the mass of vehicle under 180 kg approx.
(3) Ease of manufacturing and clean packaging
(4) Have a well tested car ready in time for competition at Silverstone

We are recruiting!

Yes! We have openings in ALL divisions of the team: Suspension and Steering, Engine, Chassis, Manufacturing, Brakes, Power Train, Supply Chain and Marketing. As this is a big project we need students from all the discipline, who will be engaged in engineering and project management. Although everyone's invited, the focus is on UG and PG freshmen keeping in mind the long term goals of sustained annual participation in FSAE from IIT Kanpur and development of an automotive engineering culture in the student body.

General Info for freshmen

(1) Open for students of all departments.
(2) No technical prerequisites (in the beginning). Just put some passion for motorsports in your fuel tank and join us! An introductory lecture series will be conducted to familiarize you with the most important technical aspects.
(3) 2011 freshmen will start work from scratch for FSAE-2013 while they will learn from seniors working on FSAE-2012 car. This will give them full opportunity to express themselves.
(4) Note that to participate in FSAE competition, student has to become member of SAE International (www.sae.org). This formality will be taken care of by SAE IITK Executive Council.

Contact

You can find us working in Design Program Lab (located next to Aerospace Building and our hub for all discussions and manufacturing) and in Autodesk Lab (located between two drawing halls, our center for CAD modeling) after 9:00pm. Or you can contact Rohit Arora (arohit@iitk.ac.in), FSAE Team Captain, IIT Kanpur.

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