ICTS Permanent Address
Survey No. 151, Shivakote village, Hesaraghatta Hobli, North Bengaluru, India 560089
Website www.icts.res.in

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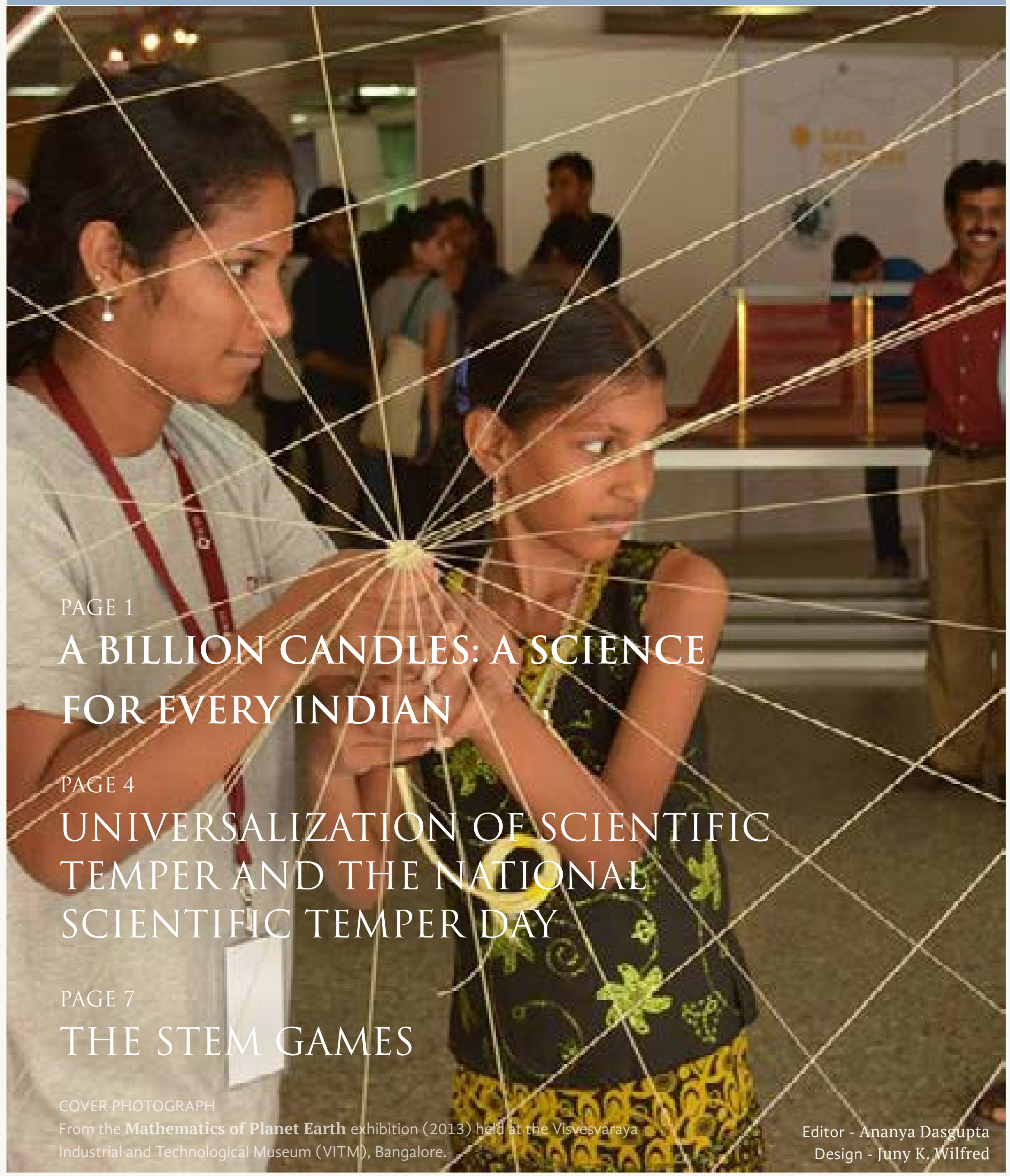

COVER PHOTOGRAPH
From the **Mathematics of Planet Earth** exhibition (2013) held at the Visvesvaraya Industrial and Technological Museum (VITM), Bangalore.

Editor - Ananya Dasgupta
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A BILLION CANDLES: A SCIENCE FOR EVERY INDIAN

MUKUND THATTAI

It is a truism that basic research leads to technological and economic progress. Governments and the public have come to see all of science through the lens of applications. This is short-sighted: in a democracy, science is a public good for a multitude of reasons.

The astronomer and author Carl Sagan spoke of science as a candle in the dark: a way to push back ignorance and uncertainty, a way to discover truths about our world and chart our way forward.

In the wake of the Bhopal gas leak of 1984, reacting to the horror of the deadliest industrial disaster in history, a collection of grassroots groups across India assembled to talk about the future. These groups, some of whom had existed for decades, were dedicated to spreading awareness of science and its fruits, in schools and town halls, through street theatre performances, and in vernacular media. Their members, mainly non-scientists, were driven by conscience and idealism. They saw a role for science in the literacy and anti-superstition efforts of the era, but also knew the limits of a science divorced from society. In 1988 they came together to form the All India People's Science

EDITOR'S NOTE

ICTS is an internationally competitive centre of theoretical research and innovation located in a developing country with huge economic responsibilities related to providing a minimum level of education, health and general welfare for its citizens. How can public funding of world-class scientific research be justified in the Indian context? What are the key benefits of curiosity-driven research, and the resultant scientific culture, to a country like India? Can we quantitatively model the growth of the Indian scientific community and its impact on our country? In this issue of ICTS News we take a break from our usual fare of articles on recent advances in science to address these important questions. ■

Network, perhaps unique in the world in its reach and depth. The Network continues to be active today, teaching and popularizing science, mobilizing thousands of people in cities and villages, intervening in public discussions about issues ranging from genetic modification to forest loss.

This is one way in which the flame of science burns in contemporary India. Yet it's not the aspect we usually talk about.

Stories about Indian science tend to focus on big-bang contributions. We're told about the ancient invention of zero, the linguistics of Panini, the medical treatises of Charaka, and the astronomical calculations of Aryabhatta. A parallel technological narrative runs from ancient textiles and rustproof metalwork to modern armaments such as the Mysorean rockets used by Tipu Sultan against British East India Company forces. We celebrate the work of Srinivasa Ramanujan, J. C. Bose and C. V. Raman in British India. Stories of science in independent India are no different. The Green Revolution of the 1960s, which increased India's agricultural capacity manifold, made M. S. Swaminathan and Norman Borlaug household names. India's pride at being able to loft spacecraft to Earth, Moon and Mars orbits has made heroes of the men behind the Indian Space Research Organization, Vikram Sarabhai and Satish Dhawan. A.P.J. Abdul Kalam was India's 'Missile Man,' and later its President. Homi Bhabha was revered throughout India's scientific and political establishment; it was through his efforts that the country eventually joined the club of nuclear powers in 1974.

But these singular achievements are not universally celebrated. The genesis of the All India People's Science Network echoed the traumatic experiences of a previous generation, when the Hiroshima bomb triggered mass movements against the proliferation of nuclear weapons. The Green Revolution has all but petered out: growth in agricultural yield is slowing, India's farmland is increasingly too saline to be usable, and the total cultivable area is dropping. The country now faces irreversible environmental degradation and loss of wildlife, a water crisis with no solution in sight, and massive displacements of people, all as a consequence of the post-independence push to industrialization. This is the people's history of Indian science, and it stands in direct contrast to the great-man narrative.

Panini is known as the 'father of linguistics'; Aryabhatta, the 'father of astronomy'; Swaminathan, the 'father of the Green Revolution'; Sarabhai, the 'father of India's space program'; and Bhabha, the 'father of India's nuclear program'. Indian science has many fathers, no mothers to speak of, and a billion neglected children.

Why does India support science as a publicly-funded enterprise? The country's total expenditure on research, including contributions from industry, has for years held steady at about 0.7% of GDP according to the Indian Government's Economic Survey of 2018. This is much lower than the 2-3% of GDP that China, the U.S., or Germany spend. However, India's rate of public investment in research is 0.5% of GDP, comparable to that of more wealthy countries. Investments on this scale can only be politically justified if they are targeted toward areas of national importance, such as defence, agriculture, and health. What about the argument for public investment in more basic research? This is often based on Vannevar Bush's 1945 report to the U.S. government, 'Science, The Endless Frontier'. Bush knew that the Manhattan Project and other major scientific achievements of the U.S. war effort relied on apparently useless discoveries of earlier decades. He argued that basic research would yield sustained technological and economic dividends, and therefore should be supported by public funds.

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Enlightenment science in the West, with its curiosity-driven ideal, was done by a small set of men who enjoyed the patronage of the wealthy or the monarchy. It later borrowed the trappings of academic rigor from philosophers and historians: practices such as the sharing of work in learned societies, peer review of research findings, and formal apprenticeship of students in universities. During the Industrial Revolution science continued within the walls of academia, while technology progressed through the labours of practical men in the outside world. However, as scientific predictions became more reliable and therefore useful to the process of invention, science and technology started to intertwine. This process culminated in the massive projects of World War II, giving us radar, transistors, computers, atomic energy, and Bush's fateful social contract. The hyphenation of science-and-technology has never been reversed since. In the post-war era governments have become the single largest funders of science across the world.

In newly-independent India science was practiced within universities, in the new engineering-centric teaching institutions such as the Indian Institutes of Technology (IITs), in the application-oriented laboratories of the Council of Scientific and Industrial Research (CSIR), and in basic research institutes such as the Indian Institute of Science (IISc) and the Tata Institute of Fundamental Research (TIFR). Some of these, including most of the universities, had existed prior to Indian independence; each had developed within its own unique circumstances and context. But these separate histories soon began to be erased, as the administration of science and education in India moved inexorably toward uniformity. Since academic positions enjoyed relatively stable funding, science grew professionalised. It became a viable and sought-after career path for increasing numbers of people. In exchange for this stability, scientists ceded control of the research agenda. National missions such as weather forecasting, agriculture, the atomic program, myriad massive engineering projects, and the expansion of India's human resources, set the direction for India's growing scientific cadre.

Now, after seven decades of public investment, the government is asking what has been achieved.

February 28, the anniversary of the day C. V. Raman discovered the effect for which he was awarded the Nobel Prize, is celebrated as India's National Science Day. Writing in the Hindustan Times on this occasion in 2018, K. VijayRaghavan, now India's Principal Scientific Advisor, made the case for public investment in 'blue skies' research. VijayRaghavan, an accomplished basic scientist himself and the former Director of the National Centre for Biological Sciences, echoed Vannevar Bush as he wrote about the benefits accrued from curiosity-driven research in India: Shambhu Nath De's work on cholera toxin, G. N. Ramachandran's seminal contributions to structural biology. He argued that much more could be expected if the right investments, incentives, and institutional environments were put in place.

Unfortunately, this narrative starts from the premise that the only justification for public funding of science is the promise of eventual applications. This gives a flawed impression of the way science works, creates unrealistic expectations, and sets funders at odds with researchers. Major Indian science funding agencies including the CSIR, the Department of Science and Technology, the Department of Biotechnology, and the Department of Atomic Energy, are under pressure to deliver on applications. Basic scientists are forced to shelter behind Bush's fragile syllogism: "Our collective work may not be useful now, but history tells us it will be someday; my own work is not useful now, so there is a chance it might be someday." Eventually that 'someday' becomes today. Judged by the very yardsticks scientists themselves have put forward, Indian science has done little for the Indian people.

The Indian scientific establishment can no longer take unquestioning public support for granted. The case of the INO, the India-based Neutrino Observatory, is revealing. In development for nearly two decades by a consortium of institutions including TIFR, the INO is a proposed detector shielded deep within a mountain which will study properties of the fundamental particles known as neutrinos. The project has a strong scientific justification, raises no safety concerns, and has recently been granted environmental clearances. Yet the effort has been dogged by claims that it will affect human health and harm forest and farm lands. Though the INO team has worked closely with the people who live around the mountain and nearby forested areas, they are accused of ignoring the sentiments of the local community. False rumours spread faster than attempts by scientists to address them. Why do these stories have so much traction? Why is it so easy to paint scientists in a bad light? Sadly, the INO is a victim of previous failures in which precisely these kinds of lapses did occur: in which scientists ignored environmental issues or local sentiments. Such concerns are not restricted to India. The Thirty Meter Telescope proposed to be built on Mauna Kea in Hawaii has met with strong protests from native Hawaiians who feel it would violate one of their most sacred spaces.

Across the world, public spending on esoteric scientific projects has always faced resistance, not just from the people but also from politicians. In 1969 Robert Wilson, the first director of Fermilab, was asked by a US Congressional Committee whether his expensive particle accelerator had any security applications. He replied: "It has nothing to do with defending our country, except to make it worth defending". Wilson was arguing that there are deep and important reasons to fund science, beyond its much-touted capacity to generate technological progress. The science-for-applications framework was articulated through negotiations between the scientific community and the government, each side driven by its own narrow and self-serving logic. It's time to ask people – not scientists, not the government: people – why, if at all, science makes a positive contribution to their lives.

Contrast the slow but steady growth of the grassroots All India People's Science Network with the precipitous decline of India's government-supported universities and the under-performance of its research establishment. The longevity of the Network is the result of many factors: the drive and dedication of its members, who see science as an instrument of broader change; the diversity of its activities, bubbling up from the preoccupations and motivations of its various constituencies; the diffuseness of its structure, each of its sub-groups having grown organically within a local context. I believe there are valuable lessons here on how to re-imagine science in India, a deeply-rooted science worthy of public support.

What kind of science would this be?

A science that inspires. There is a strong case to fund science for the same reason we fund the arts, or sport. Science is a cultural activity: it reveals unexpected beauty in the everyday; it captures the imagination of children; it attempts to answer some of humanity's biggest questions about where we came from. Moreover, scientific ideas can be a potent component of the process by which society arrives at collective decisions about the future. Among the strongest reasons a resource-limited country such as India should fund curiosity-driven science is that the nature of future crises cannot be predicted. It is impossible to micromanage the long-term research agenda, so the only hope is to cast a wide net. A broad and deep scientific community is a valuable resource that can be called upon to give its inputs on a variety of issues. They cannot be expected to always deliver a solution, but can be expected to provide the best possible information available at any time. In this consultative process it is crucially important not to privilege scientific experts over other participants in the discussion.

A diverse and democratic science. Science thrives within a diversity of questions and methods, a diversity of institutional environments, and a diversity of personal experiences of individual scientists. In the modern era the practice of science has moved to a more democratic mode, away from the idea of lone geniuses and toward a collective effort of creating hypotheses and sharing results. Any tendency toward uniformity and career professionalization dilutes and ultimately destroys this diversity. As historian of science Dhruv Raina describes it, a science that is vulnerable to the 'pressures of government' is 'no longer an open frontier of critical activity'. Instead, science must become 'social and reflexive'. Ideas and themes must bubble up from the broadest possible community. In India access to such a process is limited by the accident of one's mother tongue and social class, and this must change. Anyone who wants to should have the opportunity to understand what scientists are doing. Ultimately this must involve not only scientists, but also social scientists, historians, philosophers, artists and communicators, and the public at large.

A science that is locally rooted. Is there such a thing as an 'Indian way' of doing science? Science in the abstract is said to transcend national boundaries. In practice it is strongly influenced by local experiences and local history. Unfortunately, even as national missions have faded to the background, they have been replaced by an imitation of Western fashions. It has become common to look to high-profile journals and conferences as arbiters of questions-worth-asking. This must stop. The key to revitalising Indian science is the careful choice of rich questions. These questions could be driven by new national missions that bring the excitement of a collective effort. Or they could be inspired by observing the complex interactions of the world immediately around us. There is a great deal of scholarship and scientific inquiry that can arise from

The key to revitalising Indian science is the careful choice of rich questions. These questions could be driven by new national missions that bring the excitement of a collective effort. Or they could be inspired by observing the complex interactions of the world immediately around us.

the study of India's traditional knowledge systems. The country's enormous biodiversity and human genetic diversity are an exciting and bottomless source of scientific puzzles and important secrets. Such questions would allow for a deeper two-way engagement with India's people. This is not to say Indian scientists cannot work on internationally important problems, quite the opposite.
The scientific community in India, working within their own unique contexts, could become the source of important problems that anyone in the world would be excited to work on.

A science that builds global connections.
The internationalization of science is an important goal in and of itself. While it stimulates cross-fertilization of ideas and pushes up standards within science, it also creates opportunities for broader global discussions and engagements.
The unfortunate hurdles which curtail the ability of Indian academics and students to travel abroad, and the enormous difficulty foreign academics face in obtaining necessary permissions to visit their colleagues in India, serve no purpose. In spite of all this there is a healthy trend toward stronger international links. Major global science funding agencies such as the Wellcome Trust and European Molecular Biology Organization directly fund research within India. And while India's current capacity to train its young scientists is slowly improving, Indian students are exposed to excellent opportunities abroad. The US National Science Foundation estimates there are nearly 9,000 Indian students enrolled in science and engineering PhD programs in the US alone, with thousands more spread across the world. This is a substantial fraction of the 76,000 students presently enrolled in such programs in India according to the Ministry of Human Resource Development's 2017 Survey. Young Indian scholars abroad represent India to the world, they build links to productive academic and research networks, are trained in cutting edge disciplines and generate new scientific output, while maintaining close ties to home.

A science that renews itself and passes on its values. Academic scientists have long played a dual role as teachers and researchers. Within India science has a remarkably broad appeal. Public science talks are standing-room-only affairs, and famous scientists receive the kind of adulation typically reserved for movie stars. Students across the country are excited about science, many aspire to become scientists themselves. Historically, engineering and medical colleges have attracted scientifically-minded students, but this is changing. The Indian Institutes of Science Education and Research (IISERs) have now been running undergraduate programs for over a decade in cities across India. These institutions are to science what the IITs are to engineering, attracting some of the brightest students each year. Science programs within public universities have not fared as well, and must seize every opportunity to reinvent themselves.
A science curriculum based not on dry facts but on the history and process of discovery can form the base of a broad education, in conjunction with the humanities and the arts.

These are just a few of the reasons I believe science in India deserves public support. Every so often the work of basic scientists has led to useful applications. But there are enough instances in which actual harm has been done in the name of science. We cannot be so naïve as to claim innocence, we must take some responsibility for this and participate fully in correcting it. This does not mean overturning our lives and institutional structures. But for a start it means we must be open to ideas and criticism, sensitive to the consequences of our work, more integrally connected to the complex society around us. Words from the 1983 essay 'Toward a People's Science Movement,' by historian Mahesh Rangarajan and co-authors, remain relevant today: "science and technology has been getting alienated from the people, their understanding and knowledge, life experiences and problems."

It is time that every Indian, and people everywhere, are able to carry the candle of science in a way that brings meaning to each of their lives. ■

Mukund Thattai is a biologist and a faculty member at the National Centre for Biological Sciences, Tata Institute of Fundamental Research (NCBS-TIFR).

This essay was originally written for a forthcoming publication of the Lakshmi Mittal South Asia Institute at Harvard University, focussing on Science and South Asia.

UNIVERSALIZATION OF SCIENTIFIC TEMPER AND THE NATIONAL SCIENTIFIC TEMPER DAY

VIVEK MONTEIRO

Perhaps India is the only nation in the world which has scientific temper (ST) explicitly written into its constitution. Article 51 A, mandates, as a fundamental duty for every citizen: *"to develop the scientific temper, humanism and spirit of inquiry and reforms"*. Article 51(a) is not legally enforceable in a court of law. However, Article 21 A, which is legally enforceable, and the Right to Education Act 2009 have made universalization of education of 'good quality' legally binding. Consequently, universalization of scientific temper (UST) – as a component of good quality science education – is now legally mandatory. UST is no longer just a fundamental duty, but a fundamental right of every Indian citizen. The implications are far reaching.

Mandatory universalization poses the question: Can the task of building scientific temper on a mass scale be taken up as a scientific programme? What does it mean to take up UST as a national scientific programme?

Humankind has some genuine achievements of universalization. Deadly diseases like small pox and polio have been eradicated from most parts of the world by national and international scientific programmes. Universal literacy achieved in many countries is another example. Two hundred years back women and 'lower' castes were denied education in India. This was challenged by social reform and ideological movements led by leaders like Jotiba and Savitribai Phule. Today, almost every child in India is in school regardless of gender, or caste. These examples give us the confidence that universalization is feasible.

Though almost 10 years have elapsed since the RTE 2009 Act, UST has not yet been given serious attention by the central and state governments. As an important step to put UST on the national agenda, on August 20th, the anniversary of the assassination of Dr. Narendra Dabholkar, a National Scientific Temper Day (NSTD) was observed all over India for the first time in our history.

The 'Ask Why' campaign to observe NSTD was initiated by the All India People's Science Network (AIPSN) and the Maharashtra Andhashraddha Nirmoolan Samiti (MANS), an organization started by Dr. Dabholkar for combating superstition and religious bigotry. Many organizations and institutions joined, and during the month of August NSTD was observed in most of the states and union territories of India in tens of thousands of schools, colleges and public gatherings.

Two questions arise here: *what is 'scientific temper'* and *why has August 20th been chosen for observing NSTD.*

India's first prime minister Jawaharlal Nehru used the term in his 1946 book 'The Discovery of India', in these words: *"What is needed is 'the scientific approach, the adventurous and yet critical temper of science, the search for truth and new knowledge, the refusal to accept anything without testing and trial, the capacity to change previous conclusions in the face of new evidence, the reliance on observed fact and not on pre-conceived theory, the hard discipline of the mind ..."*

In 1981 a group of scientists and intellectuals invited by the Nehru Centre after several days of discussion, defined scientific temper in terms of four criteria, in their 'Statement on Scientific Temper' (SST):

(a) that the method of science provides a viable method of acquiring knowledge;

(b) that the human problems can be understood and solved in terms of knowledge gained through the application of the method of science;

(c) that the fullest use of the method of science in everyday life and in every aspect of human endeavour from ethics to politics and economics is essential for ensuring human survival and progress; and

(d) that one should accept knowledge gained through the application of the method of science as the closest approximation of truth at that time and question what is incompatible with such knowledge; and that one should from time to time reexamine the basic foundations of contemporary knowledge.

For reasons which are not discussed here, this writer prefers to replace the fourth criterion (d) with the following:

(d) Anything claiming to be scientific must be prepared to face the tests of the method of science. Anything which is not prepared to face the tests of science cannot claim to being scientific.

Most professional scientists will have no difficulty with criterion (a). However, they usually implicitly assume that 'science' refers to 'natural science', and that the scope of science is restricted to the natural world i.e. physics, chemistry, life sciences etc. Accordingly, the term 'scientist' is usually presumed to describe a person working in the field of natural science.

But in the definition of ST, science is not a subject. It is a method. Criteria 'b' and 'c' of SST assert that the scope of science is the entire real world including a changing and evolving social reality as well. UST has first to contend with a marked reluctance to extend the scope of science beyond the natural world.

The following examples from the writings of Prof. Richard Feynman are illustrative of this problem.

In his lecture titled 'Cargo Cult Science', Feynman gives an apt description of science as: '*a long history of learning how not to fool ourselves*'.

Yet, in another of his essays titled 'The Value of Science', he argues, *"From time to time people suggest to me that scientists ought to give more consideration to social problems – especially that they should be more responsible in considering the impact of science on society. It seems to be generally believed that if the scientists would only look at these very difficult social problems and not spend so much time fooling with less vital scientific ones, great success would come of it.*

It seems to me that we do think about these problems from time to time, but we don't put a full-time effort into them – the reasons being that we know we don't have any magic formula for solving social problems, that social problems are very much harder than scientific ones, and that we usually don't get anywhere when we do think about them.

I believe that a scientist looking at nonscientific problems is just as dumb as the next guy – and when he talks about a nonscientific matter, he sounds as naive as anyone untrained in the matter."

Evidently, in Feynman's view social problems are not 'scientific ones'. They are in the category of 'non-scientific problems', 'non-scientific matters'. In his view, quite common among natural scientists, there are two kinds of problems- scientific problems, about which one can think rigorously, and 'non-scientific problems'- like social problems - where it is not possible not to fool yourself, about which 'we usually don't get anywhere when we do think about them', so why bother anyway?

Feynman quarantines the method of science by compartmentalizing reality into two parts, one scientific and the other 'non-scientific', nature and society. Having earlier defined science as a method, he retreats to viewing it only as a subject area. To put it bluntly, in Feynman's view, scientific temper divides into two parts- one scientific and the other non-scientific.

As we all accept, the method of science is founded on skepticism- checking the evidence and always asking why. It is a definite way of approaching the question of validity through systematic doubt. Never claiming ultimate truth, what it claims to achieve is increasing levels of confidence. Or putting it in another way, decreasing levels of uncertainty and disbelief. Precisely because of its rigorous skepticism, the conclusions arrived at through the application of the method of science, claim to be the most reliable, on the basis of the available evidence.

These conclusions may be reliable, but they may not be convenient. Knowledge and responsibility are inseparable. Where knowledge is inconvenient, many prefer the bliss of ignorance. Obscurantism is a process of throwing darkness where light is possible. Though often used to describe willful deception, it would also include willful ignorance.

Because in many areas the scientific conclusions may not be convenient, promoting ST is no easy task. In my opinion, Dr. Dabholkar has made a most important contribution thus far to UST. Many otherwise excellent writings on ST by scientists and science communicators have two shortcomings- they are mostly about natural science and do not touch the inconvenient areas and secondly, though popular, they do not reach out to everyone. UST requires us to reach everyone.

In his numerous writings and lectures on ST Dr. Dabholkar addresses both these shortcomings. He reaches out to everyone. He addresses the masses. He does not shirk from the inconvenient. To explain what is the method of science he uses examples which are not from natural science, but from everyday life. He talks about the mandate for scientific temper in the Indian constitution and our educational policy. He makes clear the important point that scientific temper is not about natural science, it is about our attitude towards life. He gives a simple but powerful four-word definition of scientific temper: *'Jevda Purava, Tevda Vishwas,'* – 'As much belief as there is evidence for.'

Since natural science is a good place to begin learning about the method of science, as part of NSTD, the AIPSN has prepared a booklet of simple experiments titled 'Ask Why', which can be performed in any school, anywhere. Many other materials have been prepared in many states. Two of Dr. Dabholkar's lectures on scientific temper have been translated into English and several Indian languages, including Hindi, Tamil, Malayalam, Telugu, Oriya, Bangla and Assamese. Videos of Dr. Dabholkar's speeches have been dubbed in Hindi, English and Kannada. (These are available on the websites www.aipsn.in and www.navnirmitilearning.org)

UST is not just delayed. It has become especially urgent in present circumstances. Elsewhere in the world too, we observe an assault on science. It is inseparable from a broader assault on scientific history which attempts to concoct false historical record and distort education.

Scientific temper encourages questioning and thus is basically opposed to fundamentalism, which is based on unquestioning belief. Science, which is based on questioning, needs democracy. Questioning is also essential for democracy. 'Ask Why' will encourage critical thinking in the common citizens and therefore help to strengthen democracy.

The scientists have played an important and commendable role in the initiation of NSTD with an appeal to all educational institutions to take up the work of promoting scientific temper. This year a large number of educational institutions observed the NSTD, with lectures, presentations, experiments, cultural events, films and videos. By next year, we can surely increase the participation several fold, and with a power of ten upscaling each year it should be possible to reach the UST target of every school and college in the country within a span of four years.

NSTD is a growing collective of Indian citizens who believe in upholding their constitution. In a nutshell, the NSTD is a call to citizens of this country to work together to take forward a national movement for strengthening democracy by checking the evidence, and asking why. ■

Trained as a theoretical physicist, Dr Vivek Monteiro is the Founder and Principal Advisor of Navnirmiti Learning Foundation. He is also part of the group that laid the foundation of the Peoples Science Movement in India.

ask why AUG 20
NATIONAL SCIENTIFIC TEMPER DAY

THE STEM GAMES

NAGARJUNA G.

We often speak about the sorry state of STEM (Science, Technology, Engineering, and Mathematics) and STEM education in India. We recognize the problem, but do not appear to have a strategy to improve the situation. This is not to say there are no honest attempts at improvement, but they have, at best, worked in minimal conditions.

In this short note, I present a model-driven picture with the hope that this may help us understand the problem and, hopefully, find a road toward good STEM policy and practice.

Game as a Model

A game is a rule-following activity, where both the players and spectators are immersed. Such a game, in the absence of spectators (or audience), is not sustainable. It is dependent upon spectators, and that too, many more spectators than players.

Although spectators may not have sufficient proficiency at playing the game, their participation, from the sidelines, is crucial. The rules and the actions taken by the players of the game are also understood by the spectators, and their feedback during the period of play, and in their review, is instrumental.

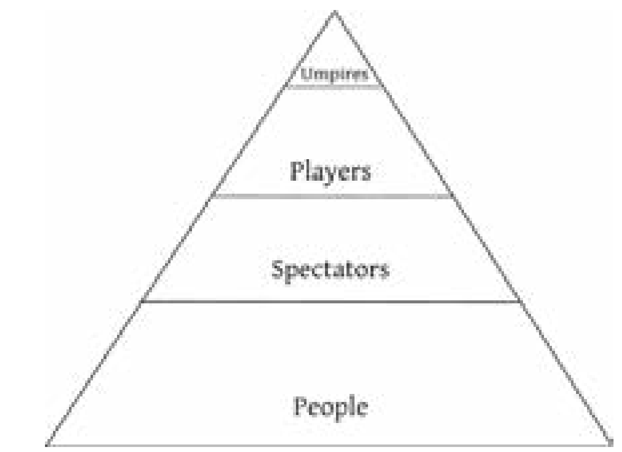
Some of the senior players, who are well-versed and have a comprehensive understanding of the rules of the game, become umpires. There is one other subcategory of players, the coaches, who are typically active or retired players themselves.

Spectators need to be players themselves, at any level, but understanding the rules of the game at some level of proficiency is necessary. Most games share similar patterns, and if we ever played at least one game, it is not difficult to play or appreciate other games.

Let us take STEM as a set of games scientists, engineers and mathematicians play. All those who have played a couple of STEM games at least once, and understood some rules of the game, will constitute the STEM spectators. The editors of the journals, senior STEM players, are equivalent to umpires, who understand the rules of STEM games very well.

A Pyramid Representation

A representation of a game-system as a pyramid may provide some light on the need and



relationship between the spectators, the players and the umpires in a game. A pyramid model also offers a good clue about where each of the agents of the game-system emerges.

In the representation, borrowed from an ecological pyramid, the base of the pyramid includes people, who form the primary support system, followed by spectators, players, and umpires. It is essential to keep in mind that the spectators also know the game, though they may not be as proficient as the players. The umpires are not only proficient in the game, but they are also skilled in judging, indeed, often framing the rules of the game.

The pyramid representation also suggests the population of the game system, in the decreasing order of people, spectators, players, and umpires. About the proficiency of the game, the order is inverse.

A Lesson from Cricket

Let us take the cricket game-system. India is one of the top-ranking countries in the world, producing several world-class cricketers. Cricket game is arguably one of the instances where India has achieved excellence. There are vast numbers of people who understand the game as well as those who play the game. The base of the pyramid for cricket, therefore, in this model, is strong and bulky.

If the national team is kept captive in a remote island with the intention to destroy the game, another team will take their place in no time with similar proficiency. There is sufficient buffer in a resilient system, and cricket in India is one such. This is an example of how equity generates excellence.

However, if the national champions of the STEM game of India are kept captive in a remote island, with the intention to destroy STEM in India, another leading team will take a few generations to reach the proficiency level of the leading players. Whichever team finds itself immediately as a replacement will be far less proficient.

We do not have a resilient STEM game-system. If a similar situation were to arise in another leading STEM country hypothetically, it would not take generations to create new STEM champions. There are plenty of potential team members of comparable proficiency available.

Why?

Using the game model, the reasons for not being able to play the STEM game proficiently emerge in quick order.

Where do people learn to play cricket in India? Anywhere that looks like a ground. Not in a classroom. Where do students learn to play the STEM game? They do not play STEM game at all, they read about STEM game in a school, and do not play it, either in a 'lab' or in a 'garage.' We in India do not cover the 'T' and 'E' of STEM in our school education. In this scenario, a 'lab' is a formal experimental space, whereas a 'garage' is an informal one.

Consider the coaching system in place for games: the coach is necessarily a player, either active or retired. In India, for the STEM game, this is not true. The majority of STEM teachers are neither players nor spectators of STEM game.

Spectators of a game are possible only if they understand the rules of the game and play some game at any level of proficiency. We do not expose our students to any of the rules of the STEM game, nor do we allow them to play. Our system, therefore, does not make sufficient spectators of STEM. Their ability to consume and appreciate STEM is negligible.

We do not play STEM game with competitive proficiency because we do not have sufficient spectators. In their absence, our STEM players are, so to speak, scratching each other back, becoming spectators for themselves. When we want to share our work, we often have to participate in a conference abroad in search of a peer group. Local peer group is essential for developing any expertise.

The need of spectators may sound counter-intuitive, because one may think only STEM experts should appreciate STEM expertise. Though umpire level decisions are the domain of experts, the rules of the game must be shared with the community, which is capable of responding to the performance of the players. However, this will only happen when more people are allowed to play the STEM game.

Even though we have produced an occasional Ramanujan or Raman, we have no spectator class to judge their achievements. If we were an immersive STEM society, then we would more easily identify such talent. We need spectators to identify and nurture talent. At around the time of Sir C.V. Raman the Indian Association of Cultivation of Science had six fellows of Royal Society, among others who are equally proficient in the game.

How are STEM game spectators created?

If the game model is a fit for STEM and STEM education, the need to let students and citizens play the STEM game, at any level of proficiency, defines itself as a necessity. If the STEM game rules are not appreciated, the appreciation of STEM in society at large itself remains a significant gap.

The STEM curriculum should, therefore, substitute the preponderance of 'reading' about the STEM game, with actually playing it.

Similarly, the coaches of the STEM game have to be active players themselves. The concept of retired, i.e., no longer participating, players do not exist in this scenario, since coaches themselves either alternate or participate directly with students and other citizens.

Otherwise, a discovery of a Ranjitsinhji, Gavaskar or Sachin of STEM is either not possible or merely a matter of luck. Given the humongous population, while 'luck,' or statistical possibility, may exist, it is not as meaningful as participation in an activity or discipline.

Rules of the STEM game

The term 'game' is used here more as a metaphor. The defining feature of a game is that it is a rule-following activity. We shall focus on this feature of a STEM game. It is ironic that when we use 'game' to refer to an activity, it does not evoke seriousness. But, rule-following does evoke seriousness. So, let us focus on this serious feature and ask the following obvious questions: (1) what rules of the STEM game that we follow (the descriptive question) and (2) what rules of the STEM game that we ought to follow (the normative question)?

Neither of these questions can be comprehensively answered here. We need a book-length treatment for doing justice to these questions. But we can at least focus on some rules that we do follow, which may give us a direction to the STEM and STEM education policy.

One may think that to specify the rules of STEM game is too ambitious since it encompasses at least four apparently different domains, S, T, E, and M. The debate on what methodologies science follows or should follow is a question that is pursued by the philosophy of science, views there continue to be contentious. Similarly, the same questions when posed for technology, engineering and mathematics would make the problem even more difficult and controversial. If even the methods are not well defined, how can one talk about the rules? First of all, are methods and rules different? If they are different what relations do they have among them? Even if one admits that science and mathematics may have some specifiable rules, can we also make a compelling attempt to specify the rules for technology and engineering? Aren't the latter more close to art, with creativity and innovation being integral to them? Can we specify any rules to be followed for creativity and innovation? What are heuristics, and how are they different from rules and methods?

All such above questions make the problem difficult to approach. So, the only way to turn this into an approachable way is to play the STEM game to define the STEM game itself: to create a microworld that makes all STEM games possible. Here the core concept is that of a microworld, so let us elaborate on this idea.

First of all, a microworld is not a microscopic world. The term 'microworld' is introduced by Seymour Papert to make abstract ideas and operations concrete. A world constructed by stipulating constraints (rules) on the possible actions we can perform on a set of available predefined objects or building blocks. Usually, most microworlds are constructed with as minimal constraints as possible. The minimalism allows the players a challenge as well as a creative space to operate in. I am liberating Papert's microworld, invented initially as a creative space to make students learn by constructing abstract representations, to characterize STEM games.

One primary reason why the model of microworlds is useful is that this idea helps us to see the common aspects of all four domains of STEM. A few examples will make this extension clearer. Let us take Alan Turing's "microworld" which was constructed by defining a minimal set of operations (a head that can read, write, move left, move right on an infinite tape). This minimal set forms 'building-blocks' and also defines the field. Originally proposed as a mathematical theory of computation, Turing's microworld allowed us to play in a verifiable manner to create the digital world. I need not argue how extensive this digital space (game field) can be, where almost every aspect of human culture is re-represented in a concrete manner so that an entire society could participate. This game has everyone, people, spectators, players, and umpires. In this space of computer science, it is difficult to separate the four domains of the STEM game as different from each other, except as distinct roles played by multiple players.

Within this massive 'microworld' several microworlds can be constructed. Alan Turing of educational microworlds is Seymour Papert, who designed Logo, where an agent called turtle can be programmed to move in a 2-D space by simple operations like moving forward, right, and left by specified units followed by pen-up and pen-down. In a typical microworld, the inventor has no clue of what constructions are possible. Though one can retrospectively verify (prove) if the created construction is actually a result of the pre-decided rules.

Papert's colleagues Mitchell Resnick and Uri Wilensky took the next step of creating a microworld of multi-agent simulations, such as NetLogo. It is a common practice to introduce the new science of complexity through Netlogo. It is one microworld where the creators of the world have no clue of who will, so to speak, inhabit in the world. Models created so far belong to mathematics, music, art, social science, economics, biology, physics and so on. This triumphant story vindicates the game theory of STEM that is being propagated here.

Looking back at the history of STEM, we could ask: aren't the following also microworlds:

- Pythagoras' microworld of natural numbers and their patterns
- Democritus' atomic microworld
- Plato's and Aristotle's microworld of relationship between ideas and propositions to explain the world of thoughts and beliefs
- Panini's generative grammar for Sanskrit language
- Euclid's microworld of geometry
- Archimedes' microworld of machines using balance and pulleys
- Newton's microworld of interacting point masses

Each of them has applied their rules explicitly enabling inter-subjective judgment possible. Rules help us in STEM to ensure rigor, consistency and community participation making STEM a genuinely social endeavor.

Microworlds are artificially constructed rule-following possible worlds based on minimalist building-blocks. They may produce finite or infinite worlds. Are
they same as what we call models? Is modeling same as constructing a microworld? It is an important question, let us pass this question for some other time.

There are other rule-following cultural practices, not usually considered part of STEM game, such as classical music and dance. Playing such seemingly different games also support STEM imagination. For example, Manjul Bhargava's exposure to Indian classical music during his childhood days helped, according to him, develop mathematical imagination.

This interpretation has the advantage of viewing what we do in STEM, whether with media (symbolic operations) or matter (engineering and technology operations), stand on similar roots. The view of theoretical modeling and mathematics as a microworld construction game on the one hand and engineering and technology to make corresponding physical microworlds, on the other hand, provide a sufficiently comprehensive picture of the roots of STEM. The possibility of creating physical microworlds give STEM participants tremendous confidence in how close they are in understanding the actual physical world.

Whether we play language games in STEM or engineering games, we construct artifacts. Construction and de-construction are common operations of STEM game.

To Conclude

Microworld as a game field for learning as proposed by Seymour Papert is extended here to all of the STEM activities. This is done deliberately to make the point that the context for learning should not be different from the context of execution by experts. Game metaphor clearly guides us to expect the teachers of the game to be the players themselves. And students will learn the game by playing, and there exists no more straightforward way of doing it.

STEM is rooted in cultural practices, such as language, which is rule-based. However, other cultural practices may not always apply as rigorously as STEM does. STEM's adherence to rigor is manifested in seeking definitions to eliminate multiple interpretations. Multiple interpretations is a game spoiler in STEM. STEM pursuit requires removing ambiguity as much as possible.

There are several other aspects of the STEM game that we could not cover here, which are better described by Thomas Kuhn as disciplinary matrix.

Formation of social groups, as clubs, is part of any cultural activity. Science clubs, whether it is Royal Society or Indian Association for the Cultivation of Science, were created to promote STEM culture. After independence, though, we established more and more Government owned institutions, which restricted broader participation. The existing colleges and universities graduated students based on a syllabus, which did not focus on the rule-following games of STEM. Neither the admission tests, like JEE, nor the graduation exams look for student's familiarity with practicing STEM games: content knowledge is tested not culture. One-third of human life is spent on a misdirected preparation. Instead, if we focus on rules, we will learn how to create content rather than memorize content.

One intervention game that can transform the existing situation: reform admission tests to check on the skillful use of the rules of the STEM game. This will transform existing schools and colleges, which will metamorphose classrooms into STEM studios. This will also create the need for coaching shops which will become STEM clubs, maker-spaces, tinkering spaces. Commercial agencies adapt to change in the rules (policy) much faster than the conservative school and college system. Can we make this reform? But, should we? Are we convinced? Let us engage and examine these questions critically as the first step. ■

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Nagarjuna G. is a faculty member at the Homi Bhabha Centre for Science Education, TIFR.

OUTREACH@ICTS
KAAPI WITH KURIOSITY

KWK June 2018 - **Michael Berry** *(University of Bristol, UK)*

KWK Aug. 2018 - **Arvind Gupta** *(Children's Science Center, IUCAA - former)*

BETWEEN THE SCIENCE

RIDDHIPRATIM BASU and **ANUPAM KUNDU** were selected as associates of Indian Academy of Sciences. This is a recognition for promising young researchers below the age of 35.

ABHISHEK DHAR has been elected as a fellow of the National Academy of Sciences, India (NASI).

AVINASH DHAR was awarded the TAA Excellence Award, 2018, by the TIFR Alumni Association.

CHANDAN DASGUPTA was awarded the prestigious Satyendranath Bose medal of the Indian National Science Academy (INSA).

BALA IYER was conferred an honorary doctorate by Central University of Karnataka.

VISHAL VASAN was selected for membership of the National Academy of Sciences, India.


Juan Maldacena interacts with students


From one of our KWK talks

LECTURES

D.D. KOSAMBI LECTURE

ICTS has introduced a new lecture series, named after the mathematician and statistician Damodar Dharamanand Kosambi, who made pioneering and foundational contributions to the methods and study of ancient Indian history. He was the first professor of mathematics at the Tata Institute of Fundamental Research (1946-62). The ICTS DD Kosambi lectures will be delivered by eminent scholars in the social sciences and the humanities.

The Fissures of Modern Hinduism: Religion and Historiography
24 May 2018 ✦ *Speaker* — Pratap Bhanu Mehta *(Vice- Chancellor, Ashoka University)*

INFOSYS—ICTS CHANDRASEKHAR LECTURE SERIES

Order, Disorder and Entropy
28 August 2018 ✦ *Speaker* — Daan Frenkel *(University of Cambridge, UK)*

Nature's Optics and our Understanding of Light
11 June 2018 ✦ *Speaker* — Michael Berry *(Melville Wills Professor of Physics (Emeritus) at the University of Bristol, UK)*

Quantum mechanics and the geometry of spacetime
24 May 2018 ✦ *Speaker* — Juan Maldacena *(Institute for Advanced Studies in Princeton, NJ)*

INFOSYS—ICTS RAMANUJAN LECTURE SERIES

Some New Results on Rationality
1 October 2018 ✦ *Speaker* — Claire Voisin *(College de France)*

INFOSYS—ICTS DISTINGUISHED LECTURE

From Bits to Qubits: A Quantum Leap for Computers
26 September 2018 ✦ *Speaker* — Susan Coppersmith *(University of Wisconsin-Madison, Wisconsin)*

PUBLIC LECTURE

What is Common Between Falling Cats and the Quantum Hall Effect?
10 August 2018 ✦ *Speaker* — Alexander Abanov *(Stony Brook University, New York)*

Chandra. The Journey of a Star
3 August 2018 ✦ *Speaker* — Giuseppe Mussardo *(SISSA, Trieste, Italy)*

Black Holes and the Structure of Spacetime
25 May 2018 ✦ *Speaker* — Juan Maldacena *(IAS, Princeton)*

EINSTEIN LECTURE

The Fascinating World of Turbulent Flows
24 August 2018 ✦ *Speaker* — Samriddhi Sankar Ray (ICTS-TIFR) ✦ *Venue* — Dayananda Sagar College of Engineering, Kumarswamy Layout, Bangalore

Einstein's Messengers
14 June 2018 ✦ *Speaker* — Parameswaran Ajith *(ICTS-TIFR)* ✦ *Venue* — Indian Institute of Technology Mandi, Kamand, Mandi (H.P.)

Space-Time and Gravity: From Newton to Hawking and Beyond
8 October 2018 ✦ *Speaker* — Spenta R. Wadia *(ICTS-TIFR)* ✦ *Venue — Assam University, Silchar*

KAAPI WITH KURIOSITY

Science, The Fulcrum for Social and Economic Change
14 October 2018 ✦ *Speaker* — K. VijayRaghavan *(Principal Scientific Adviser to the Govt. Of India)* ✦ *Venue* — J. N. Planetarium, Bangalore

A Finite Discussion on the Infinite
9 September 2018 ✦ *Speaker* — Tanvi Jain *(Indian Statistical Institute, New Delhi)* ✦ *Venue* — J. N. Planetarium, Bangalore

Making Things, Doing Science
19 August 2018 ✦ *Speaker* — Arvind Gupta *(Children's Science Center, IUCAA - former)* ✦ *Venue* — J. N. Planetarium, Bangalore

The Discrete Charm of Geometry
22 July 2018 ✦ Speaker — Alexander Bobenko *(Technical University of Berlin)* ✦ *Venue* — J. N. Planetarium, Bangalore

How Quantum Physics Democratised Music: A Meditation on Physics and Technology
10 June 2018 ✦ *Speaker* — Michael Berry *(University of Bristol, UK)* ✦ *Venue* — J. N. Planetarium, Bangalore

Black Holes and Steam Engines
27 May 2018 ✦ *Speaker* — Joseph Samuel *(Raman Research Institute, Bangalore)* ✦ *Venue* — J. N. Planetarium, Bangalore

PROGRAMS

Entropy, Information and Order in Soft Matter
27 August—2 November, 2018 ✦ *Organizers* — Bulbul Chakraborty, Pinaki Chaudhuri, Chandan Dasgupta, Marjolein Dijkstra, Smarajit Karmakar, Vijaykumar Krishnamurthy, Jorge Kurchan, Madan Rao, Srikanth Sastry and Francesco Sciortino

Summer School on Gravitational-Wave Astronomy
13—21 August, 2018 ✦ *Organizers* — Parameswaran Ajith, K. G. Arun and Bala R. Iyer

Integrable Systems in Mathematics, Condensed Matter and Statistical Physics
16 July—10 August, 2018 ✦ *Organizers* — Alexander Abanov, Rukmini Dey, Fabian Essler, Manas Kulkarni, Joel Moore, Vishal Vasan and Paul Wiegmann

Bangalore School on Statistical Physics – IX
27 June—13 July, 2018 ✦ *Organizers* — Abhishek Dhar and Sanjib Sabhapandit

Dynamics of Complex Systems 2018
16—30 June, 2018 ✦ *Organizers* — Amit Apte, Soumitro Banerjee, Pranay Goel, Partha Guha, Neelima Gupte, Govindan Rangarajan and Somdatta Sinha

Non-Hermitian Physics - PHHQP XVIII
4—13 June, 2018 ✦ *Organizers* — Abhishek Dhar, Andrew Houck, Manas Kulkarni, Bhabani Mandal, Vijayaraghavan Rajamani, Avadh Saxena and Miloslav Znojil

Summer School for Women in Mathematics and Statistics
7—18 May, 2018 ✦ *Organizers* — Siva Athreya and Anita Naolekar

DISCUSSION MEETINGS

Complex Algebraic Geometry
1—6 October 2018 ✦ *Organizer* — Indranil Biswas, Mahan Mj and A. J. Parameswaran

Quantum Fields, Geometry and Representation Theory
16—27 July, 2018 ✦ *Organizers* — Aswin Balasubramanian, Saurav Bhaumik, Indranil Biswas, Abhijit Gadde, Rajesh Gopakumar and Mahan Mj

Geometry and Topology for Lecturers
16—25 June, 2018 ✦ *Organizers* — C. S. Aravinda and Rukmini Dey

AdS/CFT at 20 and Beyond
21 May—2 June 2018 ✦ *Organizers* — Pallab Basu, Avinash Dhar, Rajesh Gopakumar, R. Loganayagam, Gautam Mandal, Shiraz Minwalla, Suvrat Raju, Sandip Trivedi and Spenta R. Wadia

RAD@Home Discovery Camp
7—13 May, 2018 ✦ *Organizers* — Ananda Hota, Chiranjib Konar and Sravani Vaddi