Policy Paper – 2

Prof. S. K. Saidapur Committee Report on

‘Revamping Science Education in Karnataka’

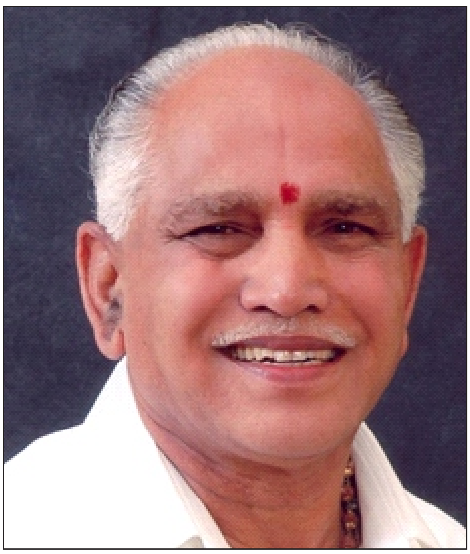
Karnataka Science & Technology Academy

Department of Science and Technology,

Government of Karnataka, Bengaluru-560097

2021

GOVERMENT OF KARNATAKA



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Department of Science and Technology, Government of Karnataka
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"Unless the real importance of pure science and its fundamental influence in the advancement of all knowledge are realized and acted upon, India cannot make headway in any direction and attain her place among the nations of the world"

- Sir C. V. Raman

Message

Karnataka is in the forefront of Science & Technology in the country, with a host of Institutions, both in the government and corporate sector. With a tradition of science learning at the Universities to innovations through start ups, the impact of S&T tools is visible across the State. Karnataka Science and Technology Academy, a Unit of the Department of Science & Technology, Government of Karnataka, has been functioning since 2005, with the objectives of inculcating scientific temper across civil society through science communication, technology dissemination, fostering innovations and entrepreneurship for societal benefits, recognizing talents and organizing outreach programs, capacity building and acting as STI Policy Advisory Body for the State. A series of Policy and Strategy Papers are also being prepared on important subjects of topical relevance.

Transformations are being seen across different sectors of economy, with new sciences and technologies. While science is universal, technology is contextual, both of which are becoming highly multidisciplinary in unprecedented ways. Education being the basis for these endeavors, there is a need to revisit both the content and delivery mechanisms, in order to achieve both excellence and relevance. The present times when the National Educational Policy (NEP)-2020 and the Science, Technology, Innovation Policy (STIP)-2020 are in place and we are approaching the 75th Indian Independence Day, offer the right opportunity to look at the current Science Education.

With the above in view, the Academy requested Prof. S.K. Saidapur, Member, Executive Council, KSTA to formulate a Policy Paper on 'Revamping Science Education in Karnataka'. The present document is an effort of a group of eminent educationists led by Prof. S.K. Saidapur, with intense deliberations. The recommendations are specific and actionable, including the ways of implementation.

I thank Prof. S. K. Saidapur and the esteemed members of the Committee for formulating the Policy Paper. I am sure this would be consulted at both the State and National levels as a way forward for quality assurance in Science Education.

Date: 9-4-2021

Bengaluru

Prof. S. Ayyappan

Chairman, KSTA, Bengaluru

Foreword

Education is the backbone of all nations. It is a dynamic process that undergoes reforms in accordance with the contemporary needs so as to sustain growth and development of nations all over the world. Keeping with this philosophy, India has now heralded a new National Education Policy (NEP-2020), and appropriate strategies are being worked for its implementation. It provides broad ideas for improvement of education in general. Perceptibly, both economy and national development hugely depend upon the various scientific advancements, development of technologies and innovations. The 21st Century focus is therefore unmistakably on skill development, critical and creative thinking and, making innovations. All these call for prioritizing *revamping and repurposing* Science education; for this the State of Karnataka is best suited as it happens to be the hub of science and technology in India.

India is bestowed with a demographic dividend in the form of large youth population. At the same time, It is facing challenges posed by *technology driven disruption in jobs* because of the ongoing IR 4.0 whose impact is massive both in *speed* and *impact*. As a result, there is a crying need for massive reforms in science and technology education. To attain global standards, the teaching-learning-assessment processes must be modernized by adopting global practices. Inspired by these concerns, the present Committee deliberated intensively over several meetings and arrived at recommendations that are consistent with NEP-2020 as well as expand and amplify the nature of deliverables with it. The policy document briefly highlights the scientific progresses, future trends and need for revamping science education. This is followed by implementable recommendations.

The Committee ardently hopes that restructuring and repurposing science education will go a long way in the advancement of scientific progresses in Karnataka. The Government of Karnataka may undertake revamping its science education in all earnestness, concurrently with the NEP-2020.

I thank Prof. S. Ayyappan, Chairman, KSTA and all members of the Committee for their enduring support, valuable inputs and cooperation in preparing the policy paper. Lastly, preparing the policy paper was a delightful and invigorating experience.

Date: 6-4-2021
Bengaluru

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Chairman, Committee for Preparing the
Policy Paper on "*Revamping Science Education In Karnataka*"

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I. Executive Summary

Quality Education is the harbinger of national development and excellence. The human species is uniquely endowed with the ability to think, create and strive to understand the nature, and purpose of life. In the process, enormous progress has been made in all fields of science and technology. Today, with many unimaginable advances and innovations in science and technology, the world is transforming rapidly and the various geographical continents have become closely interconnected, shrinking the physical world into a *global village*. The present period has rightfully earned the epithet the '*Age of Transformation*' the foundation of which is unquestionably, the education and scientific developments that foresaw four major industrial revolutions (IR 1.0-4.0). The ongoing IR 4.0 is driven by complex digital technologies with a massive structural impact and speed. For any nation, to withstand, utilize, sustain, innovate and make progress in the future there is a need to recalibrate its outdated educational system, especially the science education so as to prepare generations of students to become *future-ready*.

The education system envisioned in the recently proposed 'National Education Policy' (NEP-2020) has focused on critical and creative thinking**,** and culture of innovation. The teaching-learning processes have to be learner-centric and promote *self-learning*. Worldwide, pedagogies of education and assessment have greatly metamorphosed in recent times. Further, a '*Program for International Student Assessment*' (PISA) was formulated around the turn of the 21st century. The tests prescribed under PISA are competency-based and designed to assess higher order skills in analysis, critical thinking, conceptual clarity, problem-solving ability, working in groups (collaboration) and communication, which will guarantee global citizenship. India is also going to join the league of about 90 countries in the 8th cycle of PISA. In the light of these developments the classic text book-centric and content-based tests (examinations) conducted by various education boards have lost their relevance in the global framework.

The past century focused on manufacturing products with needed standards, precision and uniformity. The 21st Century is all set to go beyond this and provide solutions for global challenges of all kinds, scientific and technical. Unfortunately, science education in our schools, colleges and universities has not kept pace with the fast-changing global trends; partly due to the low importance accorded to experimental based learning (hands-on, trial and error, laboratory training, field-work etc.) compared to the class-room teaching alone. Likewise, there is an urgent need to recognize the changing role of the student-teacher relationship wherein the student would be at the center of learning process. Furthermore, it is necessary to recalibrate teacher's attention towards emerging frontier areas with multi-disciplinary inputs. Finally, teachers, educational institutions and their promoters have to adopt ICT (Internet and Communication Technologies) tools in pedagogy and curriculum development that promotes learning new skills. Therefore, there is urgency to rethink the curriculum development, transaction (teaching-learning processes) and assessment methodologies that are at par with the global standards. The committee also recognizes that the nature of the role of the Teacher needs to be further honed to include the function of a mentor. The existing teachers need to be empowered through adequate training programs while future recruitment of faculty should be based on their competency rather than on mere paper qualifications. In addition, one should strive to foresee many unforeseen challenges; a recent and classic example is the challenge posed by the Covid-19 pandemic which greatly affected both offline and online teaching-learning-assessment processes. Therefore, we need to gear up against such unforeseen pandemics and other disastrous situations that may crop up in future.

With the aforesaid concerns in mind, the Committee deliberated over several brainstorming sessions, identified the causes for declining quality in science education from schools to universities and arrived at specific recommendations. These will help to rejuvenate and elevate standards of science education and thereby promote quality research, development of new technologies not only for use in India but worldwide. The present Committee carefully looked into the provisions and philosophy of the NEP-2020 and our recommendations are in tune with its objectives. The recommendations (see Section VIII) are classified and listed under different headings: infrastructure development, faculty training, curriculum development, and teaching-learning-assessment processes, promoting quality research and innovations as well as need for science communication and practice of ethics in scientific endeavors.

Revisiting Science Education will be a major step in the chronicles of Karnataka, which is a home to many premier research institutes, universities, giant IT companies and public sector enterprises. These however, despite their huge potential, have not significantly influenced and strengthened science education. The State of Karnataka with its national and international glory is therefore best suited to undertake '*Revamping Science Education*'. In the process it can also become a model to the rest of the country. Sir C. V. Raman said: "*There is only one solution for India's economic problems: that is science, more science and still more science*".

As per the Department of Public Instructions, Karnataka, the State has 78,424 schools offering education at the primary and secondary levels. Out of these, 22,419 schools are located in the urban areas, whereas 56,005 are located in rural areas. Further, Karnataka has around 30 universities and about 1000 UG degree colleges and several among these also offer PG courses. Hence, large investments are needed to support the much needed and vital component of the science education spanning from schools to universities and create inspiring ecosystem needed for innovation, enlarging the pools of researchers, and overcome resource crunches. Expenditures on research (% GDP), number of researchers (per million population), and international patents filed are far lower in India compared to say Israel, South Korea, Japan, Germany, France, UK, Belgium, Sweden, Denmark and other countries and slightly higher compared to that of Pakistan and Mexico (*Source: Unes co Institute of Statistics, June 2020.* https://youtu.be/8yElkAgOyqE).

Lastly, the Committee is aware that implementation of every new policy suffers by its own set of problems. With a strong conviction, concern, will, and commitment on the part of the State Government, educational institutions, and the bureaucrats, nothing is impossible to achieve. However, liberal investments will be required; seeds have to be sown and cared for to ensure accomplished objectives. Furthermore, the entire process of implementation and sustenance has to be properly guarded and nourished so as to ensure rich harvest. The recommendations made are consistent, and expand and amplify the nature of deliverables with those of the National Education Policy-2020 (NEP-2020). Further, it is the most opportune moment for a revamp of Science Education in Karnataka concomitantly with NEP-2020.

II. Preface

Education is a dynamic process that is subject to periodic changes as per the needs of the society and the country. At the same time, it has to keep track of global trends and accompanying pressures for modernization. Till about the 8^{th} century (CE) the education in India was based purely on indigenous knowledge; yet it was well recognized internationally, and scholars from different parts of Asia visited Indian educational institutions like Nalanda and Takshila (now in Pakistan). It is obvious from the early relics and remains that the Indian subcontinent was quite advanced in the fields like Mathematics, Astronomy, Engineering (e.g. Metallurgy, Temple Architecture etc.), Philosophy, Painting, and Indigenous Medicine (e.g. Ayurveda). That India is the mother of all civilizations is recognized worldwide; besides it contributed 'spirituality' to the world as opined by eminent scholars. Mark Twain, the American author opined that "*India is the cradle of the human race, the birthplace of human speech, the mother of history, the grandmother of legend, and the great-grandmother of tradition. Our most valuable and most instructive materials in the history of man are treasured up in India only*". Likewise, Will Durant, the American historian opined that "*India was the motherland of our race, and Sanskrit the mother of Europe's languages: she was the mother of our philosophy; mother, through the Arabs, of much of our mathematics; mother, through Buddha, of the ideals embodied in Christianity; mother, through the village community, of self-government and democracy. Mother India is in many ways the mother of us all*". Lastly, Albert Einstein, one of the world's greatest scientist stated that "*We owe a lot to the Indians, who taught us how to count, without which no worthwhile scientific discovery could have been made*".

The Indian education got westernized under the influence of colonial rule; Indians learnt English and soon acquired the customs and mannerisms, and culture of the West. Consequently, culture and history of India, and indigenous knowledge in various domains including that of science received little attention. Yet, science is the foundation of tomorrow's dream. Technology is transforming the world around us and, parallel to Industrial Revolution 4.0, is the emergence of Education 4.0. Therefore, we must recognize that the technological innovations along with social, economic and cultural forces have influenced the evolution of educational systems. As the new windows of knowledge opened, while influencing the educational process have impacted technological developments and we are experiencing the '*age of transformation*'. The message is loud and clear that by nurturing fundamental sciences one establishes the breeding platforms for tomorrow's technology.

To a great extent, the challenges and concerns of science education are: 1) market driven combinations or fragmentation of subjects at the cost of the holistic approach, (2) a rarity of passionate and competent faculty, (3) poor and uninspiring curricula that do not match global standards, and (4) age-old methods of teaching-learning and assessment processes that are clearly not learner-centric. All these seem to have led to a loss of trust by both parents and students about career prospects of basic sciences thereby resulting in a negative intake of talented students in Colleges. Additional problem pertains to the vast gaps between rural and urban students in terms of their diverse backgrounds (ex: first- or second-generation learners), provision of infrastructure and lab facilities, teaching fraternity and so on; that obliterate requirements of the '*21st Century Skill Development*' programs.

Sound science education is basic to the advancement of not only scientific technologies, increasing agricultural yields, addressing biomedical issues, containment of air and water pollutions, management and sustenance of making innovations, enhancing quality of human life (e.g. protection of environment, adopting hygienic practices, management of human diseases, etc.). The hallmarks of the 21st century scientific innovations are reflected in the wide-ranging use of complex digital technologies (e.g. extensive usage of artificial intelligence (AI), digital connectivity including the driverless vehicles and automation of industrial processes), a major impact of which is *automation* and *technology driven disruption* in manual jobs. Future of India depends hugely on the development, adoption and management of science & technology and making innovations. This calls for a radical change in (1) the mindset of teachers and their acceptance of new roles, (2) teaching-learning-assessment processes, (3) revamping curriculums and adoption of modern pedagogies; all aimed at promoting critical and creative thinking, problem-solving, self-learning, and making innovations. The present policy paper should catalyze much needed revamping of science education and research in the State of Karnataka which has a huge potential and power to be the leader and a model to the rest of the country.

III. Growth of Science: A Brief Perspective

A critical understanding of the issues relevant to growth and development of science over the centuries is necessary to appreciate the need for revamping science education. Progress in science and its conceptualization have roots in various cultures: Egypt, Indian subcontinent, China, Greece and Middle East. However, modern science as we practice today is not even 500 years old and developed during and post-Renaissance periods in Western Europe and then spread through colonial rule to the rest of the world. No wonder, Science is *global* in its reach and *impact*.

Science comprises observations, hypotheses/assumptions, experimentation and deriving theories. Theory is constructed out of observations and experimental results. Sometimes the hypotheses provoke a series of questions that are tested experimentally to prove or disprove them. The principle of certainty, the confidence or the validity of observations or experimental results necessarily depends on measurements. The scientists all over the world are in a way obsessed with measurements. When measurement and analysis are restricted to the physical properties like volume, pressure, temperature, etc., the resulting body of knowledge is called *Physics*- that which tries to comprehend physical nature of the universe, the nature of '*matter and energy*'. The Newtonian world of gross objects and their interactions and the quantum world of fields and their interactions are two apparently different worlds to average citizens including educated laymen. Modern Science, especially Modern Physics developed during the 16^{th} - 18^{th} centuries due largely to the contributions of Copernicus, Kepler, Galileo, Newton and thoughts and writings of intellectuals like Rene Descartes and others. Philosophy of science is largely a contribution of Physicists. Mathematical physics played a great role in developing classical world views about space and time or the relative and quantum world. Immanuel Kant in the 19^{th} century developed the philosophy of modern science based on pure reasoning or logical thinking. Physicists very rightly had indicated that biological systems remain in a steady state away from equilibrium and that energy input/output are responsible for such a steady state (Schrodinger, 1944). Soon thereafter physicists took interest in biological phenomena and developed integrative links between physics and biology.

Chemistry is another branch of science that deals with the study of matter, composition and energy transformations in terms of atoms and molecules and in recent times to nano-particles. The matter refers to the elements and their compounds. The nano-particles of a given element may acquire some very new and unusual properties not observed in the bulk state (e.g. Gold nano-particles). Most physicists believe that nature can be better understood through mathematics and, that its language is mathematical so that the physical reality of this world can be expressed beautifully through mathematical language! In short, it is not so easy to precisely state what the science is. Karl Popper, the modern-day philosopher of science has further complicated the definition by stating that "a non-falsifiable knowledge is not science".

Unlike physical sciences, biology did not measure anything seriously for over 2000 years; roughly from 320 BCE or the time of Aristotle to 17th century CE. Obviously, structural aspects, rather than the parameters of function/s were emphasized initially in the classical or *in vivo* biology which lasted for a long time. Description of structures (morphology, anatomy etc) and their diversity across animals/plants, relationships between species requires their identification and hence taxonomy became the dominant biology for hundreds of years. Beginning the 17th century, the study of functional aspects of biological systems got prominence giving birth to physiology and experimental anatomy. Charles Darwin's ideas proposed in the mid-19th century shaped the most important concept that unified the biological disciplines under a common theme of *evolution*. When the targets of enquiry of biological systems increasingly addressed cellular and molecular levels, *reductionist biology* or the so called *in vitro* biology got established. A useful outcome was the increasing influence and application of physics and chemistry to comprehend the relationship between the structure and function of organisms. Molecular and Cellular Physiology, Biochemistry and Biophysics became the dominant features of biology for more than a century. So much so, description of molecular processes defining the living state became a passion.

Rene Descartes, the French Mathematician and Philosopher of Science had advocated that science should have applications to human welfare. The purpose of science itself was restated; it meant not only understanding the nature but also controlling it. The ability to exploit natural resources became a development index and a mark of progress in parallel with civilization. Application of science to human affairs became more important than mere pursuit of basic science and got linked to employability. Hence, professional education in '*Applied Sciences*' (e.g. engineering, electronics, medicine) acquired greater importance than the basic, pure and fundamental sciences. Biotechnology is the latest in the chain of applied sciences. Biology for a long time was lagging behind physics and chemistry in offering creature comforts to human existence. Biotechnology changed all that. Our increasing ability to handle proteins, nucleic acids, cells, tissues and whole organisms, coupled with the use of tools of information technology, enhanced the growth of biotechnology. Such progresses have led to hopes for edible vaccines, transgenic crops with drought and disease resistances and high yield, stem cell application in regenerative medicine, cell culture derived biopharmaceuticals, bioactive principles from marine biodiversity, recombinant functional proteins with thermal stability and long shelf life of fruits and vegetables and so on to name a few.

In recent years the biologists realized the importance of *interactions* among molecules, cells and tissues, in addition to isolating individual structural components, in creating 'living phenomena'. It has now become crystal clear that biological phenomena are consequences of interactions between biotic and abiotic factors and that the quantum and consequence of all processes is relative. '*Systems biology*' or the so called *in silico* biology began to gain importance by the turn of the past century. Now it is unambiguously clear that the context dictates gene function; thereby suggesting that genes should not be studied in isolation. It is now well known that DNA is not the destiny; epigenetic factors play an important role in controlling or regulating gene functions. Consequently, a distinction between 'intrinsic nature' and 'nurture' became blurred. At the same time, phenomena like instinct and learning also got clarified.

It is important to note that, historically, the pursuit of science was never a job but a matter of passion! Venkataraman Ramakrishnan, the chemistry Nobel laureate, rightly remarked that "*you go to science to solve a problem, not to find ingredients of success*". It is by the 19th century that Science and Technology became curricular subjects in the university education enabling science graduates and post-graduates secure employment in private and government enterprises, or enter investigative areas of science and technology. As of now, there are three distinct spheres of our society that offer employment to young scientists. One is the ubiquitous university system. Another is the R&D institutions set up by the Union and State Ministries as well as the private enterprises, and the third is the strategic research institutions established by the Ministries of Defense, Space and Atomic Energy, and certain private technology hubs all of which have their own mandate(s). There is no overlap of mandates between the institutions. However, the employability depends largely on the quality of education, acquisition of '21st Century Skills' and ability to think, innovate and undertake cutting edge research.

In light of what has been said above, if we attempt examining current scenario of original and breakthrough science at the Global level, reception by Indians and its influence on Indian Science and Science Education, one cannot help noticing that most of the breakthroughs are reported from the West (Europe and USA). Occasionally it is also reported from Japan. Indian scientists are quick to absorb these developments and are able to register independent progress in turning out significant work and add to the importance of those fields. In theoretical science (e.g. mathematical Physics etc) Indian work is as good as the western work. In some cases, especially Biology, lack of 'state of the art' infrastructure seriously affects Indian work from becoming competitive. New ideas and research questions and problems, invariably appear to come out of western laboratories. Further, it takes decades before the new developments become part of curriculum in UG / PG science education.

Our curricula and syllabi are rarely revised meaningfully by the Board of Studies. Often difficult topics are deleted instead of adding new topics of current importance in the name of revision of syllabi. Multidisciplinary approach to studying science subjects is glaringly missing. Furthermore, in many institutions teaching is done largely by the guest faculty working on contract basis. Furthermore, when a well-meaning Vice-Chancellor or Head of the department wishes to revise, update and modernize UG / PG syllabi, he/she will invariably face opposition from colleagues. By instinct we talk of past glory, but it does not bring forth excellence or provide future vision. Progress in Science and Technology is important for the National Development and Nation's standing in international bodies. Therefore, as evident from history, no nation can afford to have weak Science and Technology base.

As an illustration, let us consider research in biology at the global level and how much of it is practiced, leave alone developed here, in our country. Every wave of new returning post-docs from USA or Europe or Japan (and other countries) brings news of latest developments. They establish required facilities and practice the same in their careers. Despondently, they fail to create new knowledge; fail even to practice existing knowledge with technical rigor. For instance, Taxonomy, Enzymology, Structural Biology, Adaptation and Evolution, Developmental Biology, Immunology and Neurobiology are some of the teaching and research areas which are practiced in India for more than a century with little impact even on its sustainability. With the exception of G N Ramachandran, we are happy being 'camp followers' of the Western or Japanese Science. In Universities, inbreeding in the faculty appointments has greatly resulted in decline in quality and representation of new knowledge domains. Inbreeding *per se* may be useful sometimes provided it helps consolidate and expand a School of Thought. Consolidation in depth should also be followed by differentiation and addition of breadth. The department of 'Biophysics' at University of Madras, 'Chemical Technology' at University of Mumbai, School of 'Comparative Endocrinology' at Banaras Hindu University and Karnatak University, Biology of Reproduction at Delhi University, or the Schools of Cytogenetics at Calcutta, Delhi, Mysore and Banaras are minor exceptions that survived for more than 50 years at excellence level. Many other great departments at other places witnessed precipitous decline within one or two decades of existence. Such is the story of other science departments as well. Is it possible that good scientists are recruited in research institutions established by the CSIR, ICMR, ICAR, DBT and DST rather than in the Universities? Is it possible that universities have failed to attract talented faculty due to their poor academic ecosystems (cooperative and competitive environments) and recruitment policies? May be, specific surveys and studies are needed to produce a white paper on the steadily declining story of State Universities. In any case, efforts and mechanisms are needed to attract and retain talented faculty in our university system. In recent years, many colleges teaching UG courses have also started PG courses. Therefore, such colleges require competent and committed faculty.

The tradition of doing original work and incorporating new developments into higher education and training has to be part of our 'psyche'. Great institutions like the Universities of Oxford or Cambridge or Harvard and the Massachusetts Institute of Technology (MIT) have not declined in quality despite their long existence. We therefore need to learn from them on how great universities are built and sustained.

Finally, it is pertinent to note that a nation's growth in science and technology invariably depends upon three parameters: 1) sizeable number of researchers or research teams, 2) investment on science education and research, and finally, 3) making innovations. Therefore, we need a vibrant innovation ecosystem, higher number of researchers per million population and substantial financial resources (% GDP). Now, let us compare the situation in India with a few other countries with respect to the number of researchers and investments made on research. It is evident from the data presented in Table 1 and 2 that the number of researchers (per million populations) as well as expenditures (% GDP) on research in India is way lower than most other countries.

Table 1. Shows number of researchers in different countries

Country	Researchers per million population
Denmark	8065.88
S. Korea	7980.39
Sweden	7536.47
Austria	5733.07
Japan	5331.15
Germany	5211.87
Belgium	5023.26
France	4715.31
UK	4601.31
Russia	2784.33
UAE	2738.88
INDIA	252.7

Source: Unesco Institute of Statistics, June 2020. https://youtu.be/8yElkAgOyqE

Table 2. Shows expenditure on research in different countries

Country	Investment (% GDP)
Israel	4.95
S. Korea	4.82
Sweden	3.33
Japan	3.25
Austria	3.17
Germany	3.09
Denmark	3.06
USA	2.83
Belgium	2.82
France	2.20
UK	1.70
Canada	1.56
UAE	1.30
Brazil	1.20
Russia	0.98
India	0.64
Mexico	0.31
Pakistan	0.23

Source: Unesco Institute of Statistics, June 2020. https://youtu.be/8yElkAgOyqE

Table 3. Patents filed by China, Japan, South Korea and India as on 2019

Country	Resident patents	International patents	Patent Cooperation Treaty (PCT)	Total patents
China	12,43,563	84,279	58,990	13,24,847
Japan	2,45,372	2,06,758	1,10,821	4,52,130
South Korea	1,71,603	76,824	32,160	2,48,427
India	19,454	14,561	4,441	34,015

Source: https://www.wipo.int/pressroom/en/articles/2020/article_0005.html

The number of international patents filed is also dismal (Table 3). International patents filed are in fact far lower in India compared to many other countries such as Israel, Germany, France, UK, Belgium, Sweden, and Denmark and so on. India's investment on research is slightly higher than that of Mexico and Pakistan. Obviously, there isn't enough number of researchers and research teams needed to sustain cutting edge researches in India. Secondly, investment in research is miniscule compared to many other countries that are well known for their progresses in science and technology. Third, educational institutions in India need to urgently create academic ambience / ecosystem of excellence to support and sustain making innovations. Continuation of the existing trend of low numbers of researchers and research teams and miniscule investment on education and research is not sustainable as it will severely hamper developments in science and technology and in turn growth and economy of the country.

IV. Emerging Trends in Science & Technology

Both natural and social sciences evolve over time as they are always in a dynamic state. This is more so with science domain as newer developments in tools and techniques help in probing and seeking more and more information. For instance, instrumentation with greater precision has made it possible the exploration of fields like astronomy, ocean and earth sciences as well as complex biological realms at the molecular and quanta levels. All such developments are directly related to scientific discoveries and inventions which otherwise would have been unreachable. Following passages highlight the trends and developments in different branches of sciences as illustrative examples.

1. Physics: Post-Newtonian era, Physics evolved into Mechanics, Optics, Heat, Sound, Electricity and Magnetism during the 19^{th} century. The beginning of the 20^{th} century saw revolutionary ideas leading to the birth of Quantum Physics and Theory of Relativity. Planck, Marie Curie, Bohr, Einstein, among others, led the revolution. Our understanding of matter, energy and their relation was enhanced in terms of atomic particles like electron, proton, neutron and photons. As a result, new branches like Atomic energy, Nuclear energy, Condensed Matter and Laser Physics were born with unforeseen diverse applications and innovations that have since changed the course of our civilization. While the atomic bomb changed world's geo-politics, transistor and lasers technologies created game-changing communication systems and novel engineering processes including the latest LED bulb technologies, thereby bringing enormous benefits to the mankind. Einstein's *Theory of Relativity* replaced Newton's view of gravity as the geometrical property of the space-time in which the stars and planets move without being dictated by the gravitational force. It is a matter of great pride that the Indian scientists, Sir J. C. Bose, Sir. C. V. Raman, Megh~~a~~nad Saha, Satyendra Nath Bose and Dr. Homi Bhabha have made fundamental discoveries in Modern Physics. Outcome of these scientific advances is the emergence of newer multi-disciplinary branches like~~,~~ Space Science, Nanoscience, Material Science, Quantum Computing and Biophysics with physics and chemistry as their base have already demonstrated infinite possibilities of diverse applications in devices, technologies - health care to manufacturing, to name a few. Students who learn conceptual frameworks of different branches of Physics and all the novel physical theories need a strong analytical approach in teaching and a good grounding in laboratories.

2. Geosciences: Indian subcontinent has all attributes for the study of geosciences (glaciers, mountains, rivers, oceans and so on) in totality and as such an opportunity to be the world leader. However, Geoscience~~s~~ is complex in nature and now an interdisciplinary science that includes social dimensions as well: impact of earth quakes, mining, volcanoes (though rare), landslides, floods, and modeling predictions and so on. Hence, cutting edge research in geosciences requires participation of not only the scientists and teachers but all stakeholders.

Clearly, future geosciences teaching departments need to include faculty/courses from Physics, Applied Mathematics, Instrumentation, Computer Sciences, Biology, and Material Sciences besides conventional subjects to enable integrated teaching. Teaching and research in the newly emerged areas such as Geo-morphodynamics, Geo-biology, Geo-mathematics, Eco-hydrology, Eco-geo-morphology, Geo-pharmaceutics, Medical Geology, Geo-forensics, Molecular Palynology and Paleontology will then be possible (Singhvi, 2020).

3. *Chemical Sciences*: From the 20^{th} to the 21^{st} century, Chemistry, once widely regarded as an art and lab technique, has evolved into a fundamental science because its base is now molecular and its body is mathematized. Today, molecular modeling partly based on the laws of physics and partly on mathematical modeling has taken chemistry to a level of understanding very complex chemical as well as biological systems. Chemical Science has contributed enormously to the industrial growth that include pharmaceutical, specialty chemical, agrochemical, textiles, beverages, cosmetics, semiconductor and metallurgical sectors. Extensive use of metals and their composites, polymers and their composites, various nano-materials in electronics and allied areas highlight the importance of chemical sciences. Further, it is heartening to note that India is contributing to about 62% of vaccine requirement of the world. This has been possible using the principles of chemistry, biology and engineering sciences. Thus, with the advent of technological innovations, new materials for various societal benefits are emerging very fast.

To meet the growing needs of the society, industries are looking for graduates in chemical sciences with good analytical, critical and problem-solving abilities, and laboratory skills. The education sector is still to catch up the speed at which the industries are growing. At the same time, success-driven commercialized institutions as a rule lay more emphasis on students passing examinations (including entrance examinations) with high marks rather than on nurturing analytical, critical, problem-solving abilities and, practical skills. Clearly industrial growth requires workforce with inter-disciplinary knowledge of biology, physics, mathematics and computational skills in addition to basic and advanced knowledge of Chemistry. In short, revamping of teaching and research in Chemical Sciences as outlined above is required at all levels of education.

4. Biology: Compared to physical sciences progress in biological sciences has been slow in the past due mainly to lack of technology (microscopic, biochemical, and other techniques) to study the biological principles at tissue, cell and molecular levels. Biologists had to wait for development of technologies by physicists, histochemists, biochemists and instrumentation engineers. In the 20th century with progress in development of instruments (e.g. a variety of microscopes), biochemical techniques, and discovery of DNA structure, methods for tissue and cell cultures, amplification of genes and their editing and so on led to enormous progresses in basic biology as well as biotechnology. Green revolution, Blue revolution, White revolution, Pharma-agriculture, Vaccine production, Drug designing are prominent examples depicting progresses in biological sciences. At one time, biology was considered simplest of all sciences. Today it is recognized as the most complex of all scientific disciplines. Various biotechnological innovations and emergence of systems biology (that studies molecular interactions within cells), and participation of experts from all major branches of sciences: physics, chemistry, mathematics and modern digital technologies have greatly enhanced understanding the complex biological principles. Yet, we are far from understanding neurobiology, human mind, consciousness, and the comprehension of how neuronal signals are converted into pixilated memory of short and long duration will necessarily invite application of principles of physics and different states of energy. Ultimate aim of science is to understand fully the life processes as well as origin and evolution of life.

5. Mathematics: Mathematics is used widely in all domains of science because of the inductive and deductive reasoning used to arrive at scientific knowledge. It makes the base of science logical, formal, verifiable and predictive. Similarly, social sciences too are adopting mathematics to understand complex processes in terms of models with deducible properties. Modern sciences and social sciences rely on gathering and analyzing data based on mathematical models. With the application of mathematical principles, physics made the transition from a qualitative to a quantitative science about 3-4 centuries ago. In the 19th century use of mathematical principles in Chemistry led to the arrival of a discipline namely Mathematical Chemistry. The partnership between mathematics and biology began in the late l800s, primarily through studies of inheritance; Gregor Johann Mendel (father of Genetics) first introduced the concept of probability and how to 'think mathematically' in genetics. Today, mathematical-statistical analysis remains an essential and important component in Biology. Mathematical modeling has helped understanding diverse phenomena such as the cardiac function and blood flow, muscle contraction, transmission of nerve impulses, enzyme kinetics, biological clocks, the growth and dynamics of populations, ecology, animal behavior, genomics, proteomics and spread of pandemics and the exquisite process of adaptive evolution. The arrival of computational biology has changed the face of biology. It will need new mathematical and computational tools such as algorithms in the mathematical theory of directed graphs, stochastic processes and population genetic models. The coalescing of genetics, mathematics, information science, and technology, has resulted in the emergence of *Bioinformatics* and in turn to an exciting field namely '*Predictive Biology'*.

From the foregoing passages it is clear that understanding complex scientific developments and the emerging trends in modern sciences demand (1) building conceptual framework, (2) liberal use of illustrations (3) developing capabilities for problem-solving, (4) self-learning, (5) extensive usage of online teaching-learning materials (visuals, demos etc.) and finally (6) adopting international procedures of assessment that focus on competency rather than on rote memorization, the standard operating procedure in vogue for centuries. Teachers have to creatively develop teaching modules and materials as well as well-designed easy-to-perform lab experiments and combine with online learning tools including animation software. Problem-solving should become an essential component of teaching-learning processes in all domains of science and replace the present system of rote learning. Also, laying emphasis on the multi-disciplinary nature of science subjects by removing walls between subjects say, physics, chemistry, biology, maths, and computer science is needed. Today, understanding complex scientific principles and development of technology in all domains of natural sciences requires extensive use of mathematics. Even in social sciences like sociology, economics, commerce, anthropology and so on application of mathematics is crucial. Therefore, teaching mathematics, statistics and their applications is inescapable across both natural and social sciences. Likewise, methods of assessment are to be designed to test the competency and skills of the learners rather than rely upon their textbook and content-centric rote learning abilities.

V. Impact of Industrial Revolutions

It is very pertinent to note that while scientific developments usher in industrial revolutions, the latter in turn impacts education systems. Thus far four industrial revolutions (IR 1.0-4.0) have taken place. The first was *textile revolution* (IR 1.0) that took place around the year 1780 in England and heralded *mechanization* of productions. This was possible due to the harnessing of water and steam power and weaving looms. Interestingly, England does not produce cotton or coal! All cotton and coal went from India and facilitated the textile revolution which should have ideally taken place in India. The second revolution (IR 2.0) occurred after about another 100 years (around 1870) in United States of America following invention and introduction of electrical power. This facilitated *mass production* using assembly lines. Almost another century later roughly around the mid-20th century simple digital technology gave rise to *automation* which was driven largely by developments in electronics heralding the third industrial revolution (IR 3.0). It is interesting to note that while the first three IRs were roughly spaced by 100 years, the fourth IR (IR 4.0) took place within couple of decades after the IR 3.0 (Klaus Schwab, 2017). Thus, by the turn of the 20th century, owing to developments in *Complex Digitization Technology* (using Cyber Physical Systems) the 4th IR was accomplished which is massive in terms of both *speed* and *impact*. Some of the glaring and highly impacting developments of the ongoing IR are in the area of robotics, autonomous vehicles, 3-D printing, quantum computation, energy and data storage facilities, material science, nano- and bio-technologies, AI etc. These developments have contributed to new dimensions of human life like the *internet of things* (IoT), *internet of people and internet of services*. All these are fine. But, an inescapable consequence is huge loss of various types of jobs. The phenomenon is called *technology driven disruptions in jobs*. A classic example is Kodak Eastman Company; the world's largest film making company which had ~ 170,000 employees stands bankrupt today. With every passing decade several types of jobs are disappearing. Furthermore, it is possible to predict future losses in jobs. For instance, jobs like: Assembler/ Fabricator, Bank Teller, Cashiers, Dispatcher, Fast food cook, Legal Secretary, Lumberjacks, Mail carrier, Printing Press Operator and many more may disappear by 2030. The list can be endless. Yet, one need not be too gloomy. New developments in science and technology and innovations also create new jobs that require new skills for sustenance of new technologies. Undeniably, India which enjoys demographic dividend in the form of high youth population needs to overcome job disruptions rather quickly and avoid a discernible frustrating scenario. Therefore, the only solution resides in changing the existing educational systems, particularly with reference to science and technology.

VI. Need for a Globally Competitive Science Education

Science Education requires establishment of the ‘scientific temper’, learning and assimilating the ‘philosophy of modern science’ through appropriate pedagogies, the practice of answering questions based on the ‘known and unknowns’ related to the realities faced in relation to the mechanistic principles revealing their cause and relationship. In the Indian context, many factors contributed to the declining quality of modern experimental science education in the past decades. Prof Yash Pal had repeatedly emphasized that ‘*empirical experience should precede theoretical construction*’. In India, science was taught more from books and less from laboratory and field observational experiences. Experiential learning has been limited. Problem-solving, self-learning and group-learning have been conspicuous by their absence from the curriculum. Examinations and grading have largely relied upon the ability of learners based on rote learning rather than the ability for *critical* and *creative* thinking and *competency*. Doctoral and postdoctoral researches have focused mostly on repetitive rather than original research. Most doctoral theses in Indian universities and even premier institutions often do not contain a *thesis*. Consequently, such researches have not led to major discoveries and inventions. So much so, *cutting edge* research in science and technology appears mysterious to many practitioners of science in India, and could produce only one Nobel Laureate in Natural Sciences so far. Apparently, the country has not kept up with Raman’s legacy of making new innovations even after 90 long years. Despite numerous Education Commissions and Committees, science education received little emphasis and these entities focused more on general education and research than on science education, experiential and self-learning. The result was increasing gap in standards between top research scientists working in premier institutions and the science teaching and research in less endowed institutions like the colleges and State universities. There are many reasons for all such disparities.

Let us begin with school education. A proper school education in science is of paramount importance in kindling the young minds about the fascination of doing science, knowing its benefits and making innovations and developing technologies. At present, only a few basic concepts in science are being taught at the school level. History and growth of science are not taught. Further, different Boards regulate Secondary School Education (up to 12th standard) across the country. These include: CBSE (Central Board of Secondary Education), CICSE (Council for Indian Certificate of Secondary

Education), ICSE (Indian Certificate of Secondary Education for class 10) and ISC (Indian School Certificate exam for class 12); IB (International Baccalaureate); IGCSE (International General Certificate of Secondary Education); and, above all, various State Boards. Of these, CBSE curriculum is largely adopted by the State Boards including Karnataka.

During the secondary stage, the last 4 years of school education, students should be made aware of two facts: 1) that science and technology enable each other, and 2) the distinction between pure and applied sciences is getting blurred. Further, the predominant way of teaching practiced in India that involves mostly, listening, reading and remembering (passive absorption) must change to self-learning. It involves questioning, thinking, searching, doing and experimenting. It is a creative process leading to creative mind. Advances in the fields of Science and Technology depend on nurturing the creative mind leading to potential 'Researchers of High Caliber' and 'Original / Creative Thinkers'. The students thus need to be trained to have the mindset of researchers. For this, training of teachers is obligatory. Further, facilities for creative learning need to be created in schools. Greater use of ICT tools can help revamping science education in schools. It will help students to become *self-directive;* an important step in developing a creative mind. By the time students complete their school education, they should acquire the knowledge of science Concepts: understanding of the terms like~~,~~ Facts, Percepts, Concepts, Laws, Theories, Principles, and Scientific method etc. The key aspect of science education is to imbibe curiosity, wonder, imagination, and asking questions like, *what, how* and *why.* Thus, a focus on critical thinking, inquiry, discovery, discussion and analysis-based teaching and learning constitute holistic education. At the end of the school education students must learn how scientific knowledge is created and also internalize a scientist's cerebral processes.

Now let us look at the teaching program. As far as the students of science streams are concerned, in addition to Physics, Chemistry, Biology and Mathematics, a few states also offer Computer Science and/or Electronics. The students of CBSE stream can choose subjects which are grouped together under medical or non-medical groups. The students of '*Medical Group*' study English, Biology, Physics, Chemistry and one optional subject. Those of '*Non-Medical Group*' study English, Math, Physics, Chemistry and one optional subject. It may be noted that Maths is missing in the medical group while Biology is missing in the Non-Medical group. Computer base is missing in both the groups. Further, as the students of these two groups aspire for securing seats in the professional colleges (medical or engineering) which solely depends on the marks scored at 10+2, the students invariably opt for private coaching classes (NEET/CET/GATE examinations) and hence examinations-oriented curricula. Incidentally, public perception on the reputation of colleges/universities is greatly influenced by the performance of students in such examinations. Naturally, coaching exercises are solely designed to score high marks at the cost of real learning and appreciation of the depth and breadth of scientific knowledge and its value. In the process, interdisciplinary courses that enhance knowledge are rarely offered. Consequently, the present education system has deprived the students the opportunity of choosing interdisciplinary courses, open electives, and skill based courses. Thus, academic flexibility is more or less absent at a time when students have most fertile mind and ambition. In a way students are made to believe (by both parents and public) that future (employment, prosperity etc.) depends exclusively on pursuing professional courses only. Undoubtedly, coaching classes designed to score high percentage of marks fail to impart science education with focus on the fundamental concepts, excitements of science and its value. This trend is indeed a deathblow to scientific advancements, cutting edge research and innovations.

Now let us consider teaching-learning processes in the colleges. It is important to recognize that learning and deep understanding of fundamentals of science takes place by and large first in colleges and later refined in universities. At the same time, experiential learning through experiments and hands-on training can take place only in the laboratory and not in the lecture halls. Unfortunately, many senior teachers with experience show reluctance to undertake laboratory teaching. As a result, laboratory teaching is generally left to inexperienced junior faculty, research scholars, and guest/ contract faculty. Formerly, positions of science teachers as 'demonstrators' were available in colleges and universities and such faculty members used to manage the laboratory works rather very well. Abolition of these positions has undoubtedly contributed to undermining the experiential-learning. Furthermore, self-learning, group-learning, project-based learning, problem-solving and critical thinking are glaringly absent in our teaching programs. Availability of laboratory teaching kits has further worsened the situation because students no more learn how to gather required materials and prepare various solutions (e.g. preparing a buffer solution, stains or preparing certain chemicals for various assays etc.), and tools for their experiments. Promotion of rote-learning, conducting experiments with readymade kits (easy option) and so on has taken away the curiosity-based learning as well as critical thinking. Therefore, framing curriculum of UG courses should be such that it enables the learners to develop capabilities to ask (a) right questions and (b) think creatively (depicting originality). Indeed, these are two main pillars on which the edifice of science stands. Accordingly, the teaching should include apprising learners the various ways of thinking and also thinking like a genius. Breaking the rules meaningfully and getting out of the rule rut needs emphasis. As to asking questions, students, at every stage, must ponder over -"what don't we know", what are the limits of validity of the present understanding of a given phenomenon / theory and so on. That, a question leads to more profound questions should be illustrated with suitable examples. Learners should also be exposed to examples which were once considered impossible, have now become possible.

Notwithstanding what has been said till now reforms in science education were undertaken seriously at some universities in our country like Madurai, Pune, Delhi, BHU, JNU and many more. Most of them addressed problems of pedagogy, balancing Laboratory/Field work and Theory classes etc. These reforms mostly influenced PG level science education. Chemistry education saw a paradigm shift with IIT, Kanpur and then got further boost by the reforms at Central University of Hyderabad. In some sense institutions like IISc and JNCASR, Bangalore made significant contributions to PG level science education and research in Chemical Sciences. Further, the three science academies took initiative and made significant recommendations on post-school science education. These were agreed upon by IISERs, IITs and some selected university Professors in 2008. As a result, integrated PhD programs were also started in some institutions. Major reforms were carried out in UG level science education (design and curricular content) by the newly formed IISERs. Biotechnology programs were also getting reformed and standardized in the country, thanks to huge financial support from Department of Biotechnology (DBT), New Delhi. Significant, novel and innovative changes at UG level science education (4-year pattern) were initiated at Delhi University (DU). The curricular content and pedagogy however differed between these centers of excellence. Notably, the NEP-2020 has brought all these reforms in one place and also emphasized the pivotal importance of recruiting competent teachers for succeeding in these efforts. No less important is the mission mode project initiated and sustained by JNCASR in designing, manufacturing and propagating the use of low cost scientific equipment. In rural and small town establishments which are less endowed, these educational initiatives have greatly helped in understanding fundamental sciences like the Chemistry and Biology. In post-independent India, many great Teacher-scientists also served the university sector with distinction. Panchanan Maheswari, TR Seshadri, DS Kothari, BGL Swamy are some examples. In the year 1994 the Indian Academy of Sciences, Bengaluru set up a Science Education Panel (SEP) which conceptualized variety of programs for students and teachers. In the year 2007, Indian National Science Academy, New Delhi (INSA) and National Academy of Sciences of India, Allahabad (now Prayagraj) joined the SEP programs. Under these programs, there is a provision for nearly 2000 Summer Research Fellowship (SRF), Lecture Workshops and, Refresher Courses for students and teachers. Such summer internship not only allows students to learn modern research techniques and laboratory practices but also help them experience the culture of research and development, as well as open the doors for advanced studies and employment. Indeed, these programs have made an impact by way of inspiring students to the pursuit of science.

Clearly, it is crucial for students to be initiated to the culture and nature of science based on 'appreciation', 'conceptualization' and 'problem-solving' by way of real-time experience during the formal education in order to instill passion and confidence in Science. The students need to understand the importance and inevitability of interdisciplinary / multidisciplinary approach as well as using mathematical language to understand the true nature of science. Science being universal, there is nothing like Indian Science or Western Science. Pursuit and applications of science and technology are global in nature. India has to gear up to meet the global challenges through quality science education, research, innovations and development of newer technology from time to time. For this, science education that is at par with the global standards is needed.

Education systems have evolved globally and in India too from the so-called “Gurukul” system to the presently ongoing Education 4.0. However, as outlined above, the science education has become somewhat outdated and remained uninspiring largely due to (1) poor infrastructure, (2) paucity of highly competent faculty in adequate numbers, (3) reluctance to modernize teaching science courses through: (a) integrating trans-disciplinary courses, (b) conceptualization, (c) mathematization, (d) making learner-centric, (e) promoting self-learning, group-learning, project-based learning, seminars, quizzes and, blended-learning.

On the top of the outdated teaching-learning processes outlined above is the age old examination system that relies on rote-learning. Such examination systems do not test ability of problem-solving, self-learning, creativity and making innovations. In this context, one may recall what Albert Einstein said on the prevailing examination system. He said “*Everybody is a genius. But if you judge a fish by its ability to climb a tree, it will live its whole life believing that it is stupid.*” But one may say that ‘for a fair selection everybody has to take the same examination.’ Imagine we are examining a monkey, a penguin, an elephant, a fish, a seal and a dog. Suppose we ask all of them to climb a tree and then award marks! Anybody can guess the outcome. Moral of the story is that we need to address our examination system and make it more meaningful and realistic. For this, one best way is to adopt continuous assessment system based on the everyday performance of the learners in class rooms, laboratory, seminars, quizzes, project-based studies, ability for group-learning, self-learning, creativity, critical thinking, and undertaking innovative projects and so on. Till now, education in science, just as other areas of human knowledge has largely indulged in information transfer and hence training the student to pass the examination. A continuous assessment system in place, the semester-end examinations may have minimum importance or it may even be done away with. In short, major reforms are needed in judging the students’ performance and awarding marks. Besides, worldwide, pedagogies of education and assessment have greatly metamorphosed in recent decades. Accordingly, it is high time to take cognizance of PISA formulated around the turn of the 21st Century. The tests prescribed under PISA are competency-based and designed to assess the 21st Century skills, notably, higher order skills in analysis, critical thinking, conceptual clarity, problem-solving ability, working in groups (collaboration) and communication, which will guarantee global citizenship. India is also going to join the league of about 90 countries in the 8th cycle of PISA. In the light of these developments the classic text book-centric and content-based tests (examinations) conducted by various education boards have lost their relevance in the global framework.

Further it may be noted that the concept of 'Make in India' and 'Self Reliant India' (*Atmanirbhar Bharat*) can only be driven by innovation; therefore we need to press the accelerator of innovation. The fact that even after 90 years, we have not kept up with the legacy of Sir C. V. Raman in the field of innovation. Obviously, there are reasons for this and the country needs to review this scenario and initiate appropriate steps to revive the legacy of Raman. Indian scientists who went abroad in search of a rewarding academic ambience congenial for discoveries and innovations have shown that given a chance they too can make great discoveries and innovations or breakthrough researches. Preeminent among these are Subramanyan Chandrashekhar, Hargobind Khorana, Venky Ramakrishnan, and Abhijit Banerjee. One might wonder if they were to stay in India, and without the ecosystem of excellence, could they have still succeeded in getting the Nobel Prize. May be yes; and maybe not. In any case, without first providing the needed infrastructure, competitive and cooperative *innovation ecosystem* it is unreasonable to expect breakthrough research.

In short, India needs a very robust and globally competent program of education in science and technology. The present system of science education in the context of changing global scenario needs to change considerably. While modernization of science education and research require significant improvements in the infrastructure, curriculum, adoption of modern teaching-learning techniques and digital pedagogies, the most important of all is a need for change in the *mindset* of teachers who are the chief architects, and prepare themselves to assume new roles of being a Facilitator, Mentor, Guide, Philosopher and Life-long learner. Ultimately, it is the quality of teachers, their commitment, competence and ability to inspire the learners to sustain technological developments and making new innovations matters. At the same time, the State government should extend uninhibited academic flexibility as well as administrative and fiscal support to schools, colleges and universities such that teaching and research improves and culture of making innovations is promoted as well sustained.

The present *policy paper* is thus a consequence of a deep concern originating in response to changes that have sweeping impact on global higher education especially in the field of science and technology. Whether the changes at the pedagogy level, or, in the context of exponential explosion of knowledge, re-drawing of the traditional barriers of disciplines, need for technology-enabled learning, or a combined effect of all these, the higher education is at the cross-roads. The traditional relation between the teacher and the student is changing, making the student a center of all learning processes. Therefore, teachers, schools, colleges, universities and governments are all called upon to respond adequately to these sweeping changes. These and various other compulsions explain the genesis of the policy paper which attempts to make broad recommendations to enable institutions to bring about structural changes in the framework of education in Science in the State of Karnataka.

The present Committee deliberated exhaustively before formulating its recommendations. Two major objectives envisioned are: 1) revamping science education in the light of changing global scenario and, 2) enabling science education to focus on learning how to learn, unlearn and relearn and, to acquire skills to undertake cutting-edge research, the psyche of an innovator. Indeed, repurposing science education and research can address the issues arising out of technology driven disruptions in jobs and such other unforeseen challenges (growing youth population for instance) of the future, and at the same time the country should remain relevant in the rapidly changing world scenario. In short, we need to provide UG/PG education to students which make them *future-ready*.

VII. National Education Policy in Brief

It is heartening to note that the Government of India is in the process of overhauling the entire education system through a National Education Policy (NEP-2020). The NEP-2020 has rightly diagnosed certain defects in the present system**.** The most relevant among these are: (a) severely fragmented higher educational ecosystem; (b) low emphasis on the development of cognitive skills and learning outcomes; (c) a rigid separation of disciplines, that drives students into narrow areas of study without adequate domain background, (d) low standards of UG education; (e) contracted faculty (that often lacks professional competency) and institutional autonomy; (f) general lack of focus on research at both colleges and universities, and (g) lack of tough and competitive peer-reviewed research funding across disciplines. The NEP-2020 underscores the urgency to provide holistic education with multi-disciplinary approaches in UG / PG degree programs and at the same time allow multiple exit points as well as opportunities for lateral and multiple entries. Accordingly, the Committee took cognizance of the various recommendations made in NEP while proposing plans for basic science education.

Briefly speaking, the new education policy envisages first 5 years of the child to represent the foundational program / *Early Childhood Care and Education* (ECCE) which represents 3 years of preschool + Grades 1 & 2. The next 3 years are considered as *preparatory* stage and covers Grades 3-5. The subsequent 3 years (Grades 6-8) constitute *middle school* where the science teaching in a way begins. This is followed by *high school* or *secondary stage* comprising of 4 years of study (Grades 9-12). In this stage, focus is on multidisciplinary study with subject oriented pedagogies and curricular style of the middle stage but with greater depth, critical thinking and, greater attention to life aspirations and flexibility in student choices. The emphasis is to be on the real understanding rather than on rote-memory and, learning how to learn.

As far as higher education (post Grade-12) is concerned the major structural reforms suggested are: 1) universities and colleges to be multidisciplinary, 2) adopting 'school system' for trans-disciplinary courses to strengthen interdisciplinary / multidisciplinary approach in teaching and research, 3) providing academic flexibility with many open electives, add-on courses (skill development, etc.) and, exit and lateral entry provisions, 4) mobility from one institution to the other with credit bank facility, and 5) phasing out the present system of affiliating colleges, and making them autonomous. An undergraduate student completing one year can exit with a certificate, after 2 years with a diploma, and after 3 years with a degree; a possible repercussion is that this may create a huge bureaucracy of certificate production and delivery system. Then there is a 4 year degree program as well to enable further consolidation of expertise in a chosen subject with research. Further, the Master's degree program may consist of one or two years depending upon the UG degree program opted by a candidate; this may create confusion with respect to the equivalence across different institutions, states and disciplines. In addition, there is a provision for 5-year integrated Bachelor's / Master's degree program with research.

Designing inter-disciplinary courses for various UG / PG classes as envisioned by the NEP-2020 is not very easy in view of the multiple exit / entry options (see above). Further, learning any subject and mastering it require a continuity of thoughts and evolution of concepts with increasing complexity as the learners enter higher classes (under UG or PG programs). In addition, the changing times demand adoption of new teaching methods and tools to make teaching-learning processes more productive and learner-centric. Also, it is time to develop robust, adaptive, accessible digital teaching-learning platforms for self-learning and blended-learning. Undoubtedly, those involved in drafting syllabi for various courses have a daunting task, and more so for science education. Development of a good curriculum (syllabi) should be entrusted to subject experts, rather than to the presently existing formal Board of Studies (BOS) where teachers are nominated based on seniority or elected (in some States). Finally, the examinations system that is age-old and relies on memory based, text book-based, or content based, is no more adequate. The system should allow testing competency of learners, ability to self-learn and working in groups, critical thinking and so on. Continuous assessment should more or less replace semester-end examinations. Ideally, procedures laid down by the international protocols like the PISA needs to be adopted as the country is going to join the league of some 90 countries using this option. If done so, our students will be in a better position to face international pressures and challenges. The present Committee has made its suggestions that are largely complimentary to NEP-2020 as well as in consonance with its viewpoints.

VIII. The Recommendations

Reforming, restructuring and repurposing education system requires multiple approaches. Accordingly, the process of revamping science education may encompass both 'top-down' and 'bottom-up' approaches as these are not mutually exclusive. The top-down approach involves enhancing teacher quality: good teachers at the PG level would train PG students well who will later become better teachers in colleges and train well their UG students, who in turn will produce good teachers needed in school education. This may be wishful thinking. But being optimistic, if students are well trained in a given subject domain, develop passion for reading, writing, teaching and research, making innovations such as small gadgets or conducting novel experiments will help them greatly enjoy teaching and use the opportunity to nourish their passion and in turn inspire learners. Inspirational teaching will go a long way in sustaining science education that excites learners to take up careers in science. This is top-down approach. In actual practice, the bottom-up approach is the best because learners are given quality education right from school days to the PG level. The creativity embedded in the young minds needs to be kindled, nourished, and harnessed by the time the student completes 10+2 level courses by which time she/he reaches age of ~18 years. Students, for any reason failing to get inspired by this time, are likely to lose the ability of critical thinking, creative thinking and making innovations; producing sparks at later stages of education (UG/PG) would be rather difficult. However, there would be some late bloomers (though rare) who will also do well in their science career. Therefore, both *bottom-up* and *top-down* approaches are complimentary to each other.

This Committee resiliently believes that it is time to repurpose science education all the way from school to UG / PG levels so as to prepare students for: (1) Career management i.e. diversification of options available at UG level to build career, (2) Skill empowerment i.e. to enable direct employment, (3) Research ability and intellect i.e. to empower them to undertake research, (4) Right scholarship – deep and broad i.e. to nurture hunger for knowledge, desire to know, and (5) Becoming independent thinkers i.e. to develop 'seekers'

The above objectives guided the Committee in formulating the recommendations. The recommendations are clearly illustrative and far-reaching in scope and impact. They are classified under six major categories as shown below:

(A) Creating 'State-of-the Art' Infrastructure

(B) Empowering Faculty to take on New Roles
(C) Curriculum Development and Assessment
(D) Teaching-Learning Processes & Assessment
(E) Promoting Research & Innovations
(F) Science Communication & Practice of Ethics

(A) Creating 'State-of-the Art' Infrastructure

Good infrastructure, academic ambience and proper academic ecosystem (cooperative and competitive) play a pivotal role in the promotion of education. The 21st century science education largely rests on both online and on-demand systems with extensive use of computers, apps, virtual lecture halls and labs. Yet, it is desirable to ensure that hands-on training in labs is not replaced by virtual labs because that will destroy attempts to establish *Mind to Hand* connection and experiential training. The entire process of education has to be learner-centric. Therefore, the existing classrooms and labs need redesigning and remodeling to accommodate newer ways of teaching that necessitates procurement of various digital devices and technologies, high speed internet provision in all educational institutions so as to facilitate adoption of modern educational pedagogies concerned with teaching- learning and evaluation.

Creating such facilities across all educational institutions will need enormous funds and the government must prepare itself to invest massively to promote science education especially in colleges located in rural areas that require infrastructure comparable to their counterparts in urban localities. Supporting and nurturing science education in rural based educational institutions through a liberal investment is perhaps the answer.

Ownership of 'classroom spaces' especially the virtual lecture rooms and labs should be central as *lecture complexes* under 'school' systems, offering inter-disciplinary courses. Cluster of departments or even colleges could utilize such costly infrastructures optimally.

A cadre of "Lab Managers" (including women graduates) may be created and sustained for management and usage of laboratory equipment, museums and so on. Creating a good research ambience in colleges and universities will go a long way in paving way for a globally competent science education in India.

(B) Empowering Faculty to Take on New Roles

Teachers with a commitment and passion are essential to promote science education. They need to teach *creative* and *critical* thinking, and solving problems. Today, self-learning, group-learning, and project-based learning, seminars, quizzes have assumed great importance. Mentoring of students by the teachers to inspire them about science, scientists and scientific discoveries is very important. The absence of a formal *mentoring system* is a biggest lacuna in colleges and universities. As every sphere of human activity is influenced by technology, particularly the Information Technology (IT) and Computer Science, future teachers have to be fully conversant with Information-Communication Technologies (ICT) and be able to master not just the pedagogical skills but also generate new content. A most likely problem in the near future would be the widening *digital divide* between teachers and the learners wherein the latter will always be ahead of the former. Hence, strategy for faculty training in modern pedagogies from time to time needs to be in place. In short, revamping science education involves in a large measure training the existing faculty on one hand, and appointment of teachers with high commitment and competency on the other. Appointing qualified teachers is not the same as appointing competent teachers. In addition, empowering the existing teachers through new type of refresher / orientation courses to mentally prepare them to handle new programs at all levels (schools to PG courses) is necessary. This means training teachers for their skill up gradation as well as change in the *mindset*. Furthermore, both College and University teachers will need training to shift from memory-based education and assessment, to teaching students to utilize their critical thinking, and, then assess their analytical ability. Teacher training must be designed to make learning, a lifelong activity as well as to do justice to 'Rule of valid knowledge'. For instance, teaching fragments of biology as 'Information' is not valid knowledge. Valid knowledge leads to understanding the domain knowledge including its dynamics. Thus, the teachers (current and new) also have to be 'future-ready'.

An equally important issue is the recruitment of quality teachers who are capable of inspiring and mentoring. This may necessitate having in place, revised policies for recruitment and sustenance of highly competent teachers in our schools, colleges and universities. Also, there should be gender parity in the appointment of faculty. Finally, teacher transfer policies may also have to be reformed to ensure that teaching programs are not disrupted or hampered in schools and colleges.

(C) Curriculum Development

Curriculum development is a process that considers among other things the national interests and designed to impart required education, skills, training to the mind and hands. The past century focused on challenges of *manufacturing* with needed standards, precision and uniformity. However, the 21st century goes beyond this and attempts to provide global solutions to challenges arising out of global scientific and technological advancements. For instance, innovations may occur in one country, manufacturing in another country for mass production. Surely, many countries will use the products and require repair and maintenance. Therefore, there is a need for a rethink on the curriculum development, transaction and assessment not only in higher but even in school education. \

Curriculum development is a complex issue. First, the experts preparing curriculum / syllabi should have sound domain knowledge of a given paper/

course (e.g. Physiology) as well as a good perspective of the main subject as a whole (e.g. Biology). Only then a proper integration of trans-disciplinary subjects becomes possible. It may be noted in passing that integration is different from expansion to absorb. The total duration spent in teaching-learning should contract. Second, grasp of concepts from simple to complex must evolve gradually and progressively from lower to higher classes to ensure continuity of thought. In science, 'conceptualization' is very important. Scientific concepts are better understood using mathematical language and mathematization. Hence, curriculum must also encompass needed aspects of mathematics in different science subjects. Following are some specific recommendations for development of curriculum:

i) History and growth of science should be part of curriculum at the school level itself. Seminal contributions of Indian scientists of the bygone and modern era in different fields of science and technology, and those who contributed to breakthroughs in space science, atomic energy, nuclear power generation, '*Green revolution, Blue revolution and White revolution'* and so on should become part of the curriculum. Finally, contributions of preeminent scientists of Indian origin settled abroad should also be highlighted in the respective fields of study. Knowledge of contributions of Indian (and Indian origin) scientists will help inspire and instill confidence in students. A recent book entitled *"Founders of Modern Science in India"* by C.N.R. Rao and Indumati Rao will be of immense value in understanding the progression of science in India. It is sure to inspire the students and teachers of science streams engaged in teaching and research.

ii) The curriculum should focus on: a) training the student to become an independent thinker, b) preparing the student for research, c) preparing the student for career building and, d) preparing the students with skill sets for vocational system and so on. Vocational training should involve training in workshops for undertaking metalwork/woodwork/ assemblage/ drawing/ planning/drafting etc. At the same time, curriculum should help to meet market needs (industry, teaching, etc.).

iii) A short introductory course on the '*Excitements in Contemporary Sciences*' should be introduced.

iv) At present, there is repetitive teaching of the course-contents at the cost of incremental teaching. Therefore, there is a need to reach a consensus between school and college syllabi to remove repetitions, so that the subject can be taught in an incremental manner. This will remove confusion and create academic time and space for other essential courses.

v) Courses offered at UG/PG levels have to be classified horizontally and vertically to enable heterogeneity and progressive conceptual complexity.

vi) Educational institutions (schools to universities) must strengthen their laboratories to provide hands-on-training.

vii) Role of science and importance of making innovations in the societal development needs emphasis in the curriculum.

viii) A center for '*Human Sciences*' may be created where social anthropology, psychology, sociology, neuro-psychology, economics, history and ethical values are integrated and taught as 'Evolution of Human Societies'.

ix) Students need options to switch over from the 'Major' discipline studied at UG program, to allied as well as non-allied subjects (subject to stipulated regulations) and allow exploring novel sub-disciplines. For example, students of various science streams may be allowed to pursue Master's degree in say 'Economics' or 'History' or other social sciences and humanities depending upon their aptitude and desire.

x) Institutions need autonomy in appointing faculty based on the need or demand. For instance, there may not be a sanctioned post for a particular subject, say Biochemistry/Statistics but a teacher in this subject will be useful to students of all biological science and other science streams. Hence, the institution should be able to appoint a teacher in these subjects out of the total faculty strength sanctioned to the institution.

xi) Compartmentalization should be avoided during first four semesters. Interactions among students with diverse interests will promote fructuous debate, discussion and questions. Practical classes should correspond to lectures in all courses and should include *complementary* experimental studies with hands-on experience and expertise to facilitate better understanding and appreciation of the concepts learnt through lectures and reading.

(D) Restructuring Teaching-Learning Processes & Assessment

i) Science education revolves around curiosity driven pursuits with critical thinking, learning and creativity that may lead to innovations. These aspects have to be emphasized beginning from high school education, a time when the young minds can learn and absorb what is taught very effectively.

ii) The contemporary teaching-learning processes involve: using virtual class rooms / labs, Blended-learning, Group-learning, Project-based learning, Seminars, Quizzes, using various Apps, Social Media, Content sharing, offering Trans-disciplinary courses, Courses on skill development, and establishing inter and intra institutional collaborations & linkages. However, it must be borne in mind that virtual labs may be effective in demonstrating a technique but do not promote the *mind-to-hand* connection.

iii) A judicious management of teaching and the economics of resources require careful consideration. For example, those teaching Physics / Chemistry / Mathematics need not cater to one department. They can teach wherever their domain subjects are offered (e.g. various Biological science courses). Teachers may thus have fixed affiliation but a responsibility to teach across multiple subjects / disciplines.

iv) *Student Assessment*: Rote memorization has been the educator's standard operating procedure for centuries. It has outlived its utility. Besides, the

21st century education calls for higher order skills that typically include critical and creative thinking (ability for objectively analyzing an issue), conceptual clarity, problem-solving, and collaboration and communication abilities. Therefore, objective ways of testing the *competency* of the learners needs to replace tests based on rote-learning. India is going to join the league of 90 nations practicing PISA and therefore the future assessment system should be in conformity with it. Besides, applying PISA standards can help our students earn the global citizenship. The NEP also recommends competency-based assessments rather than textbook-centric and content-based tests presently in vogue. Therefore, the Committee recommends switching over to continuous assessment system based on the performance of learners and their competency rather than memory based semester-end examinations. Continuous assessment system may be evolved based on the performance of learners in a variety of activities like: seminars, quizzes, project works and assignments, ability for group learning, self-learning, critical thinking, problem solving and so on. It is heartening to note that CBSE is in the process of launching competency based assessment framework aligned with NEP-2020 for classes 6 to 10 and replace the existing rote learning model in the next 2-3 years. The new assessment processes should be extended to higher levels of education as well.

(E) Promoting Research & Innovations

In all institutions of higher education, teaching and research go hand in hand. Further, as a rule, promotion of faculty members is based on the research output in the form of number of papers/books published and doctoral students supervised. In actual practice however, most faculty members undertake repetitive research and publish their papers in predatory journals. The race for publication of papers often leads to poor quality output and neglect of teaching. Purpose of research should be to create new knowledge. Therefore, Institutions may evolve mechanisms to oversee, promote, and safeguard meaningful, relevant and quality research. A 'Thesis' is a document written in support of an idea that is presented for discussion. But, at present, most (over 99%) doctoral theses do not qualify this definition; they are better called 'doctoral dissertations' to avoid embarrassment. Following are some recommendations for promoting research and innovations in colleges / universities.

i) Institutions should develop mechanisms to promote quality research aimed at creating new knowledge or development of technology. At the same time, research on mundane, repetitive and irrelevant research topics should be discouraged. On the other hand, research on topics of national priorities should be encouraged and supported.

ii) The institution should encourage and foster collaborative research on interdisciplinary areas between different science departments, and also with industries through appropriate linkages.

iii) Each institution should create corpus funds to provide '*seed money*' to young and newly appointed faculty to support their research activities.

iv) In most institutions there is a suboptimal usage of major equipment procured with support from various grants received from R & D agencies. This amounts to colossal wastage of national resources. Major equipment that actually belongs to the institution could be housed in a central place (Instrumentation Facility). Further, institutions should facilitate usage of such equipment by all researchers by formulating suitable guidelines. It is desirable to appoint trained technicians (for central instrumentation labs) to handle the major equipment and thereby help researchers as well as maintain the equipment in working condition.

v) The universities should run compulsory instrumentation courses for research students and faculty and also for those working in colleges around them on demand basis.

vi) The universities/colleges may appoint one or two *Honorary Research Directors* (say in physical sciences and one in biological sciences) who is an eminent and accomplished superannuated scientist or a fellow of any of the science academies (preferably not from the same institution) who can guide the faculty members on various issues related to both teaching and research (e.g. applying for projects, undertaking research in frontier areas, recommending the institution to support good researchers, promotion of interdisciplinary researches, collaborations and linkages, organizing lecture workshops, refresher courses, curriculum development etc.). The Research Director will be a good link between researchers and Head of the institution.

vii) Institutions should have a stringent mechanism in place to ensure that there is no scope for plagiarism and unethical practices in research, student projects etc.

viii) Institutions should support research on 'out-of-box' / 'innovative' ideas.

(F) Science Communication & Practice of Ethics

Learning science also includes communicating science (vide the policy paper by Karnataka Science and Technology Academy-KSTA, 2020) to appropriate peer reviewed scientific journals as well as popularization of science and spreading scientific temper among the public. Therefore, the Committee recommends the following:

i) Each University/College should have a '*Center for Science Communication*' with facility for preparation and dissemination of contents in the form of books, manuals, soft copies, recording audio-video talks of faculty members and so on.

ii) Further, science departments of all institutions should earmark 3-4 days in a year to conduct '*open house*' and interact with general public and school children.

iii) Teaching the importance of ethics and avoidance of plagiarism and other malpractices in publications should be part of graduate level science education.

iv) Every teaching and or research institution, university or College, Private or Government, Medical Research Foundations etc., should establish a mechanism to analyze and detect malpractices such as data theft, data copying, copy-text/plagiarism etc. Institutions should seek expert opinion from existing institutions/gateways like pubpeer.com etc. Each institution should address such malpractices by way of sanctioning appropriate sentence. Indeed, creation of editorial entities in each institution will go a long way in improving the quality of presentations of thesis and research communications,

v) The State of Karnataka should establish an office of '*Academic Integrity*' with branches in universities and colleges.

vi) The State may undertake production of quality study materials (prepared by eminent experts) in English as well as in vernacular language.

This policy paper should be seen as an 'action-oriented' document with a high potential for revamping science education in Karnataka. It advocates for focusing science education on *creativity*, *critical thinking* and *innovativeness*, the aspects that are latent in NEP. It also appeals for radical reforms in assessment methodologies; principally involving testing the *competency* of the learners using *continuous assessment* rather than rely on content-based, text-book-centric rote learning (semester-end exams). All these call for empowering teachers with adequate trainings and bringing about a change in their *mindset*. Undoubtedly, high quality science education is crucial for our overall welfare in the face of global competitions as well as to earn global citizenship.

IX. Closing Words

Reforms in 'Science Education' should become a continuous and institutional process. Educational reforms are like Darwinian Evolution. While change is inevitable, it is mostly adaptive and therefore one should not resist change. In principle, the selection pressure will ensure that 'bad reforms' are eliminated, but *Homo sapiens* may be opaque to this principle, thereby demanding additional safety clauses. All reforms may not guarantee improvement of efficiency. But as long as they are in the direction of 'realizing the set goals', we are safe. Realistically speaking, higher education in India has unintentionally veered away from the design of in-depth learning and has concentrated on preparing students to pass examinations. One may recall what the eminent scientist and Bharatratna Prof. CNR. Rao once said: "*India has no education system but only examination system*". It is high time to change this scenario by taking the bull by the horn.

The State of Karnataka is a premier hub of science in the country and, should take the lead in implementing these recommendations and incorporate improvements where needed. These recommendations, if implemented earnestly, will go a long way in reestablishing Karnataka as the leading State in providing high quality Science Education in the country. To set the stage for this transformation, the three major paradigms of change are: (1) Restructuring Science Education, (2) Ensuring continuous and quality Teacher-training and Teacher Recruitment Programs and, (3) Establishment of a 'Center for Human Sciences' bridging natural Sciences, Social Sciences and Humanities.

For reasons beyond the purview of the Committee it has not ventured to suggest possible designs of trans-disciplinary, core and elective courses or for that matter curriculum for various UG/PG science programs. These can be evolved with the help of eminent subject experts drawn from premier institutions, universities across the nation, fellowship of the science academies, and industries. In doing so, we should keep in mind the questions like "*do schools kill creativity*" and *is India prioritizing rote learning over research*? Such questions are timely and very relevant in recalibrating the science education in the country. In India, universities blame colleges for poor training of the students. The Degree Colleges in turn blame the Pre-university or Junior Colleges offering 10+2 courses. Obviously, incremental progression in learning science is not happening satisfactorily. It is also true that learners' mind when young (say 10+2 classes, at an age of 16-18 years) is most fertile. That is the time when science students are subjected to *coaching* rather than on teaching. Variety of coaching institutions operating all over the country, have become a $130 Billion (~9000 Billion Rupees) industry (source: https://youtu.be/8yElkAgOyqE). Coaching is to score high percentage of marks so that students secure seats in professional courses. Unfortunately, the scores thus obtained are not the IQ markers. It is in this process of rush for high scores, we seem to kill *creativity* and *excitement* of science. Instead, we need to adopt other parameters like the PISA for assessment of students' competency/performance using parameters like creativity, problem-solving and working in-groups, seminars, quizzes, project works and so on.

Lastly, it may be noted that absence of developments and cutting edge research and hence poor development of technologies results in stunted growth of a nation. This is an issue of great concern. Therefore, intellectuals and political leadership must deliberate on this issue and evolve mechanisms to ensure that scientific talents in the youth are nurtured and nourished to facilitate their full blooming and at the same time make India self-reliant (*Atmanirbhar Bharat*). The two processes, 1) '*Make in India*' and 2) becoming *self reliant* are possible only by pressing the accelerator of innovation; for this, the State of Karnataka has all the potential. Further, now is most opportune time to initiate transformation of science education concomitantly with the NEP-2020. In this venture, the Karnataka State Higher Education Council (KSHEC) has to play a crucial role in taking forward the mission of revamping science education successfully while the KSTA may augment its efforts when needed. This process will require working out implementation strategies by the KSHEC for which it is eminently competent.

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