1.0 Introduction

Science and technology initiatives over the years have been projected as national drivers for economic growth. In India major investments in the Science and technology sector have come through public funding. The proposed STI policy 2021 also emphatically states, “Science, technology and innovation (STI) are the key drivers for economic growth and human development.”

If we look at the past, the decade of 2010 to 2020 was declared as the ‘Decade of Innovation’. It was expected that this would lead to creation of innovative institutions and mindsets for national progress. In 2013, government formulated Science, Technology, and Innovation Policy 2013 (not just S&T policy which was the past practice.) The key features of this policy were to build S&T -based innovation ecosystem in the country. In addition, it was expected that private sectors will increase investments in R&D. In contrast to the past scenario, the proposed STI policy 2021 has emerged through a challenging scenario of COVID pandemic which brought S&T and researchers to the national focus. The pandemic challenge has highlighted the need for long term fundamental research, mission mode outcome-oriented projects and a powerful mechanism for delivery of research outputs for benefit of all. These initiatives cannot operate in isolation. Appropriate political will and financial commitments are essential for such ecosystems to emerge. We, academicians and researchers have critical role. At times we need to make difficult decisive choices, which may not be obvious, but necessary to contribute meaningfully and remain relevant. Science and innovation can only ensure sustainability of the humanity against known and unknown global threats.

2.0 Science and Invention

Science is pursuit and application of knowledge for understanding nature and social world through systematic unbiased observations, experimentations and evidence based reasoning. (This is how Science Council of UK defines science which provides a comprehensive way of looking at both social and natural sciences). Science represents the spirit of inquiry and discovery. Questioning is the basis for evolution of science. Science tells not to believe anything no matter what be its source until and unless it is consistent with evidences and reason. This essence of science gets epitomised in the motto of ‘The Royal Society’ - ‘Nullius in verba’ meaning ‘take nobody’s word for it’. It expresses the determination of the scientific community to withstand attempts of unscientific domination and to ‘verify all statements by an appeal to facts determined by experiments’[2]. Science fundamentally leads humanity to new knowledge which are basic principles of natural and social world until and unless those are proven wrong and replaced by new knowledge.

Engineers make use of scientific knowledge to design processes, structures and equipment meeting a variety of human needs. Each engineering discipline is founded upon a set of theories derived from core science. Basic or fundamental research in engineering is the development of such theories through attempts to establish a basis for empirical observations and develop new methods for engineering analysis. Research aims to advance state of the art by framing newer techniques and causal basis for design of engineering systems. Using these principles and methodologies solutions ranging from tangible artefacts to complex socio-technical systems are delivered by engineers.

Fundamental research leads to discovery of new principles which helps us to understand natural and social world. To discover is to bring something into existence that was not known. Discovery may be accidental and need not be an outcome of a structure process. A discovery is illumination of a pre-existing thing, such as the discovery of a natural law. Thus, discoveries in that sense are limited to what is already here or to the world of the possible. Discovery adds to the body of human knowledge and explains some unresolved problems. Creativity in problem solving leads to discovery. Quest for solving problems to make human life better, to satisfy human aspirations, leads to inventions. Inventions, such as transistors or cellular communication, have uniqueness - they are new to the world. Inventions emerge through a process of exploitation of natural phenomenon/laws discovered by scientists to synthesize something new and unique.

Ever since the prehistoric stone tools were invented, humans have lived in a world shaped by inventions. Paleolithic stone weapons made hunting possible. The printing press, introduced in the 15th century, once and for all democratized the process of expression of thoughts. The typewriter, which came to market in 1870s, was instrumental in freeing women from housework in the western world and changing their social status for good. Internet and cellular phones have completely changed the way we interact with each other. From ideation to experimental validation to conversion into a product for general/popular use is, however, a long cycle.

There is a continuous spectrum of scientific activity linked with the process of discovery, invention and productization. At one end of the spectrum is basic scientific research; at the other end, engineering development. Moving from the pure-science end of the spectrum to the engineering end, the goals become more closely defined and more closely tied to the demand of the solution of a specific practical problem or the creation of a practical product. Inventions, in this context, can be divided into two broad classes: fundamental inventions and incremental improvements on existing technologies. It is clear that discovery and basic inventions generate fundamental knowledge and know-how to solve problems. Investments in this invention life cycle are not expected to yield products but generate knowledge to make a product. An engineering researcher is more likely to be involved in invention rather than scientific discovery. Discovery and invention life cycles effectively convert investment to intangible knowledge for humanity.

3.0 Moonshots

Throughout the course of history a number of disruptive scientific or technological changes have happened only when people have ventured into projects with wildly ambitious goals, may be fraught with possibilities of failure. A moonshot project typically has ambitious, exploratory goals expected to produce ground breaking results. Normally there are no expectations of near term achievements. These projects also have a very high risk of failure.
The idea of moonshot projects has an interesting genesis. In 1962, the then US president, John F. Kennedy in his speech at Rice University, disclosed his dream to put a person on the moon by the end of the decade. Audacity of this challenge not only inspired motivation and passion of the scientific community but also public imagination. Public support and political will to take the project forward despite setbacks were exceptional. A project with a smaller goal possibly could have never triggered this level of commitment.

Today, Japan has well organised Moonshot Research and Development programmes that aims to create disruptive interventions to solve issues facing future society by supporting projects which are much more than just extensions of conventional technologies. We can look at some examples:

1. Realization of sustainable medical and nursing care systems to prevent and overcome major diseases by 2040, for everyone to enjoy life without health anxiety until 100 years old. This has a number of moonshot goals
   (i). Realization of a society where everyone can prevent diseases spontaneously in daily life
   (ii). Realization of a medical network accessible for anyone from anywhere in the world.
   (iii). Realization of drastic improvement of QoL without feeling load (realization of an inclusive society without health disparity)

2. Realization of a society in which human beings can be free from limitations of body, brain, space, and time by 2050. Moonshot goals of this project are
   (i). The Realization of an Avatar-Symbiotic Society where Everyone can Perform Active Roles without Constraint
   (ii). Liberation from Biological Limitations via Physical, Cognitive and Perceptual Augmentation
   (iii). Cybernetic Avatar Technology and Social System Design for Harmonious Co-experience and Collective Ability

Outside Japan, the European Union, the United States, and China aim to introduce disruptive innovation by announcing their ambitious moonshots and setting their goals for resolving difficult issues in a manner that was unthinkable in the past. Research institutions and universities have also initiated moonshot projects. MIT launched Intelligence Quest in January 2018. It has two parts – Core and Bridge. The key output of the “Core” will be machine-learning algorithms which can advance understanding of human intelligence with insights from computer science. The second entity – “the Bridge” is positioned to explore application of MIT discoveries in natural and artificial intelligence to all disciplines. Key questions being pursued in this initiative, in words of MIT president – “How does human intelligence work, in engineering terms? And how can we use that deep grasp of human intelligence to build wiser and more useful machines, to the benefit of society?”. An active industry player pursuing moonshots is X - formerly Google X, now a separate subsidiary of its parent company Alphabet.

The dream of the moonshot to put human being on moon was a one-time engineering feat. Today’s Moonshots would require a new set of technologies to be invented and then integrated for the benefit of humanity. Present challenges, like medical care for all or transporting billions of people, are also fundamentally different as scales involved here are different. It is not just more challenging but qualitatively different. Engineering devices or systems, that are both effective and affordable at a global scale for billions, will be difficult and will be a problem of different kind.

Moonshot thinking is pursuing things that appear impossible, but if achieved has potential to redefine the future of humanity. Moonshots have multi-dimensional implications - it can be in any field, not necessarily only in science and technology. These are initiatives which would appear today impossible science fiction like but if successful will affect million or billions of people. Getting into moonshot thinking requires an spirit of adventure, ability to imagine with audacity, love failures as opportunity to learn, willingness to work in multi-disciplinary teams. Even there are games to get initiated into moonshot thinking ([https://x.company/moonshots-game/setup](https://x.company/moonshots-game/setup)). However, all moonshots are big budget items – risk investments with potential of huge return or huge loss.

4.0 Innovation

Encyclopedia Britannica defines innovation in the following way: “Innovation, the creation of a new way of doing something, whether the enterprise is concrete (e.g., the development of a new product) or abstract (e.g., the development of a new philosophy or theoretical approach to a problem).” While invention requires the creation of new ideas and processes, innovation requires implementation of the invention. Innovation targets to derive a positive outcome from the invention.

Transformation from invention to innovation is not straight forward. There are questions, challenges, trade-offs and financial implications. Key issues are:

(i). **Solution Readiness**: How can one generate a solution from an invention? what problem is the solution ready to solve? When is a solution really ready for the market?

(ii). **Production Readiness**: How can one build/manufacture a single instance of a new solution? 10? 10,000? What sort of facility is required for production? And how can one fund this?

(iii). **Team Readiness**: What type and size of team is needed? How can one build, prepare, and manage that team? And what sort of characteristics is expected of the team?

(iv). **Stakeholder Readiness**: Which stakeholders are most important (e.g. regulators, investors) and how can you best manage them? How does one engage them in the solution readiness activities to ensure that they too are ready?

An invention may be feasible and novel in an experimental set-up. However, utility of the invention can only be established if it addresses economic and operational constraints of the target application in the context of a market. Creating a market value for an invention requires design of appropriate techniques and technologies to transform the invention to a marketable solution. This productization process requires a precise understanding of the intended market and the requirements of the customers. In many cases, artistic creativity in design of the solution enhances the value of innovation. Following is interesting excerpt: “We’re all searching for the next iMac or VW Beetle—any worthwhile innovation that captures the public’s imagination and strengthens the company’s brand (Excerpt From: Tom Kelley. “The Art of Innovation”).

5.0 Changing Dynamics

Innovation requires knowledge and strategies which go beyond the realm of traditional academic research. Discovery and invention consumes financial resources to generate knowledge. Innovation transforms knowledge to financial assets. Innovation ecosystem is critical and requires careful nurturing in the academic system. Start-ups provide the pathway for academic knowledge production system to get engaged actively with the innovation ecosystem and
financially exploit discovery and inventions. Consequently, we find globally, a strong support system for start-ups and technology parks in the academic institutions. Incubators nurture start-ups for generating tangible financial value for institutional discoveries and inventions. On the other hand technology parks are expected to house matured industries to provide inputs for use inspired research to the academic ecosystem. The application scenarios and problems faced in delivery of solutions for practical problems can lead to generation of knowledge by the academic ecosystem which has value for industry. Presence of these essential enablers for taking research to the field are expected to offer academia new benchmarks to evaluate their research. Not just citations or high impact publications but patents of commercial value, start-ups promoted, consultancy for use inspired research and finally marketable outcome of research have become indicators of contributions by a faculty. Obviously, in today’s academic ecosystem a faculty is not just knowledge producer but also knowledge consumer for value generation along with imparting education to the students. Even education for the students are not just acquisition of analytical skills to solve problems but also to acquire the ability to identify problems to create knowledge and consume knowledge for creation of value through start-up’s or similar ventures.

Start-up’s from a practical perspective begin their journey typically somewhere in the invention life cycle and not typically in the discovery phase. An academic research provides in many cases the core inspirational input for innovation. However, its journey to become a solution requires a variety of investigations for putting in place auxiliary components required for creating value out of the solution. In many cases, start-ups engage themselves in those aspects of inventions in collaboration with faculty mentors. However, the most important contribution of start-ups are their effort in transforming knowledge into a marketable prototype through a process of refining the output so that performance parameters are adapted to meet market demands, so that the solution hasrepeatable, reliable and consistent performance in different operational situations and designing an unencumbered process for manufacturing the solution. Subsequent scaling up and productization including refinement of usability aspects are another stage in the process of innovation. Typically start-up’s by this stage attracts commercial funding which then are clear indicators of commercial value of the innovation. Whether, this will be a successful product or not depends number of other factors including market dynamics.

Dynamics of research ecosystem today expects a close synergy between academic research and innovation process. Policy for funding research, in many cases, is getting oriented towards estimating return of the investment in terms of tangible value creation along with intangible knowledge outcome. Academicians are therefore, expected to pursue research projects, may be in association with start-up’s so that there is a linkage with innovation ecosystem for possible value creation. We need to position basic and fundamental research and use driven research in a new way.

Solutions of critical problems we are facing today in Climate Change, Energy, Food, Water, Health and others require long term fundamental moonshot efforts. For example an Energy moonshot can be: To find a energy source that is cheaper than today’s hydrocarbon energy, that has zero (carbon dioxide) emissions, and that is as reliable as today’s overall energy system. These Moonshots require miraculous discoveries. These discoveries frequently do not come from extensions of known science and technology but from foundational conceptual revolutions. These also do not emerge from vacuum. There is a dynamic interaction between scientific insights and the technologies, financing, engineering, as well as the standards, regulations, and policies that complement, enable, and develop them. They can form the nucleus for a dedicated knowledge and value producing ecosystem with a long term possibility. But they are not goal directed research.

However, the ability to perceive moonshots requires intellectual attributes of a different kind. Thinking about moonshots is an exercise in logical imagination – generating novel problems which can have long term attention of research groups. Some of the sub-problems emerging out of this exercise can be pursued with limited funding but can have substantial impact if they can navigate the discovery-invention-innovation life cycle to reach end-users.

Basic disruptive research is neither divorced from all technological and practical concerns, nor just concerned with mere practical necessity, characterised by rather unpredictability. There has to be dynamic interaction between domains of science and technology, between foundational research and commercial research. We can imagine a 2D space. One of the two dimensions will represent utility - utility in terms of the degree to which the pursuit is curiosity driven and the other dimension can represent the degree to which it is necessity-driven and viable. In this representation the search for extra-terrestrial life belongs to the extreme corner of purely “I’m curious” and have “no idea” how useful the answer is. Any scientific discovery and invention can be placed around in this space as all effort to create something disruptive today is a combination of discovery and invention and not just discovery followed by invention along a linear path.

6.0 Conclusions

All these are clear indicators of changing times and changing expectations. It is always a challenge to get transformed with new demands. However, success visits an institution when it can transform itself with time and evolve with changes and more importantly can define the changes.