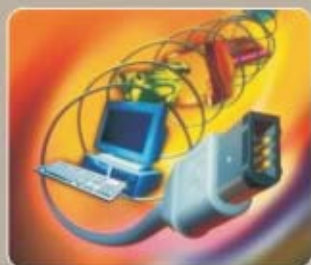


# BASIC *OR* APPLIED RESEARCH

## Dilemma of Developing Countries

### Editors

Dr. Hameed A. Khan  
Prof. Dr. M.M. Qurashi  
Mr. Irfan Hayee



*September 2007*



**Commission on Science and Technology for  
Sustainable Development in the South**

11

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**BASIC OR APPLIED  
RESEARCH**

*Dilemma of Developing Countries*

*September 2007*

*Edited by*

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*Views expressed in this Book are only those of the authors and  
do not necessarily reflect those of COMSATS or THE EDITORS*



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**Edited by**

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Prof. Dr. M.M. Qurashi  
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Sustainable Development in the South**

# BASIC OR APPLIED RESEARCH

## *Dilemma of Developing Countries*

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## FOREWORD

It is obvious that no nation in today's competitive world can progress without effectively conducting and utilizing scientific research, which is ultimately the basis of a nation's development in the form of knowledge-capital, human resource, economic growth, improved standard of living and environmental sustainability. The importance of research may vary according to kind, especially in the case of basic and applied, but both are the sources of knowledge-generation. Basic research, applied research and development are closely interlinked in the form of an R&D cycle, which following a series of steps becomes the source of new knowledge and understanding, as well as products and processes. Basic research gives way to applied research that accelerates the development-process, which in turn often stimulates new avenues for basic research to generate deeper fundamental understanding. Moreover, advances in basic research come often, but not always, as the result of advances in applied research and development. The R&D cycle, thus, works to constantly expand the frontiers of knowledge, as well as, to enhance the pace of development.

After having realized the importance of research for the development of a knowledge-based economy, the developing countries ought to prioritize their research activities and create a balance between basic and applied research. The dilemma for the developing countries has been the inconsistencies in policies viz limited national budget for scientific research for effectively addressing a country's short-term and long-term concerns. The appropriate use of basic and applied research has brought enormous benefits to the developed countries, while the developing countries still lack a strategic approach in this regard. Developing countries are in dire need to distinguish between meaningful and non-meaningful research. Once this is done, the next important step is to conduct and utilize the research through a thought-out plan, and this is what the present book highlights in general.

I am pleased to note that this book carries nicely blended views and ideas of experts from the fields of both, basic and applied research. A wide range of issues concerning developing countries have been aptly discussed that include: the importance of research for sustainable development in the South, maintaining the right balance between basic and applied research for a developing country, commercialization of research, promotion of R&D culture through education, as well as, significance of international collaboration in basic and applied research. These comprehensive discussions lead to the importance of devising workable ideas in the developing societies regarding scientific research and development, by adopting an optimum mix of basic and applied research after accurately identifying and assessing their needs and priorities.

This book reflects the expertise and experiences of seasoned scientists from Pakistan and abroad. Keeping up with its tradition of bringing out scientific publications, COMSATS has once again come up with a book that brings into focus the dilemma of

developing countries in maintaining the correct balance between basic and applied research and presents some useful solutions in this regard. I must appreciate and acknowledge the efforts put in by COMSATS' team in accomplishing this challenging task. I particularly applaud Dr. Hameed A. Khan, for being a true advocate of the advancement of science and technology in the countries of the South, and for bringing out this important publication.

The book is highly recommended to academicians, scientists and professionals in the fields of Science & Technology, especially the government functionaries. It is also meant for a person willing to grasp a thorough understanding of issues related to basic and applied research. I sincerely hope that this book, showing a detailed analysis of the relative importance of both basic and applied research with great precision, and presenting useful suggestions, will enable the developing countries to strategically plan their R&D activities, which in turn will take them forward in their struggle to become part of the developed global community.

**(Dr. Ishfaq Ahmad, N.I., H.I., S.I.)**

*Special Advisor to the Prime Minister of Pakistan*

## PREFACE

There always has been a debate on the relative importance of basic and applied research when it comes to setting priorities and earmarking financial resources by the governments. The phenomenon is true for both developed and developing countries. Now it is widely recognized that 'knowledge', or if we may say 'scientific & technological knowledge', has become the main factor of production that contributes to a nation's wealth. The basis of knowledge-based economy is derived from the same conception. The world is experiencing a period of unprecedented advances in science and a colossal growth in the knowledge-base. Today, more than ever, research in science and its applications in the form of technology are indispensable for development. Science has contributed immeasurably to the development of modern society. The application of scientific and technological knowledge continues to provide powerful means for solving many of the challenges faced by humanity, such as poverty, hunger, malnourishment, scarce healthcare facilities, lack of access to safe drinking-water, deforestation, global warming and climatic changes.

Scientific research is the principal tool for human beings to explore and make use of nature for improving the quality of life. In this context, the emphasis is mainly on two major forms of scientific research, i.e., basic and applied. Traditionally, basic research, often referred to as fundamental or curiosity-driven research, was considered as an activity that preceded applied research, which in turn fosters development; thereby applied research is for a specified period of time and is interchangeably used for mission or problem-oriented or even industrial research. Nevertheless, another school of thought believes that now the boundaries between basic and applied research are eliminated because of the expedited rate at which basic and applied research is being commercialized and implemented for satisfying the human needs. The debate on the importance of individual or blend of both forms of research-activity fervently continues in the present era, which has been nicely captured in this compilation.

The idea to compile a book on this subject was triggered by a series of debates with representatives from COMSATS' member countries, who every now and then spoke and indicated the issues on various fora and platforms of COMSATS. It was with this background that COMSATS, which representing the developing countries, planned to bring out a monograph while taking stock of the issues from its member countries, in particular, and developing countries, in general. COMSATS reveres the support and genius of Dr. Ishfaq Ahmad who has been part and parcel of COMSATS since long and guided us through, in realizing this idea.

This monograph aptly attempts to identify the various myths that have been associated with the phenomena under discussion and tries to explicate the question of "basic or applied research". It aims at bringing visibility to the nature of scientific and technological research, its historical importance and future implications for the developing countries. An effort has been made to present these comparative

advantages of both basic and applied research, while identifying the needs for mutual cooperation between developed and developing countries to address issues of key importance. The consequent effects of neglecting this crucial tool, i.e., regional cooperation for development have been touched upon, while taking into account the relatively different characteristics, needs and problems of the developing world.

The book conclusively calls for formulating and adopting a realistic, strategic and multi-channeled approach in conducting research, whereby subsequent national exchequer is consumed. It has also been emphasized that research-policy of a state should be country-specific, need-oriented and sensitive to existing human, financial and intellectual capacity and capital.

I am extremely grateful to all the authors who are leading scientists and engineers from world renowned-international institutions and laboratories. Their invaluable contributions have made this book a worthwhile resource in the domain of scientific and technological research. I must also acknowledge the efforts and dedication of my colleagues, particularly Prof. Dr. M. M. Qurashi and Mr. Irfan Hayee of COMSATS, who made this publication possible.

In the end, I would like to conclude by saying that this book is a humble effort on the part of COMSATS, whereby contributions from a limited number of professionals and experts were sought. However we look forward to and welcome the valuable suggestions and comments from the readers that shall help us bring out even a better publication next time. I hope this book gives you an enlightening experience.

**(Dr. Hameed Ahmed Khan, H.I., S.I.)**  
Executive Director, COMSATS

## **SECTION A**

# **INTERRELATION BETWEEN BASIC AND APPLIED RESEARCH**

# CAN APPLIED RESEARCH SURVIVE WITHOUT BASIC RESEARCH?

**Riazuddin**

*National Centre for Physics,  
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*“The relationship between applied and basic research is that of fish and water. Without water, fish cannot survive. So it is with applied and basic research”.*

(T.D. Lee)

## 1. INTRODUCTION

The role of science in development of human society has been crucial. It has not only made an enormous impact on the human intellect, but also changed the living conditions of humanity. It has also given a new conception to man's place in the universe. It is an undeniable reality that scientific and technological development is a prerequisite for socio-economic development, of any society, although it alone does not ensure it. However, it is crucial to make clear that sustainable growth cannot be based on mere transfer of technology. Since scientific inventions keep on changing, the technology these create also change. Unless the underlying scientific knowledge is there, growth cannot be sustained. Abdus Salam stated: “Tomorrow's technology is today's science, so technology transfer, if it is to work in the long term, must be accompanied by science transfer,”. Thus a nation must invest for the promotion of basic research to attain real development.

One of the basic instincts of man is the desire to know, to look at the intricacies of nature and try to discover the simple laws that control her process. Ever since his creation, man has done his best to satisfy this instinct. Whenever man discovers something new and solves one riddle, it becomes the starting point for another riddle, making scientific research a living process of investigation, an intellectual adventure and a process of creation. This quest for knowledge has given man the power to drive. Man has increasingly been captivated by the beauty of nature and keeps trying to understand it because ‘the end of understanding is enjoyment’. But nature, though simple and perfect, has been very skilful in hiding her secrets under covers of darkness. This romance of nature has given man a purpose, which is to reach the ultimate understanding. It is vague, but it is there. Although nobody knows whether man ever will be able to find the ultimate understanding, but the hope is still there. In fact, this very uncertainty is the source of interest and dynamism in man's quest to discover new boundaries of nature. As a result of this struggle, man has gathered a great treasure of coordinated and organized knowledge about nature. This is called scientific knowledge. Thus our science is a store of knowledge of natural phenomena.

Having defined science as a systematic study of natural phenomena, let us now discuss

how this study is done. This study is based on man's power of observation, his ability for generalization, imagination, and ultimately his mind's capacity to evolve concepts, to construct theories to explain the facts he observes, and to predict new things which he then tries to discover. Traditionally this scientific method is based on two steps: theory and experiment, with the newly added third step of mathematical computation. As a result of great advances in computing capacity, the third step allows us to design mathematical models of systems which are too complex to measure or quantify directly, and to answer those questions which were beyond understanding only a few decades ago [1]. There is another related shift towards the systems-approach [2]. Our efforts traditionally have been to dissect complex phenomena into fundamental and elementary components and then try to understand these components one by one. Assumption is then made that once the components are understood, one can easily synthesize the complex phenomena out of these components. This "fundamentalistic" or "reductionist" approach may not be adequate for many systems where the system itself has certain laws of its own, which need to be combined with the component behavior in order to understand the system. Thus, there is a need for more effective methodology, which may be called "systems" approach. There are many examples which would require such an approach viz:

- i. *Strongly nonlinear (chaotic) systems*; examples include: e.g. seismic phenomena, the mixing of oceans and atmospheres, which is far more complex than the normal diffusion process, such as the spreading of ink through water [1].
- ii. *Complexity in life sciences*; examples include: e.g. attempt to model by computer the cellular systems, where the interactions between molecules in a cell have feedback effects that increase or decrease the expression of other cells. Such efforts have even created a new cross-discipline – bioinformatics. [1]
- iii. *"Social sciences*, where the isolation of components continues to be a utopian goal". [2]

The scientific method also provided a powerful tool for technological research. Its impact on technology became clearly visible after this method was introduced in technological research at the turn of the 20th century.

With the growth of scientific knowledge, there has emerged a very important by-product i.e. practical application of known scientific knowledge for the benefit of man. It is here that we classify scientific research into basic and applied research. One can define basic research as an act through which one simply fulfils his instinct to discover something new, to satisfy his curiosity, to get a sense of excitement and satisfaction of accomplishment, without much thought how it will be used. This does not necessarily mean that results will lack utility, but only that the utility is not the primary purpose. Applied research, on the other hand, is there to improve mankind and to provide material benefits to humanity by exploiting the known scientific discoveries or by inventing new ones. As such, it is done with specific goals in mind.



Applied research can be further divided into two types. In the first type we face a practical problem whose solution we understand and where research will usually involve the application of known techniques. But before we devise a method for solution, we may need a lot of data and its analysis. Here we seldom do anything new. We simply apply the known to solve our problem. This kind of research is very often unattractive for a creative mind. In Pakistan, the problem of salinity and water-logging and its related issues come under this type of applied research.

In the second type of applied research, our research is still directed towards the solution of practical problems, but ones the answer of which we do not understand and in which the approaches likely to be successful are yet undefined. In such problems we encounter new fields and new ideas, in fact we really contribute to the scientific knowledge. This kind of applied research is often indistinguishable from basic research, and in any case, requires attitude and training of basic science.

This second kind of applied research, which I would like to call creative applied research, is rather difficult because here the choice of problem for the investigator is limited, while his approach is undefined. We shall come back to this point and discuss how, in many cases, creative research depends on interaction between basic and applied thinking.

## **2. POSSIBLE CATEGORIZATION OF RESEARCH**

### **i. Basic or Applied Research**

This classification may be useful for recognizing limitation of some kinds of research, with respect to expectations which may not be realizable. "Basic research is that which may take longest time to come to a utilizable fruition, and must be judged by the scientific criteria of conceptual significance and generality. For applied research, one expects a shorter time of payoff but does not necessarily demand generality or high intrinsic interest"[3]. However, in the prevailing conditions, the time between discovery made in basic research and its fruitful technological utilization is now shrinking. This is illustrated by the fact that, while it took nearly 38 years for radio transmission to reach 50 million users after the first radio station in 1920, Personal Computers (PC's) reached the same number of users in less than 15 years after 1980, and World Wide Web reached that number in less than 5 years after its invention during the 1990s.

Another important point is that, unlike basic research, which is mainly driven by innate curiosity, "applied research is most effective when it is compelled to "market" that provides an automatic measure of effectiveness of the end product of research. The existence of a market gives a continuous incentive for self-appraisal, which is often lacking for activities performed in the public sector" [3]. This is the reason that many research councils, which were created in Pakistan for applied and/or technological research, failed to make an impact. Apart from budget constraints, the basic reason for

their failure is that they could not establish themselves as customers to prospective contractors in industry, utilities and government departments. Unless a customer – contractor relationship, which has a built-in accountability process and research support, is established, such public-sector organizations are not going to be successful. “It is probably no accident that, by and large, government-supported research has been most successful in defense, where the government itself is the customer for the end product” [3]. This is true even in Pakistan.

## ii. Mission-Oriented Research

The mission may refer to an objective defined in intellectual, technical or social terms. We shall discuss how a research, undertaken for a particular objective has gone in many cases much beyond its original motivation and contributed to creative research.

### a. Intellectual

A good example is Fermat’s last theorem. Piene de Fermat (an amateur mathematician who published no papers), conjectured that no finite number solution exists for:

$$x^n + y^n = z^n, \quad n = 3,4,5,\dots\dots$$

Written in 1637 (when he came across the Pythagorean equation), most of us learn it in school:

$$x^2 + y^2 = z^2$$

Fermat noted that for any exponent – or a power – greater than 2, the equation could not have solutions in whole numbers. This conjecture was proved only in 1993 by Andrew Wiles and depended on fundamental advances in number theory over a period of 350 years, and especially during the last half century [1] when a new branch of mathematics, called algebraic geometry, which found application in String Theory, was developed. This is an example of intellectually challenging problems, which require new ideas and new techniques for their proper solution.

### b. Social

This relates to seeking answers to practical questions for improvement of human health, agricultural crops etc. Some examples are as follows: Louis Pasteur was led to fundamental discoveries about basic biology and germ theory of disease by practical questions from medicine, wine making, and agriculture. Gregor Mendel discovered basic laws of genetics by seeking practical answers to improving agricultural crops.

### *c. Technical and Industrial Needs*

A prime example [4] of peacetime need-driven technology is the invention of the transistor which created a revolution in computers and communications. Mervin Kelly, who was Executive Vice President of the Bell Telephone Laboratories (BTL), reached the conclusion that neither mechanical (relay) nor vacuum tube technology could provide for the foreseeable growth in telephone switching-needs and thus recognized the need for low-power, high-speed, compact switching elements. The recognition of this need led to the formation of a Solid State Physics research group at BTL. This led to the invention of the transistor by Bardeen, Brittin and Shokley, and then to the integrated circuits, programmable microprocessor, LSI, VLSI etc. Thus, the semiconductor electronics was built on basic research, but the driving forces for technological development were the needs, as recognized by certain people at BTL. The other example is that of Dr. F.B. Jewett's recognition at AT&T of the need for audio amplification (again for the telephone system) and the awareness of the high potential for satisfying this need with electron beams. Thus was born the so-called high-technology, using atomic particles, so different from the technologies of coal and iron. Moreover, studies of semiconductor devices opened up whole new areas of basic Condensed Matter Physics, e.g. tunnel diode, which probably would not have been otherwise possible.

### *d. National Security*

Historically, national security has played an important role in deriving technology. Just to give one example, the problem of detecting low-flying aircrafts during the second World War led to the invention of Cavity Magnetron by a physicist, not by an electrical engineer; a small device which powered the microwave radar and gave a crucial advantage to British and American forces. Since this device could be installed in aeroplanes, it revolutionized not only the science of warfare but also the civil aviation. Another example is the Manhattan Project for the development of technology of nuclear weapons, where physicists and those trained in basic research, played a crucial role — for good or bad.

### **iii. Academic Research**

Academic research, including both basic research and applicable (rather than applied), is largely done within the framework of graduate education and faculty in various departments of different universities, with little supporting staff. Traditionally, and most of the time it is [3] 'little science', with relatively small infrastructure and low ratio of supporting staff to researchers, which is done in universities. Some universities now also take part in 'big science' carried out in national and international centers like CERN, Geneva. Big science involves expensive, complex and huge infrastructure and equipment, with large supporting staff. Most important examples of big science are high energy physics, space science, astronomy and astrophysics. Big

science involves a different culture and ‘team research’. Important spin-offs of big science, which involve some of the most fundamental investigations in astrophysics and cosmology and elementary particle physics, led to technological and large-scale computing developments that have found other uses of social importance, e.g. in medicine (particularly diagnostic and oncology), climate change, and information-technology like the World Wide Web.

Academic research is essential, since a university has to be not only an effective transmitter of knowledge but also a diligent discoverer of new knowledge through research and innovation, and has to remain responsive to societal and technological needs. As such, higher education and research cannot be separated. Higher education cannot sustain itself without research; research cannot survive without higher education. A university has to produce new generations of researchers. For this purpose, academic research needs patronage and financial support from government, industry and endowments created by philanthropists.

### **3. WHY BASIC RESEARCH IS NECESSARY?**

#### **i. Education and Training**

We have already discussed the synergy between graduate education and basic research in the previous section. This does not exclude creative applied research as advanced training in engineering, medicine and agriculture. This may be in the form of research apprenticeship. The basic sciences tend to be a net exporter of people into other more applied fields of science or into technology. It is also essential for the existence of an intellectually vibrant society, and to keep the spirit of enquiry alive.

The way of thinking that a scientist learns is supernally powerful: a scientist learns to solve a problem by analyzing it into small bits, taking care of all the important factors in that problem and to attach to each bit its due weight (the so called scientific method). That is how physicists are going into other fields: finance (for risk analysis), computer software, biology and medicine.

#### **ii. Cultural**

Some of the conceptual achievements in science serve for ever as a testimonial to the highest intellectual achievement of mankind. Every new discovery in science changes our vision of the world where we live. Pure science is as fundamental to culture as music, literature or art. Presumably, in laboratory courses and in research projects with his teachers, a student can learn the values of honesty, creativity and full disclosure that are hallmarks of good science.

#### **iii. Social**

Applications, which result from basic research, can help in finding solutions to many

problems which society faces, such as finding new sources of energy, environmental protection, climate change, earthquakes, water resources, national resources, urban transportation, food sufficiency and improving human health.

According to C.P. Snow, “science is more oriented towards the future than most other disciplines, and scientists are animated by a belief that problems are soluble. Such natural optimism, even when unjustified, is an asset in attacking some problems, such as disarmaments, territorial disputes, which have resisted solution for such a long time” [3].

Science cannot flourish in isolation and scientists have to be in an international environment. That is why they can work in every culture and that is why they can be helpful to each other and to decision makers.

#### **iv. Economic**

Importance of technological innovation for economic growth is now generally accepted by economists. To an increasing extent such innovation is dependent upon results of basic research, although the degree of this dependence is difficult to quantify. There is no modern industry that not based on atomic physics or chemistry. There are three ways in which basic scientific research can contribute towards technological innovation [4]:

- a. Providing a basis for modern technology.
- b. Providing a powerful tool, in the form of scientific method.
- c. Through the use of scientists in goal-oriented research and technology.

Furthermore, we need to be aware of potentialities for emerging technologies. It must be realized that when the revolution of new technologies, which would govern the minutiae of living and non-living matter (e.g. biotechnology, nano-structures, new materials, quantum information and computing), is on us by 2020, we should be ready for it. This is only possible if we invest in frontier science now, to reap its benefits later.

#### **v. Entrepreneurship**

Here we need academic science, because high technology depends on the knowledge, training and culture provided by it. Science develops new tools and softwares in laboratories for its progress, and trains students and technicians to build them. These tools find uses outside, and some young people become entrepreneurs and launch their own craft industries. In turn, these craft industries grow into big enterprises. This cycle is repeated again and again and it is the rapid progress in science that makes it possible [5]. This is how-high tech. industrialization grows. However, such companies grow around big centers of scientific research, for example, Silicon Valley around

Stanford University [5]. But the Third-World Countries do not have big centers of science. So do they have a chance, or they have lost for ever? I think, the answer lies in linkages with big science-centers in industrially advanced countries.

#### **4. UNITY OF SCIENCE**

There are various aspects-integration and unification-within one discipline, another is inter-relationship and interdependence between various branches of science. The latter is relatively recent and one already sees a shift towards interdisciplinary research. In fact derivative science and technology, involving many disciplines, is becoming important. One branch of science can make discoveries which can be adapted and/or adopted to solve problems in another area. For example, physics had great success in creating new tools for research, in its own discipline, that had started revolution in astronomy, biology, computer science, communication engineering, and medicine. Some prime examples are [5]:

- i. Crick-Watson revolution (1950) resulting from the use of X-ray crystallography to determine the structure of DNA in biology.
- ii. Invention of the transistor resulting in the advent of computers and memory-banks in the 1960's. This has a great impact on society. Electronic data-processing and simulation revolutionized every branch of science, increasing the power of scientific theories to interpret and predict new phenomena. Computers, becoming cheaper and smaller, have become personal and are used for a variety of purposes, from toys to highly sophisticated scientific work. They, together with the invention of World Wide Web, developed at CERN for basic research, have revolutionized the communications and the mode of information and finance.
- iii. Development of computer-aided axial tomography (CAT) was invented by A.M. Cormack, an accelerator physicist, and got the Nobel Prize in medicine in 1979. Similarly, MRI is based on a purely Quantum mechanical phenomenon, Nuclear Magnetic Resonance. Both the development of CAT and MRI scanning technology were built upon integrated geometry [1].
- iv. The generation of codes for secure transmission depends on the arithmetic of prime numbers, while the design of large and efficient networks in telecommunication uses infinite-dimension representation of groups [1], an abstract subject which nobody could have imagined to have practical application.

Finally to bring out an integration of many activities of science with different aims and character, let me quote V. Weisskopf [6]:

Science contains many activities of different aims and different character: the several basic sciences, with all their variety of approach from cosmology to biology, and the numerous applied sciences that are spreading and involve ever more aspects of human concerns. Science is like a tree, in which the basic sciences make up the trunk, the older ones at the base, the newer, more esoteric ones at the top where growth into new areas takes

place. The branches represent the applied activities. The lower, larger ones correspond to the applied sciences that emerged from older basic sciences; the higher, smaller ones are the outgrowth of more recent basic research. The top of the trunk, the frontier of basic research, has not yet developed any branches.

Applying this picture to the physical sciences, we would locate classical physics, electrodynamics, and thermal physics at the lowest part of the trunk, with broad branches representing the vast applications of these disciplines. Higher up the trunk we would put atomic physics, with well-developed branches, such as, chemistry, materials science, electronics, and optics. Still higher we would find nuclear physics, with its younger branches symbolizing radioactivity, tracer methods, geology, and astrophysical application. At the top, without branches, so far, we would locate modern particle physics and cosmology. There was a time, only sixty years ago, when atomic physics was the branchless top.

All parts and all aspects of science belong together. Science cannot develop unless it is pursued for the sake of pure knowledge and insight. It will not survive unless it is used intensely and wisely for the betterment of humanity and not as an instrument of domination by one group over another. Human existence depends upon compassion and curiosity. Curiosity without compassion is inhuman; compassion without curiosity is ineffectual.

## **5. CONCLUSIONS**

My thesis is that without ‘research’ one cannot even talk of applied research and it certainly cannot be sustained without basic research. All basic research done so far has either already been applied or will be applied. The time between a scientific discovery and its application in technology, or otherwise, is shrinking, making the distinction between applied and basic research disappear. In the example of tree given by Weisskopf, one has to strengthen the trunk, a weak trunk will not be able to support branches and would collapse under its own weight. Thus, in my opinion, there is no dilemma in basic or applied research: every country, and more so a developing country, has to support basic research. Those societies that do not contribute to basic science are doomed to subjugation. Furthermore, the promotion of basic research is not so expensive. According to V. Weisskopf, “All basic research, from Archimedes to the present, is less than the volume of 12 days of World’s industrial production” [6]. There is no other enterprise which has paid so much dividends, with so little investment. Research and Development (R&D)’s spending in industrialized countries is 2 to 2.5 percent of GNP, 10 percent of this spending is on basic research, the same on applied research and twice as much on R&D related “high technology”. The rest is on creating infrastructure for research and training, overheads and “low technology”. To conclude, developing countries should at least spend 10 percent of the R&D budget on basic and academic research, mainly in universities. If research in universities,

whether basic or applicable, is not good, the research outside cannot be any better.

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# **CREATION & UTILIZATION OF KNOWLEDGE: RELATIVE IMPORTANCE AND INHERENT LIMITATIONS OF DEVELOPING COUNTRIES**

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## **1. INTRODUCTION**

A look at the past reveals that creation and dissemination of knowledge, has always been a constant feature of every society, whether modern or traditional, and this trend continues till date. The ability to generate, acquire and appropriately utilize knowledge and ideas by inventing and innovating products, processes and systems, is what puts societies onto the road of socio-economic progress and growth. Knowledge creates the ground for innovations that serve as a means to improving the standards of living and also as a source for transforming the world around them.

The major difference between developed and developing countries today is the amount of knowledge being produced and utilized by both. While the strategy of production of knowledge and knowledge-utilization (technology) has enabled the developed countries to achieve socio-economic development, the developing countries still remain surrounded by lingering shadows of ignorance. It is quite a well-known fact that nations cannot embark upon the path of development, unless they accept to transform themselves into knowledge-based and information-based societies. The 20th century saw the face of many scientific revolutions. Science provided us with remarkable insights into the world we are living in, as well as gave birth to many technologies, which promise to establish and conquer new grounds. Power, development, and enlightenment are closely linked to knowledge and, it is only through knowledge and its fullest use that one can achieve the state of power, development, and enlightenment. Knowledge being the basis for S&T, makes it necessary here to define knowledge and explain some of its important aspects.

## **2. WHAT IS KNOWLEDGE?**

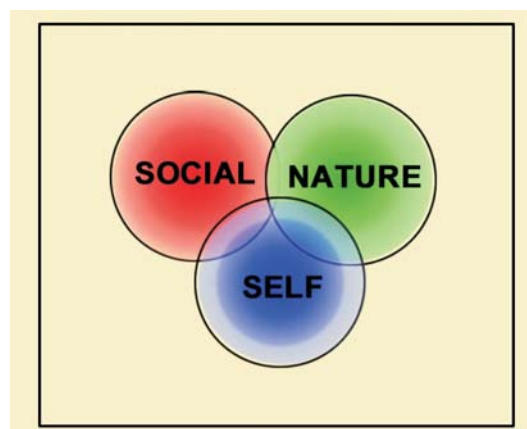
*“Our knowledge is sobering and boundless, indeed it is precisely the staggering progress of the natural sciences which constantly opens our eyes anew to our ignorance...with each step forward, with each new problem that we solve, we not only discover new and unsolved problems, but we also discover that where we believed that we were standing on firm and safe ground, all things are insecure and in a state of flux.”*

(Karl Popper)

'Knowledge' like several other concepts is abstract and not easy to define. The definition of knowledge has gone through a transformation over the years and various scholars have defined it differently. The simplest definition is that, 'what a person understands of something, or the information he/she has about something'. In this sense knowledge is 'what is known'. How this is known may vary. It may have been known through incidence, experience, or study and research. Information, learning, erudition and lore, are sometimes used interchangeably with the word 'knowledge'. Knowledge can be a combination of these overlapping terms, however, it is important to make a distinction between each one of them. 'Information' is a collection of facts and data, 'learning' implies knowledge gained by schooling and study; 'erudition', is used to describe some profound and often specialized knowledge of a particular domain, while 'lore' is knowledge that has generally been acquired through tradition or anecdote.

The acquisition of knowledge is composed of a set of complex processes, involving perception, learning, communication, association, and reasoning. The two key characteristics of knowledge, which allow it to revolutionize the world, are its 'velocity' and 'viscosity'. 'Velocity' is defined as the speed with which knowledge is spread. It relates to how quickly and widely knowledge is disseminated and is enhanced by the use of technologies, such as Information & Communications Technology. 'Viscosity' is the richness or 'thickness' of the transferred knowledge, and is enhanced by the richness of the medium through which it travels. 'Richness' essentially determines how much of the transferred knowledge has been absorbed and applied. This transference is only possible through a series of lecturing and hands-on experiences, because these are the only ways in which a recipient acquires large amounts of detailed knowledge over time (DFID, 2000).

The following Figure-1 represents the three contexts of knowledge, in general, and scientific knowledge, in particular, namely self, nature, and social.



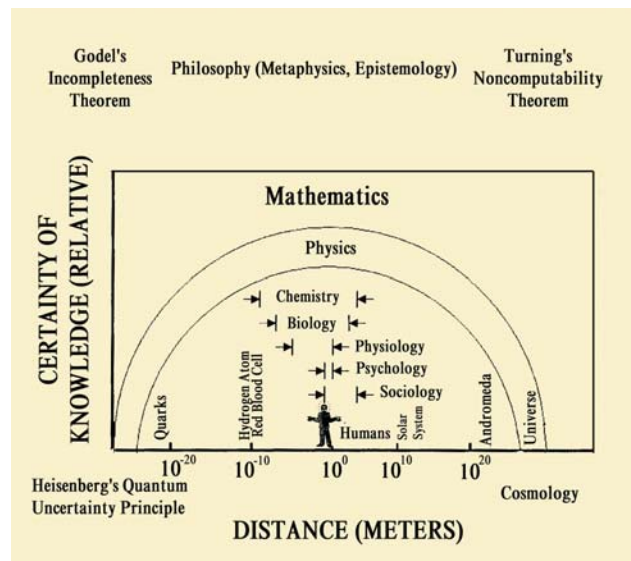
**Figure - 1: The Three Worlds of Knowledge**

In Figure-1, it is demonstrated that the frontiers of knowledge essentially exist at the boundaries of the worlds of nature, self, and social. These frontiers are also present where each world of knowledge intersects another. Indeed the area where all the three intersect is the most critically important area with regards to knowledge itself (Larry L. Hench).

### Limitations of Scientific Knowledge

A particular misconception about science that generally exists in the minds of certain people is that science creates certainty. This is quite an untrue notion, as knowledge is not a limitless phenomenon. On the contrary, it is essentially limited by three key factors, namely distance, time and theory. Figure-2 and Figure-3 depict how time and distance influence the relative certainty of knowledge (Larry L. Hench).

Figure-2 demonstrates the level of certainty of scale, or distance as against the relative certainty of knowledge. This is essentially a hypothetical cross-section of the sphere of knowledge, as against an axis of distance, expressed in meters. This figure essentially illustrates that the level of certainty depends upon knowledge. It says that the level of certainty of the realm of Physics is higher than that of Chemistry, which in turn is greater than that of Biology and Physiology, and so on and so forth. Moreover, the certainty of knowledge of the behavior of very large systems is limited. Although the behavior of individual atoms is not certain, thermodynamic quantities can be defined which are certain.



Source: Larry L. Hench, "Science, Faith and Ethics", Imperial College Press

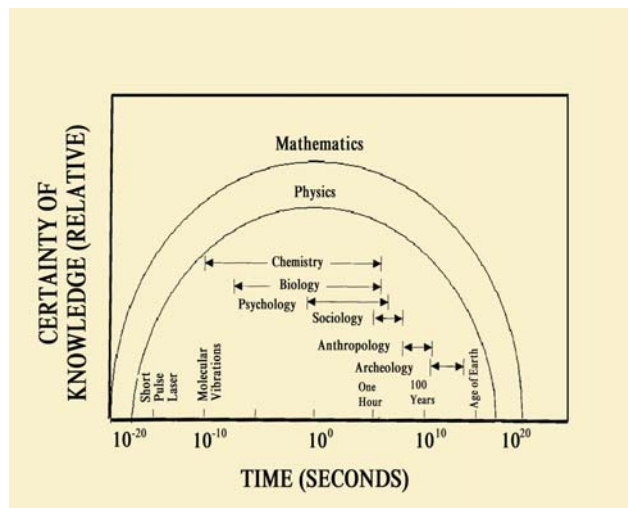
Figure -2: Limits of Knowledge: Effects of Scale

The study of the nature of knowledge, which is called epistemology, further exemplifies the fact that there is a theoretical limit on certainty of what we know or can possibly know. The problem essentially lies in the process of defining the criterion for judging the truth and falseness of the manifestation of things.

Figure-3 essentially illustrates the effect of time on the certainty of knowledge (Larry L. Hench). It demonstrates that when the duration of time is in the scale of man's general perception, i.e. in seconds, minutes and hours, the certainty of both observation and knowledge is high. But, in view of the circumstances when we extrapolate backwards in time, i.e. the sphere of historians, archaeologists, geologists, etc, the level of certainty of knowledge decreases with the number of years of extrapolation.

A fascinating aspect of time itself is mankind's capability to extrapolate backwards and forwards. Cosmologists freely predict physical events in time backwards by  $10^{17}$  seconds and forwards by equally sizeable increments. As per the figure, the level of certainty of these extrapolations is very low. According to Hawking, time doesn't exist as a fundamental property of the universe. He says that we experience only transitory moments called 'nows'. Indeed, our brains incorporate the immediate 'nows' into what we assume as a continuous and non-stop flow of time, it on the contrary is just an illusion.

As a final thought, it can be said that there are essentially three limits on comprehending the universal nature of things. First, we must not put our trust in knowledge so much that we forget mortality. Secondly, we must always apply knowledge to achieve that which is good, rather than that which is not. And lastly, we



Source: Larry L. Hench, "Science, Faith and Ethics", Imperial College Press

Figure -3: Limits of Knowledge: Effects of Time

must not presume to attain the mysteries of God by studying nature itself.

### **3. IMPORTANCE OF KNOWLEDGE AS AN ECONOMIC GOOD**

*'He who receives an idea from me receives instruction himself without lessening mine; as he who lights his taper at mine receives light without darkening me'*

(Thomas Jefferson)

Thomas Jefferson has pointed out one of the most important and fundamental traits of knowledge – the fact that knowledge is the only resource that does not deplete upon sharing and in effect has the potential to further enrich once shared. Unlike other factors of production, such as capital and labour, knowledge strives to be a non-rivalrous public good. In pure economic terms, once knowledge is discovered and made public, the marginal cost of sharing it with others is zero. Although patents, copyright, and trademarks are barriers to knowledge-sharing, most knowledge is readily available to a large group of users. It is common knowledge today that disparities in the productivity and growth of different countries have less to do with their lack or abundance of natural resources than with their ability to improve their quality of human resources and other factors of production. The World Development Report 1999 states:

*'For countries in the vanguard of the world economy, the balance between knowledge and resources has shifted so far towards the former that knowledge has become perhaps the most important factor determining the standard of living – more than land, than tools, than labor'.*

### **4. SCIENCE AS A FORM OF KNOWLEDGE**

Having defined knowledge, it is important to mention that science does not constitute the only form of knowledge as such. Science is linked to certain other forms and systems of knowledge. The word 'science' comes from the Latin word meaning 'knowledge' and we generally refer to science as the knowledge that man has accumulated as a result of his quest to understand the world. Science uses observations and experimentations to investigate various phenomena, and to gain knowledge about events in nature. The methods of obtaining this knowledge have been constantly changing and improving, and have been made more objective and reliable over time. Thus, science as it is perceived by all is the body of truth, information, and principles acquired by man through constant learning and investigations. Another way to put it is that science includes processes and a body of knowledge that involves conceptual understanding. Processes are the ways scientists investigate and communicate about the natural world, whereas the body of knowledge includes concepts, principles, facts, laws, and theories. As Einstein rightly said,

*"The whole of science is nothing but a refinement of everyday life".*

Science and technology are connected. Technological problems create a demand for scientific knowledge and modern technologies make it possible to discover new scientific knowledge. Generally used as a single term, S&T are two different yet overlapping phenomenon. Technology is derived from the Greek word meaning 'art or skill'. It is the application of science that helps us to better adapt to the environment by finding solutions to our problems. The main aim of technology has usually been the achievement of objectives, which are particularly industrial or commercial in nature.

As is commonly known and understood; the end-product of a scientific endeavor is knowledge, both in terms of the scientific papers and related literature. This produce of science is a public good, which is utilized in a fashion of mutual sharing that most certainly implies that "more for one" does not translate into "less for another". All in all, the entire human race benefits from the findings of scientific discovery, without having to pay an extra penny. Given the noteworthy advances in the realms of science-based technology, one cannot help but note that the human adjustment to his habitat, to his preferences, is as constrained as is his understanding and knowledge of physical reality through science.

## **5. ROLE AND IMPORTANCE OF S&T IN HUMAN DEVELOPMENT**

S&T being the outcomes of extensive basic research (knowledge) and applied research (innovation), it seems appropriate here to highlight their importance and dynamic role in shaping human life. Advances in S&T are fascinating and have done wonders for humanity. The contributions of scientific knowledge, and the use of appropriate technologies in the development of modern societies, has made S&T indispensable tools for development.

Science & Technology, together have enabled mankind to overcome, or at the very least, reduce, critical problems like food-insecurity, water-scarcity, environmental degradation, poverty-eradication, and elimination of diseases, to name only a few. In short, the outlook of societies, cultures, nations, economies, environment, and above all life, has been significantly altered by this knowledge.

The continuously increasing need for scientific knowledge in public and private decision-making, including the significant role of science in the formulation of policy and regulatory decisions, has been adequately emphasized and ascertained. It is also agreed and understood that scientific research has always been a major driving force behind progressive development for the betterment of mankind and, that greater use of scientific knowledge is a must for securing our future. The relationship between science and technology has been described by some as mutually dependent. Technology is said to be the mother and the daughter of science. Independent of the proper description of their relationship, there is a mutual debt and feedback between the two that grows with time. As mentioned earlier, one must realize that the road from science to new technologies is not a straight highway, but a kind of spiral of science, enabling new technologies that, in turn, allow new science that again creates new

technologies and so forth (Christophorou L.G., 2001; F.N. Magill, 1990).

## **6. SCIENTIFIC RESEARCH & IT'S SIGNIFICANCE**

*"The process of scientific discovery is, in effect, a continual flight from wonder"*

(Albert Einstein)

The significance of scientific research for the rapid growth of scientific knowledge and emerging technologies is acknowledged by all. The importance of scientific research and the role of S&T in promoting sustainable development, and in transforming our society is a matter that needs no mention. The information-age, in which we are living today, is a result of the breakthroughs in fields of computer- science and communications science.

Scientific research has continuously kept on increasing our knowledge and understanding of worldly phenomenon, inspite of the changes occurring in patterns of sustainable development. Scientific research is the principal tool for human-beings to explore and make use of nature for improving the quality of life. In this context, the emphasis is mainly on two major forms of research, i.e. basic and applied. Although many developed countries are struggling to conquer new arenas of knowledge through scientific research; both basic and applied, yet, in the developing countries this still remains an unaccomplished task. All major forms of scientific research can be broadly categorized as either need-oriented research or curiosity-driven research. Applied research, mssion-oriented research, problem-oriented research, and industrial research can all be termed as need-oriented research, while basic research is essentially driven by curiosity. It is pertinent here to briefly describe these forms of research:

- i. Basic Research
- ii. Applied Research
- iii. Mission-Oriented Research
- iv. Problem-Oriented Research
- v. Industrial Research

### **6.1 Basic Research**

This is usually termed as 'mother of all inventions', since it provides the required 'scientific capital' for new scientific knowledge and understanding needed for technological breakthroughs. The most commonly accepted definition of basic research (also known as pure or fundamental research), is that it is motivated by a researcher's curiosity or interests in a scientific question. The main motivation is to expand man's knowledge, rather than to create or invent something particular. In other words, it is scientific research conducted without any immediate practical ends in mind. The characteristics of this type of research are:

- It cannot be easily defined operationally.
- It cannot be tested in advance for utility.
- The process of innovation is interwoven with the production of new knowledge.

Some typical questions, which basic research tries to answer, include:

- How did the universe begin?
- What are protons, neutrons, and electrons composed of?
- How do slime molds reproduce?
- What is the specific genetic code of the human-being? (LBNL, Online)

Basic research is that component of knowledge, which does not involve any immediate or foreseen commercialization or commercial viability. The ultimate objective is, therefore, not to serve any pressing need or attend to a current problem, but to aim at discovering knowledge with a universal perspective and a broader horizon. This trait of basic research allows many an invention and technologies to stem from the accumulated reservoir of knowledge built through continued basic research. Informational input attained from conducting basic research is the essence for instigating inventive activities. More specifically, answers to scientific questions are the building blocks for technological innovation and further scientific development, and basic research undoubtedly is the essential means of gathering such answers. Christof Lichtenberg's comment, which he wrote in his diary about 200 years ago, firmly establishes the importance of basic research:

*"To invent an infallible remedy against toothache, which would take it away in a moment, might be as valuable as and more than to discover a new planet... but I do not know how to start the diary of this year with a more important topic than the news of the new planet".*

Common examples of basic research include: research on the chemical properties of bacteria, analysis of the interaction of the oceans with the atmosphere, and investigation of neural pathways in the human brain (AAU, 2002). Other examples of basic research include: the understanding of how a protein folds, or how a specific molecule elicits a particular biological response.

Careful studies indicate that basic research serves as a foundation of modern technology. The following important contributions in this regard are worth noting:

1. It provides the required basic knowledge, or acts as a "Scientific Capital" necessary for making the application a reality. It is firmly believed that industrial development would eventually stagnate, in the absence of the supporting basic research. This stage is felt only when the "Scientific Capital" runs out.
2. Broad-based basic research is a prerequisite for solutions to various problems. Solutions are not forced or obtained abruptly. They are preceded by necessary knowledge, often obtained by basic research.



3. Basic research provides the foundation of education and basis of training the people working in industry and technological setups.
4. It cultivates scientific climate conducive to understanding the objectives of technology.
5. Basic research serves as a source of intellectual standards for applied research.
6. It is the net exporter of techniques to industry. Techniques such as, vacuum technology, cryogenics, X-ray diffraction, radioisotopes, with their origin as techniques of basic research, are commonly used in industry these days.
7. Basic research, therefore, must not be taken as a peripheral activity or be forced to provide short-term solutions under excessive pressure and/or limited support.

**The Unpredictable Nature of Basic Research:** Christophorou L.G (2001), Braben D (1994), Ziman (1976), while talking about basic research, argue that the nature of basic research is highly unpredictable. As discussed earlier, the results of most of the basic research- work contained unexpected practical applications in store. Such is the uncertain future-impact of basic research-work that some entirely wrong predictions were made regarding their practical utilization. History of scientific research contains a number of such instances.

**Conversion of Basic Research into Industrial Applications:** It is interesting to note that some applied form of research (the products that are developed), can somehow be linked to the fundamental research. Examples can be given in this regard: the transistor was developed as a result of research in condensed matter physics, and Magnetic Resonance Imaging technology was developed due to investigations in nuclear magnetic moments. More recently, Frances W. Clarke of the U.S. Geological Survey, in a speech also protested that:

*"Every true investigator in the domain of pure science is met with monotonously recurrent questions as to the practical purport of his studies; and rarely can he find an answer expressible in terms of commerce. If utility is not immediately in sight, he is pitied as a dreamer, or blamed as a spendthrift."*

The return on investment in basic research is not often so immediate. However, over the long term, it can impact substantially, and often as least expected. Indeed, investment in basic research produces a multifarious payback, a clear example of which is the creation of an entire new economy, based on information-technology (Birgeneau, 2001).

Some of the contributions of basic research in Physics, which have led to its industrial applications, include the following:

- Improvement in accuracy of data and its processing.
- Miniaturization of physical and chemical servicing-devices in health care.
- Real-time imaging and analysis.
- Designing and development of lighter and more robust devices.

- Developments of in-vivo robotic systems, tools for endoscopic surgery and intelligent implants.
- Physics-based surface-engineering in clinical advances (i.e. use of plasmas to improve artificial body parts).
- To reduce the prices, where possible.

The following examples of basic research contributing to the study and understanding of one of the world's most frightening threats, AIDS, are still true and important to further improvement in the knowledge of this area (The Scientist, June 28, 1993, p.7):

- Biologists studying the structure of CD4 (a protein embedded in the cell surface of helper T-lymphocytes) found that HIV invades cells by first attaching to the CD4 molecule (CD4 receptor)
- Immunologists asking basic questions about T-cells (also known as T lymphocytes; a thymus-derived white blood-cell that participates in a variety of cell-mediated immune reactions)
- Geneticists manipulating genes that the virus uses to replicate
- Scientists conducting basic research in the molecular structure of the virus
- Virologists conducting basic research in the genetics of the virus (NCABR, 1998).

The importance of basic research to the control of imminent and re-emerging diseases cannot be over emphasized. Research on emerging diseases, encompasses and engulfs many disciplines, fields and research advances that fall under it; the research will be pertinent not only to specific diseases being studied, but also to a wide array of disciplines, such as vaccinology, immunology, and drug development. Subsequently, research in these areas is crucial to advances in emerging and re-emerging diseases (Fauci, 1998).

Another example, that of Laser-based Technology, is of scientific knowledge lying dormant until scientific advances in neighboring areas and technological needs in neighboring fields made its development inevitable. The name LASER is an acronym for Light Amplification by the Stimulated Emission of Radiation. Indeed, the process of stimulated emission of radiation had been shown to be possible in 1917 by Einstein and thus, since that time, light amplification and the invention of the laser were in principle possible (Bellis [online]). The laser however, was not invented until after WW-II when, as a result of the development of radar, during World War-II and the extension of that work to higher microwave-frequencies, conditions were explored under which laser action can be achieved. Thus, in the early 1950's came the invention of the MASER (Microwave Amplification by Stimulated Emission of Radiation) and in the late 1950's the extension of maser principles to the optical region of the electromagnetic spectrum. By 1960, a number of groups were investigating systems that might work as the basis for the optical maser or laser.

Today, materials for lasers are many and include gases, liquids and solids. Lasers come in many varieties, power levels, wavelengths (infrared, visible, ultraviolet, and possibly also X-ray), and types (continuous or pulsed). In layman's term, lasers are currently being used in daily examples, such as to cut precise patterns in glass and metal and to reshape corneas to correct poor vision. They are also being used in supermarket checkout lines, CD players, and for the transmission of most telephone signals. Among other utilities, they are also used in scientific experiments, to provide intense heat in controlled fusion experiments.

Lasers led to new technology which, in turn, facilitated new science, which again led to new technology and yet again to new science—a continuous interplay that is still unfolding. High-quality lasers and hardware can now be purchased readily, enabling laser-based technology to be used in virtually everything; industry (e.g., cutting, welding), communications (e.g., via satellite, fiber optic, or laser printing), weapons (e.g., directed energy weapons), information storage (laser recording, optical disk storage), remote sensing, and so on.

Laser-based technologies are also used in microstructure engineering, microfabrication, semiconductor processing, material deposition and etching, and a host of methods for altering the morphology of a solid-surface, with special resolution, down to the nanometer scale. Very high-power lasers have a potential application in fusion-energy sources, and short-duration laser-pulses are basic to man's ability to modify and/or switch material properties.

## **6.2 Applied Research**

Applied research is directed at finding solutions to the practical problems of the modern world, rather than to just acquire knowledge for the sake of knowledge. The focus of applied research is on pre-determined outcomes, i.e., to solve problems, to make decisions and to predict and/or control. It is primarily carried out to use findings of basic research to uncover practical ways benefiting human-beings and society.

Applied research is aimed at gaining the knowledge or understanding to meet a specific & identified need, or solve a particular problem. It includes investigations oriented to discovering new scientific knowledge that has specific objectives, with respect to systems, products, processes, or services. Finding a better treatment or diagnostic for a disease is an example of applied research.

The three predominant characteristics of applied research are:

- Generation of knowledge that will influence or improve application, e.g., clinical practice
- Potential for contributing to theory development, and that the
- Researcher has access/control over phenomena being studied

Applied research is carried out to find practical solutions for current pressing needs. In essence, the problems of the society in general, and the industry in particular, are assessed and addressed by applied research, which results in the improvement of a product or a system.

This research is primarily done because the performer “expects to benefit from it in some direct way, such as through a future business return or a direct financial interest” (Lukasik, 2000).

In other words, applied research is work that translates into products, goods, or services, that contribute to the GNP. It is the investigation of some phenomenon to discover whether its properties are appropriate to a specific need or want. It aims to answer real-world problems and not just abstract or theoretical ones. It focuses on solving problems, evaluating projects, and making policy or managerial decisions, and plan and forecast. All in all applied research is that kind of activity whose informational output is an input in productive commodities. General examples of applied research would include using bacteria to inoculate plants against particular diseases, developing computer models of the atmosphere to improve weather forecasting, and creating drug therapies for brain-related illnesses (AAU, 2002).

Applied research is an original research just like basic research, but is driven by very specific, practical objectives. Examples are all researches for the formulation of public policy (on education, health, economic, environmental, etc); research into how industrial development can take place with simultaneous protection of the environment; research into the provision of adequate, cheap housing; and research around finding cures for diseases.

### **6.3 Mission-Oriented Research**

Weinberg A.M (1967), states that, mission-oriented research is simply defined as “a broad-based research, carried out in support of a particular mission or the achievement of a certain technological goal”. The ‘mission’ or the ‘technological goal’ could be any broad-based programme aimed at the developmental work, for a certain scientific system or establishment of a proper infrastructure/ know-how, necessary to make the project ‘Critical’ and workable for the aim with which it was initially started. It may consist of different combinations/phases of “basic” and “applied” research project/sub-projects. Some examples of “mission-oriented research” are:

1. Development and establishment of nuclear-energy programme
2. Research leading to the development of radar system, missile programme, space exploration, etc.
3. Research aimed at:
  - Development of X-ray lasers.
  - Understanding the effects of radiation on matter.
  - Development of a cure for cancer, aids, etc.; &

- Controlled Fusion/thermonuclear reactions.

Mission-oriented research focuses on developing new knowledge of direct relevance. It is interesting to note that Mission-oriented research does not deal with only applied research, but has also greatly contributed in the advancement of basic research, with the development of new gadgetry helpful for the generation of new and high-level basic knowledge. Some of the relevant examples are:

- i. Basic research in superconductivity greatly benefited from the programme carried out for the development/advancement of new energy sources.
- ii. The Space-programme helped (and vice versa) in securing handsome government grants for the advancement of atomic and molecular physics.
- iii. Basic research in atomic & molecular radiation, and radiological physics, for example, draw valuable support from Organizations carrying out extensive research/programmes in studying the effects of different types of radiations on living cells.

It is, thus, clear that in Mission-Oriented research, the benefit is mutual, i.e. the applied and basic research help each other. Experience shows that this mutual benefit was a maximum when the interpretation of “Mission Relatedness” of “basic research was not narrowly defined”.

#### **6.4 Problem-Oriented Research**

Christophorou L.G (2001), states that problem-oriented research is simply defined as ‘research work carried out to solve a specific problem arising during a certain research programme’. This is a relatively narrow research activity aimed at some difficulty or hurdle faced during a broad research-activity. It can also be aimed at resolving certain technical fixes. In certain cases, it may be carried out to find a quick/ immediate (on relative time-scale) solution to meet certain societal needs. Some specific examples may be as follows:

- Problems relating to public health, pollution, etc.; other immediate community related problems, such as water, energy, transportation, & waste disposal.
- Suitable replacement of useful but hazardous materials – such as PCBs (polychlorinated biphenyls), CFCs (chlorofluorocarbons), etc.

Problem-oriented research is primarily concerned with current issues and problems, as well as the relevant social actors and stakeholders. The primary objective of this type of research is to analyze perceptions of the problems at hand, related models for action and means of knowledge and then to transform these into scientific questions and research-strategies. This research claims to bridge the gap between natural sciences, humanities and social sciences, and uses the impetus on predicaments to reach interdisciplinary and/or transdisciplinary approaches. The fundamental goal is to amalgamate scientific analysis with action, keeping in mind the interests of societal

decision-makers and stakeholders (ITAS, 2000).

To achieve the goal of problem-oriented research, the scientific, technical and sociological theories, methodologies and data must be systematically interlinked with the visions of sustainable development or recycling economy, or more specifically visions of a technological nature or those related to ethical standards. By doing this, problem-oriented research focuses more on the relationship between normative determinations and empirical analysis of results. What lies at the heart of problem-oriented research, is essentially the integration of social reflection and the dynamism of scientific knowledge into decision-maker's strategies for action (ITAS, 2000).

### **6.5 Industrial Research**

Schon D.A (1971), states that scientific discoveries coupled with technological developments enable the industrial sector to convert the new knowledge, so gained, to practical applications in an effective manner. Such a conversion of new knowledge into industrial products should preferably take place as early as possible, if an effective edge over other competing industrial set-ups is to be achieved. In addition to this, industry carries out its own research-programme. This research, carried out by industry, under its own programme, is generally known as Industrial Research.

Industrial research predates invention, involves highly knowledgeable men of vision and is aimed at obtaining knowledge and new ways that facilitate the emergence of new technology. It is, therefore, clear that it is extremely important to get new and good ideas, which enable the industry to: (a) improve the quality and usefulness of its products, and (b) make them relatively more durable and inexpensive. It clearly indicates that many industrial set-ups are well aware of the importance of new/basic knowledge, because it acts as the seed for obtaining a better and more efficient product, which will ultimately result in increased profit and more financial gains for the industry concerned.

Experience shows that there seem to exist (a) "time continuums" from fundamental knowledge to usable/marketable industrial products, and (b) "diffusion time", a period necessary for the diffusion of "technological innovations". It is interesting to note that both of these durations seem to be getting shorter and shorter with the passage of time. Superconductivity is also one such area for which Theodore H. Geballe said:

"It took half a century to understand Kamerlingh Onne's discovery, and another quarter to make it useful. Presumably, we won't have to wait that long to make practical use of the new high-temperature superconductors."

## **7. IMPORTANCE OF RESEARCH-BASED KNOWLEDGE**

The relative importance of 'basic' and 'applied' research has been a widely discussed topic for quite some time now. There is still little consensus among scientists and

philosophers as to which of the two types of research is more significant than the other, in this rapidly changing scenario. It is important to note that applied research does not always follow basic research, as it is generally believed. There is a common misconception that basic research is supposed to lead to applied research, which in turn leads to industrial development, and then to products. While there are many cases in which this has happened, it is also easy to find examples of advances in technology which have led to advances in basic science, such as that given by George Porter (Nobel Laureate in Chemistry) who pointed out that:

*"Thermodynamics owes more to the steam engine than the steam engine owes to science".*

Similarly the development of large Radar Antennas for applied purposes, led to basic research in Radar Science and Radio Astronomy or the case of the development of pure materials for technological applications, which stimulated fundamental investigations in Solid State Physics. To put it simply, basic and applied research is not a one way process, where one follows the other. Instead basic and applied research is a mutual process where not only basic research leads to applied research, but also sometimes advances in applied research might give way to pure and basic research. Although basic research and applied research are closely interlinked, they have a different orientation from each other. What is important is the way basic research directs and supports applied research that determines the necessity and usefulness of both kinds of research. J.J. Thomson - the discoverer of the electron - in a speech delivered in 1916 differentiated between basic and applied science as follows:

*"By research in pure science I mean research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the "utility" of this kind of research, one that has been brought into great prominence by the War - I mean the use of X-rays in surgery...*

*Now how was this method discovered? It was not the result of a research in applied science starting to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of Electricity"..  
pg 198 (Lord, 1942)*

As mentioned earlier, applied research is aimed at gaining knowledge or understanding to meet a specific, recognized need, or to solve a specific problem. It includes investigations oriented to discovering new scientific knowledge that has specific objectives. Recently many of the modern scientists have been arguing about the viability, significance and importance of applied research over basic research. Their arguments are supported by the assertion that global overpopulation, pollution, and the overuse of natural resources, is consistently generating complex problems for the human race, and the focus should be on the type of science that can improve the

human conditions by providing practical solutions to their problems, rather than indulging in knowledge-seeking activities only, which have no immediate direction in sight. The process of applied research is usually spread over a large span of time and, normally a large number of people are involved in attaining the invention stage. History contains several examples, where applied research has had a major impact on our daily lives. In many cases, the application was derived long before scientists had a good, basic understanding of the underlying science. This fact is clearly illustrated by envisioning a scientist saying to himself, "I know it works; I just don't know how it works!"

Inventions such as that of the transistor was also a revolutionary application of scientific research and proved to be a major milestone for the electronics industry all over the world. It proved to be a starting point for the design and manufacture of integrated circuits (ICs). Previously vacuum tubes were used as the only means (as triodes) in electrical devices (Bindloss, 2003).

It must be kept in mind that applied and basic research both go hand in hand. Neither can be left behind during the process of development. There are some examples in the recent past, where some nations of the world have supported applied research and product development against basic research, and have usually left the production of knowledge through basic research, to other nations of the world. This thought might seem quite effective at first, but the results in the long-run are not very promising. The fact that results of basic research are unpredictable does not mean that economic incentives to find solutions to specific applied problems are futile. But it is important to understand when such incentives are likely to be effective and when they are not. A comparison between economies of Japan and USA in the last two decades is an interesting case in question.

Wong (1996), in his work 'An Economic Case for Basic Research', writes that during the 1980s when many science-based markets were lost to Japan, especially in the USA, including very sophisticated areas such as dynamic random access memory, the question was raised whether the US semi-conductor industry could survive at all. Japan (together with Singapore, Hong Kong, and South Korea) was often quoted as a country that had been very successful economically, and captured science-based markets, since it had supported applied research and product development rather than basic research. The US semi-conductor industry did not die out completely, but while critics were predicting its downfall, US researchers were involved in creating revolutionary new markets in biotechnology, multimedia, computer software and digital communications, etc. Meanwhile the Japanese economy has, of course, been in relative decline since 1989. In any case the Japanese Government has no wish to leave basic research to others, and the Science and Technology Basic Plan, published in 1996, foresees a 50% increase in science funding in five years (although the initial rate of increase has not been maintained). Furthermore, earlier arguments based on comparative levels of investment in R & D as a percentage of GDP in the USA and Japan has been re-examined. Data had been used to argue that the larger Japanese



investment in applied research and technology was the origin of Japan's economic success in the 1980s. However, the figures for overall non-residential capital investment as a percentage of GDP suggested a different conclusion. The factors that fuel economic growth are the supply of labor and capital. Labor markets having been stable, growth might be expected to be proportional to total investment, and therefore on the basis of these figures some one-and-a-half times higher in Japan than in the USA. In fact, however, sustainable growth is estimated to be 3% in Japan compared to 2.5% in the USA. It, therefore, seems that the Japanese economy is considerably less efficient than the US economy (similarly in Singapore, for example, growth has been three times that in the USA, but investment has been four or five times as large). Reversing the traditional arguments, it has even been suggested that the relative inefficiency of the Japanese economy is due to the facts that there is less emphasis on basic research, and that the universities in Japan are weaker than in the USA. Basic and applied researches are both significant, and neither can be underestimated in its approach and scope. Having said that, we are faced by an important dilemma of prioritizing one type of research over the other. In view of the changing global scenario and increasing number of problems, for both developing and developed countries alike, the focus gradually started shifting from purely basic research towards applied research for achieving immediate results. This trend, it is believed, is forced by the problems resulting from issues such as global overpopulation, pollution, and the overuse of the earth's natural resources. Some basic scientific research probably has no practical value other than "knowledge for knowledge's sake". In such a case it is not advisable for developing countries to spend millions of dollars on conducting research that apparently has no practical value. There is still lack of sufficient evidence to support the unusual assumption that de-emphasizing basic research would be a wise policy for development. However, the fact is that a shift in emphasis away from purely one type of research; either basic or applied, towards a more balanced approach which effectively combines both types of researches, is the need of the hour. The growing importance of applied research cannot be ignored, but at the same time the importance of basic research for the establishment of a powerful science-base can also not be denied; rather a 'balanced' approach is required which effectively creates the required knowledge and utilizes it in an appropriate way.

However, this is not possible unless the importance and utility of both types of research is duly recognized by the government, academia, and industry; each has to determine its appropriate role in basic and applied research. This is especially true for developing countries. Although developing countries are moving on a track of achieving industrialization that is being led by the progress in fields of basic and applied research, yet their efforts are not fully capable of bringing about the desired results, due to lack of a strategic approach towards basic and applied research. The role of all three pillars of society government, academia, and the industry is critical for recognizing the importance of knowledge-creation and knowledge-utilization. Each of these institutions, has to identify and perform its proper role.

## **8. BASIC & APPLIED RESEARCH IN DEVELOPING COUNTRIES: ROLE OF GOVERNMENT, ACADEMIA, AND INDUSTRY**

The increasing gap between the socio-economic development of developed countries and most developing countries can be attributed to a number of factors. One of these factors is the extremely important role of scientific (basic) and technological (applied) research which cannot be overlooked. It is no hidden fact that the developed countries of the world have been investing substantial funds and resources for scientific research and development, which has resulted in their current economic strength. Unfortunately, this trend has been missing in the case of developing countries. A good sign, however, is that there now is an increasing awareness, amongst the experts in these countries that scientific and technological research has an extremely important bearing on the sustainability of programmes and policies at the national and international levels. As mentioned earlier, the role of government, academia and the industry, in the developing countries, is critical in this regard. Each of these institutions has to identify and perform its due role. In the current global context, which is characterized by rapid technological changes, innovations and ever-growing industrial applications, lack of attention towards basic and applied research and the maintenance of an optimal balance between both types of researches, is placing a negative impact on the growth and development of the developing countries, and can continue to do so in future if appropriate measures are not undertaken by these countries in a timely manner.

Science & Technology cannot actually contribute to the success of any form of sustainable development without basic scientific and technological capacity. This much needed S&T capacity comes from extensive basic and applied research. It is only through basic and applied research that understanding of complex systems is developed, disciplinary research takes place, ambiguities and uncertainties are removed, integration of knowledge across fields becomes possible, and eventually the capacity for technological innovation is built that is diffused within both the private and public sectors. Shortage of S&T resources in developing countries has always hindered progress in research & development. The need is to organize appropriate R&D programmes, as well as to start new programmes in order to cope with the changing requirements.

**8.1. Basic Research as the Primary Focus:** Basic research should be supported by governments, as their first priority compared to funding of applied research, and developing countries should not leave this task for others to carry out. Knowledge, which will be produced by academia, will eventually lead to its industrial applications. Any new innovation will not be successful until it has a solid ground, based on scientific knowledge. The simple fact is that applications of scientific knowledge within any society would be much more effective when made on the basis of knowledge rooted within that specific context rather than on the knowledge-base of another society. However; this does not mean that applied research should not be supported at

all. As stated earlier basic and applied researches have to go on simultaneously because neither can exist without the other.

The first important step for all is to realize that an active basic research-base sustains and fosters technological development. Basic research is very important for developing countries that are still struggling to achieve economic stability. Yet for them this task is not easy to carry out due to lack of R&D capacity and lack of expertise. Any little basic research which is being produced by these countries in the face of their meager resources is not of great value and is usually placed at sub-critical levels. Universities and academic institutions have to redefine their traditional roles by promoting sustainable basic research, in order to protect the sustainable progress of basic research. Further more the standard of universities and academic institutions should be raised to such a level where these institutions become capable of pursuing intellectual goals and conducting quality research.

**8.2. Funding and Support for Research:** It is a widely accepted fact that the capacity of many developing countries, including Pakistan, to carry out basic and applied research, is limited and evidence shows that very little work is done in the industry or the nations' universities, and research and academic institutions. This has been generally due to the lack of support from the industries and governments. As a result, most of these institutions lack the required capacity to conduct and engage in advanced basic or applied research and other critical activities required for supporting the development of a globally competitive information, knowledge-based, and high-tech societies. Not only governments but also industries should bear the responsibility of supporting basic research, since their technological advancements are often the result of someone else's basic work. Since the final outcomes of any type of research are extended over a long period of time, therefore industries or the private sectors are least likely to invest in such long-term research activities. Meanwhile the governments should know when and how to support the need-oriented research activity. Since the outcomes of scientific research are too long-term, therefore, private investments particularly in basic research in the areas beneficial to society are least likely. Therefore, governments in most cases, become the sole bearers of the responsibility of funding and supporting basic and applied research.

On the part of the governments, it is required that governments show more commitment in promoting and supporting R&D initiatives to enhance their respective country's capacity to develop and produce a knowledge-based economy. Government should also make best use of ICT products as well as services, as a step towards developing a globally competitive nation. Strong support is required for academic institutions -- universities, R&D institutions, and national laboratories -- as a part of a nation's S&T infrastructure. Governments at the appropriate level should take necessary steps to promote a balanced and effective approach towards basic and applied research with the assistance of international and regional organizations as well as non-governmental organizations, the private sector, academic and scientific institutions,. Once this is done, then steps for improving research activities can be

taken by acknowledging the extremely important role of research in training scientists experts, who may later contribute to the industry. Secondly, by enhancing geographical proximity of research centers, an added advantage can be achieved that would be in the form of exploitation of their production and outcomes.

In Pakistan, the R&D Fund is a part of the commitment to meet the needs for sustainable growth in the ICT-sector of Pakistan. The Fund would be the first independently managed organization that would play an instrumental role in the enhancement of R&D culture in Pakistan. The R&D Fund Policy Framework sets out a road map for the development of Pakistan's ICT industry. The development of this policy framework was based on a nation-wide consultative process, involving all key stakeholders in public and private sector and from both industry and academia. The major objectives of various research councils and institutes established by the Ministry of Science and Technology of Pakistan are to conduct R&D work on problems faced by the industrial sector; goal-oriented or applied research, research in the areas of molecular biology; to provide better health to citizens through research in areas of water management and quality of water resources; to maintain linkages through seminars, workshops, publications; to undertake cooperative research with local and foreign R&D organizations and commerce-industrial outfits on projects of national interest; to establish comprehensive scientific and technological information-dissemination centers and promote basic and fundamental research in the universities and other institutions. (National ICT R&D Fund Policy Framework-Ministry of Information Technology IT & Telecom Division Government of Pakistan, pg 6)

**8.3 Establishment of University-Industry Collaboration:** Another very important aspect is to create the required synergies between industry and the research institutions that are necessary for commercially driven work and its outputs. This is in effect negligible in the developing countries. Academia, which is mostly responsible for conducting basic research, and industry which is usually concerned with applied research (since it cannot simply afford to engage in long-term research- projects due to a competitive commercial environment), have to establish an effective collaboration with each other whereby the research findings can be used for the mutual benefit of both. Universities can lend easy access to knowledge to the industry for conducting applied research. In turn, the technology produced by the industry can be used by the universities to carry out basic research on a more detailed and extended level. Secondly, by enhancing geographical proximity of research centers, an added advantage can be achieved that would be in the form of exploitation of their production and outcomes. Research work is being carried out at universities and within the industries, however, due to lack of collaboration and coordination, the fruits of knowledge produced, are not being fully utilized by either of them. Once these institutions stop working in isolation and provide easy access to their research findings, the combined efforts of both institutions can bring far-reaching results.

Science is increasingly becoming inter- and multi-disciplinary, and this calls for multi-institutional and, in several cases, multi-country activity. Major experimental

facilities, even in several areas of basic research, require enormous material, human and intellectual resources, which can be facilitated only through collaboration at both the national and regional levels.

**8.4 Bridging the Gap between Developed and Developing Countries:** The present level of efforts of developing countries in S&T is much lower than required and this has led to a widening gap between the developed and developing countries. Developing countries are particularly in a dire need to bridge this gap. Developed countries can promote collaborative research programmes in developing countries, to support their research activities in fields of basic and applied research. They can also accelerate the pace of technology acquisition, transfer and adaptation, in order to support basic and applied research in developing countries. A major reason for lack of research activities can be highly attributed to lack of funds and resources to carry out long-term research. Developed countries can play an effective role by providing means of funding for basic research, to the developing countries, which in the long run will ultimately be in the interest of both the developed and developing countries as a whole. Finally the sharing of information is an affective step towards bridging the wide gap between the developed and developing countries. Sharing of information should also be facilitated between the developing countries. Keeping in mind the fact that the capacity to generate new scientific and technological knowledge is mostly concentrated in the developed countries, and is mainly utilized to address their own material needs, information exchange and creation of innovative ideas has to be facilitated between the developed and developing countries, with the help of information and communication technology. As yet, not much of the new knowledge, gained by developed countries, has been used to address the critical predicaments of poor and developing countries:

*“All the rich-country research on rich-country ailments, such as cardiovascular diseases and cancer, will not solve the problems of malaria. Nor will the biotechnology advances in temperate-zone crops easily transfer to the conditions of tropical agriculture... rich and poor countries should direct their urgent attention to the mobilization of science and technology for poor-country problems.” (Sachs, 1999, p. 18.)*

According to Mohamed H. A. Hassan of the Third World Academy of Sciences (TWAS), partnerships between the developed and developing countries can be of great benefit to the South. Strategies of South-South cooperation can help develop and sustain indigenous capacities in science and technology to the developing bloc. A good example in this regard is that of the development of Brazil's space-programme and satellite technology. Brazil set up a National Space Commission in 1961, in order to develop its satellite technology. In 1993, Brazil launched its first resource data-collecting satellite from Kennedy Space Center, Florida, with the assistance of a private US space firm. Ever since, Brazil has pursued two inter-related space programmes. One is the Brazilian Space Mission and the other is the China-Brazil Earth-Resource Satellites programme. These ventures use satellite-technology to

address down-to-earth concerns, which include changes in temperature, humidity and carbon-dioxide concentrations in the atmosphere, as well as real-time data on alterations in quality of soil and water. More importantly, the information collected from these satellites has been shared with scientists in other developing countries, through more than 300 Earth-data collecting platforms in Brazil and neighboring countries. Brazil has also offered access to the data, to countries of Africa. Brazil's surfacing space-programme is a premier example of how North-South cooperation can be utilized to further South-South cooperation. This endeavor began with the training of young Brazilian scientists and technicians, primarily in the universities and R&D laboratories of USA. The primary building-blocks of the programme were laid with the help of private firms and public institutions in the North, not to mention the fact that Brazil's first satellite was launched from the soil of United States.

The knowledge and technical skills that Brazilian space-scientists and technologists have attained is currently being put to meaningful use via critical examination of environmental problems, for the benefit of nations throughout the developing world. Simultaneously, the initiative has raised the standard and level of Brazil's overall scientific skills and facilities. Today, a cooperative partnership with China has allowed the country to further advance in the fields of satellite earth-observing, data-collection and communication. Such examples carry the promise of permitting researchers in the South to become partners with the scientists of the North, in projects devoted to global scientific issues (Hassan, 2000).

In a world where the accumulation of scientific knowledge and its technological applications are accelerating at a fast pace, it is a well-known fact that the developing world contributes only meagerly to modern science and technology. Yet, if acquired and utilized appropriately, the new trends in S&T offer tremendous potential for solving many of the problems hampering economic progress in the developing world. Collaboration and cooperation-mechanisms without discrimination and with transparency of activities should provide useful results. Creation of new ideas and their dissemination are one of the many ways by which the purpose of the ongoing global initiatives on sustainable socio-economic development could be advanced. Knowledge, expertise and equipment has to be shared and it is, therefore, important that the developing countries effectively utilize their resources for scientific and technological research, in a manner that would help in addressing their own pressing needs and also promoting scientific and technological cooperation at the regional level for the following main reasons (Kane, 2000):

- There is a need to avoid the duplication of human, material and financial resources in crisis-situations or in the cases of under-development, which are impediments to optimally realizing the scientific and technological potential of developing countries and ensuring its optimization. This is an ailment, common to most of the developing countries, and can be reduced or eliminated through mutual collaboration.
- There are quite a number of similarities in the environmental conditions of the

various developing countries, which give rise to general developmental problems that are similar in several critical sectors of their respective economies. The existence of common problems within the South is undoubtedly the most important reason for cooperation in scientific and technological research. Science and technology are considered to be the likely key-factors in solving critical problems of the South, such as food-insecurity and diseases. Some of these issues have little express impact on the countries of the North, and are thus unlikely to be given high priority in the S&T research-agendas of the North. Cooperation of developing countries, in such areas, could be very beneficial in discovering and disseminating effective solutions.

- Globalization and liberalization of the world economy, followed by the tremendous advances in new Information and Communication Technologies (ICTs) and, most importantly, self-interest in safeguarding the trade-agreements and blocs, are such phenomena that must be tackled by the developing countries, in a collective manner. This is extremely important because, individually, these countries do not stand a chance. While literally all developing countries have been adapting their domestic policies to the new global trade and economic dictation in the recent years, their capacity to protect their own interests in a global epoch, remains restricted due to the lack of capability for institutional and technological innovation - and this is where the role of mutual cooperation comes in. One aspect of globalization, in its present form, is that it forces developing countries, in need of international financial support, to accept imposed conditionalities with respect to the macro-and micro-economic conditions under which they operate. This often leads to reduction in governmental expenditure, with associated pressure on the budgets of the spending ministries, including that of education. Thus, structural adjustment, whether imposed or voluntarily adopted, has put pressure on public funds available for science in these countries.
- There are several large and complex problems, such as environmental degradation and natural disasters, whose solutions can only be found through a collective approach by the entire global scientific community. This firstly calls for greater cooperation in areas of basic and applied research at the regional level, and then at the international level.
- Developing countries must intensify co-operative efforts to enhance their indigenous capacity to generate, manage, and utilize S&T in ways that address its own basic needs. They have to enable their scientists, researchers, and policy-makers to address the problems and to devise a strategy for checking them. They need to train, retain, and promote native scientist and technologists insufficient numbers. Efforts must be aimed at exploring the applications of S&T for economic development, as well as ensuring the sustainability of society and environment by striking a best mix.

For these reasons, the developing countries need to closely work together and build their innovative and creative capacities. As mentioned earlier, no developing country, on its own, has the capacity to shape the processes that can inspire the development of a global economy. However, in adapting local institutional systems to the requirements

of the global economic order, every developing country has a lot to gain by cooperating with other such countries. Particularly, those countries that are technologically disconnected can gain from those that have recently transcended to the level of technological innovators. The basis of cooperation amongst developing countries is that, when the wealth of knowledge and capacity in them is systematically assembled and channeled, effective participation between developing countries can be facilitated in the global economy (Kane, 2000).

#### **9. ROLE OF 'CENTERS OF EXCELLENCE' IN ESTABLISHING REGIONAL COOPERATION IN SCIENTIFIC RESEARCH**

Establishment of new Centers of Excellence at leading universities, industries and other R&D institutions, specialized in fields of S&T, is also an effective strategy. Centers of Excellence are the key to innovation, and their importance cannot be underestimated. Developing nations should have centers of excellence of local, national, and more importantly of regional, and international status awards to enhance their countries S&T and R&D capacities. These Centers of Excellence should be created, or should be included in the future R&D strategies of every developing nation particularly, in order for its developmental capacity to grow. Such Centers can serve as the main nodes for individuals or groups engaged in enhancing empirical knowledge of national and regional importance. Furthermore, these Centers should have institutional autonomy; sustainable financial support; knowledgeable and capable leadership; international input; also a focused research agenda that include interdisciplinary themes, applied research, as well as basic research; technology transfer; peer review as a systemic element; merit-based hiring and promotion policies; and mechanisms for nurturing new generations with talent in Science & Technology. Where such institutions already exist, they should be reinforced or, if necessary, reformed. (IAC Report).

Apart from the establishment of new Centers of Excellence, the developing countries need to establish centers of noble standards such as The Abdus Salam International Center for Theoretical Physics (ICTP). It is very unfortunate that presently there is only one existing center which is fulfilling the R&D needs of so many developing countries. It is urgently required that more centers of such standard be established in various regions of the developing world, probably in Asia and also in parts of Africa that are capable of supporting scientific research in developing regions. These centers should be focused on mainly few fields of scientific interest at one time, for example biotechnology, information technology, etc.,. Stepping into so many fields at once will certainly lead the developing countries nowhere and will instead dilute their efforts. Such centers along with other centers of excellence can help in promoting and enhancing world-wide scientific and technological capacity, which will facilitate basic and applied research. An innovative and ambitious initiative would be to compel the already existing Centers of Excellence in developing countries to play their due role effectively in Research & Development activities in their respective countries by:



- Supporting high technology ventures through a collaborative approach among the state, academia, private venture-capital companies, and other private and public sector parties.
- Encouraging rapid commercialization of scientific breakthroughs.
- Allowing coordination and information-exchange between R&D institutes in developing countries.

## **10. SOME PROPOSALS FOR SUSTAINABLE DEVELOPMENT OF THIRD-WORLD**

Having discussed the importance of research-based knowledge and a balanced approach to basic and applied research, especially for the developing countries, some useful and important recommendations in this regard can be put forth as follows:

- It is important to establish international and regional cooperation and coordination between experts in universities, academic institutions, and industry, while carrying out basic or applied research. Centers of excellence and Centers such as The Abdus Salam International Center for Theoretical Physics (ICTP) can facilitate this sort of cooperation. The objective behind these efforts should be to develop collaborative programmes for building the capacity for scientific education and research, and to establish trends of knowledge-sharing through regional alliance among academia, governments and industries, to address real-life problems. The ability of countries to participate in, benefit from and contribute to the rapid advances in science and technology can significantly influence their development.
- Regional efforts must be vigorously pursued. Efforts for Regional cooperation should be intensified and strengthened towards the developing countries' indigenous capacity-building in science and technology, including their capacity to utilize scientific and technological developments from abroad, and to adapt them to suit local conditions.
- Developing countries in this regard need to adopt and pursue policies of non-secrecy to other parts of the developing world. They have to show their willingness to propagate and further the South-South collaboration in S&T. Their commitment to solidarity in the collective augmentation of capacities and acquisition of necessary technologies is indispensable for achieving success.
- Developed countries can promote collaborative research-programmes, in developing countries, to support their research activities in fields of both basic and applied research.
- Developed countries should accelerate the pace of technology acquisition, transfer and adaptation, in order to support basic and applied research in developing countries.
- A major reason for the lack of research activities can be lack of funds and resources to carry out long-term research. Developed countries can play an effective role by providing the means for adequate funding of basic research, to the developing countries, which will be ultimately in the interest of both the developed and

- developing countries as a whole.
- The concerned authorities in the developing countries should implement ways to efficiently mobilize and utilize the funds and resources. New and innovative funding-mechanisms need to be established to make available more resources for basic and applied research that will ultimately facilitate the process of sustainable development.
  - Each developing nation requires to put up a coherent national framework for actions that directly affect the promotion of scientific and technological research. Such a strategy should be developed by the government, in consultation with scientific, engineering, and medical academies of the country, and the state should learn and benefit from the experiences of other countries.
  - The planning authorities, government, industry and research institutions should identify priorities and launch national R&D programmes in areas of basic and applied research, to serve the industrial strategies for the development of technology domains. This will allow concentrated efforts towards improving the overall economic situation of the subject country.
  - A sound infrastructural base for S&T is essential, and this can be achieved by building new, and strengthening already-existing, research laboratories, educational institutions, and skilled human resource.
  - Developing countries can engage in capacity-building, by outlining their strengths and weaknesses in respective areas of basic and applied research, and then devise appropriate strategies to progressively reduce these weaknesses. Promoting effective cooperation among governments, between public and private sectors, both within and across frontiers should be ensured.
  - Research, whether basic or applied, should be carefully planned and executed to produce the results that may, in the long or short term, benefit the humanity at large.

## **11. SUMMARY AND CONCLUSIONS**

In today's competitive world, the key to sustainable development, without a doubt, lies first in the creation of scientific knowledge and second in its utilization. It is knowledge which gives birth to Science & Technology (S&T) and in turn it facilitates the generation of new forms of knowledge. S&T have profoundly influenced the course of human civilization and have stood out as the two main fundamental components aimed at fostering socio-economic development, since the last couple of decades. Meanwhile the scope of sustained socio-economic development has been dynamically shaped in the past and the same can be seen in the present era. Despite the changes occurring in the direction of sustainable development and progress, perhaps the only thing which has remained constant is the creation of knowledge through continued scientific research. Knowledge has always been marked with certain limitations and uncertainties, and the purpose of scientific research has been to overcome or, at the least, reduce them. Scientific research is the principal tool for human-beings to explore and make use of nature for improving the quality of life. In this context, the emphasis is mainly on two major forms of scientific research, i.e., basic and applied.

The usual consensus has been that basic research creates the knowledge which is called science and this science is used for devising applications that is referred to as the technology - essential for addressing problems faced by human beings. In view of the changing global scenario and increasing number of problems, for both developing and developed countries, the focus gradually started shifting from pure basic research towards applied research, for achieving immediate results. This trend, it is believed, is forced by the problems resulting from issues, such as, population explosion, increasing pollution, and the overuse of the Earth's natural resources. The growing importance of applied research cannot be ignored, but at the same time the importance of basic research for the creation of a powerful science-base can also not be denied; rather a 'balanced' approach is required. However, the fact is that a shift in emphasis away from exclusively one type of research; either basic or applied, towards a more balanced approach, is the need of the times.

The importance of creation and utilization of knowledge has to be duly recognized by the government, academia, and industry. Each of the above mentioned pillars of society has to determine its appropriate role in basic and applied research. An important strategy in this regard is the establishment of international and regional cooperation and coordination between experts in universities, academic institutions, and industry, while carrying out basic or applied research. In case of regional cooperation, the role of Centers of Excellence is pivotal in promoting South-South and South-North cooperation. Other strategies could include the establishment of university-industry collaboration at the local levels and improved mechanisms for funding and support. Developing countries particularly need to pay attention to these issues, and remove their inherent limitations if they are to practically achieve the targets of sustainable development in its true sense.

### **Some of the Key Recommendations for Promotion of Science and Technology**

- In the context of a radically changing world, which is characterized by a host of pressing challenges, rapid technological change, and globalization, most societies are fast transforming into knowledge-based and information-based societies, for which the importance of research-based knowledge has to be duly recognized.
- It is high time that the developing countries recognize the importance of a powerful science-base and overcome their limitations, if they are to fully participate in today's world, where traditional economies are fast switching to knowledge-based economies.
- It is generally believed that, in many developing countries, applied research will be more appropriate because of limited availability of resources and scarcity of staff and funds. This might seem to be an effective strategy at first, but it is not very promising in the long-run; therefore cooperative mechanisms, such as South-South or North-South should be made to use.
- Applied research cannot be ignored but, at the same time, the importance of basic research for the generation of pure scientific knowledge cannot be denied; there is a growing need for a strategic approach viz-a-viz research.

- The roles of government, academia and the industry are critical in the process of knowledge-creation and knowledge-utilization; each of these institutions has to identify and play its due role. Governmental efforts must be addressed at supporting and funding research activities and infrastructure at universities and academic institutions, while industry-university cooperation also needs to be established, whereby the research findings can be quickly used for the mutual benefit of both.
- Basic research should be consistently supported by governments as their first priority, compared to funding of applied research. And further more, the research activities of each country have to be necessarily tailored to their particular situation.
- The force and quality of knowledge required to achieve success for sustainable socio-economic development, in a timely manner, has to be galvanized as quickly as possible. Research organizations, universities, think-tanks, world intellectual forums, NGO's and others have to be brought together both from the developed and the developing world, in order to provide a solid foundation on which mankind could build its future strategy and practicable action plans to achieve success.

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# **FUNDAMENTAL RESEARCH: THE ENGINE OF INNOVATION – EXAMPLE OF PARTICLE PHYSICS**

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As one of the missions of COMSATS is to bring about sustainable socio-economic development in the South, it is very much fitting that the centrality of science and technology in the development process be explained again to policy makers. Therefore, I welcome COMSATS' initiative to compile in one book, thoughts on the respective roles of basic research and applied research, even though it is a vast subject that could easily fill more than one single book.

It would be presumptuous on my part to imagine advising developing countries of the South on their research policy. I would rather like to reflect here on the historical role of fundamental research; provide some recent examples from the field I am most familiar with, which is high-energy particle physics; explain how fundamental research drives innovation, and simply express some personal views.

It is generally agreed that one could define fundamental research as the process by means of which science progresses, while applied research is the development of innovations based on the results of fundamental research.

In my view, there should be no real dilemma for any country to choose between fundamental research and applied research. Both are important; however, without fundamental research there is no innovation, and without innovation there is no economic development. I believe that a strong fundamental research programme is the basis for success. Fundamental research requires government funding [1] accompanied by the development of education, as money alone will never create new ideas. It also requires promoting scientific culture so that a large number of the young people, precisely those who can invent new ideas, understand that by developing science they can at the same time enjoy a great adventure and help develop their country. I strongly feel that investing in science is the best way to promote the interests of a country in the long run, and probably the most cost-effective one, much better than investing in weapons. On the other hand, applied research is best funded by the private sector as eventually the result of applied research can be commercialized, thus bringing financial benefits. The detailed mix between fundamental research and applied research does not matter too much, as I do not believe that there is a magical and universal recipe. However, again, without a strong fundamental research programme, a so-called "developing" country will remain, forever, a "developing" country. It is of course understood that sufficient wealth is required to be able to invest in fundamental research, and that the first most cost-effective step is to join international collaborations, which are excellent platforms for the training of young

researchers.

Fundamental research is the expression of human curiosity: of the need to understand the structure of matter, life, the structure and evolution of the Universe, which are the main subjects of fundamental research, so that we can decode our past and predict our future. For instance, the laboratory where I am carrying out my research work, the European Organization for Nuclear Research (CERN) [2], unlike what its historical official name might suggest, is entirely devoted to fundamental research, in the domain of high-energy particle physics, even if in practice there is also some applied research occurring at CERN, for reasons which I shall explain below. As I have mentioned already, curiosity is the motivation of scientists; it is also remarkably characteristic of children who need this curiosity to develop, and it is presumably this very curiosity which is at the basis of the evolution of humankind. I could imagine that the evolution of humankind accelerated smoothly as soon as human beings were able to ask questions about their environment.

Both, fundamental and applied research, are directly linked to science, and it might be appropriate to note that, unfortunately, society often confuses science with technology. Robert Oppenheimer once said: “Too often science is being blamed for the misuse of the technology it allows”. Science can be defined as a coherent ensemble of knowledge related to certain categories of facts, objects, or phenomena obeying certain laws and verified by experiment. Therefore, science cannot be bad in itself. One should, however, regret that the traditional goal of science, i.e., to understand nature, the Universe and its evolution, is not understood by most people in our society. No wonder that, in making a hotchpotch of science and the political use of science, many believe science to be guilty and socially irresponsible. Therefore, investing in research should only be one aspect of a general programme based on the improvement of scientific education. Science should become a natural part of culture. While the use of knowledge is an ethical matter, the search for knowledge must be absolutely free, and the two should not be confused.

Science represents one of the most noble and ambitious endeavours of human beings who, by trying to discover the nature of the Universe in which they live, are in fact trying to discover themselves and understand their own place in this fascinating and highly puzzling world. Somehow, over the years, science has strongly changed the way human-beings understand their place in the Universe, from ancestral times when the reference frame was the village and its neighbourhood, on to a region, a country, a continent, the Earth, the solar system, the Milky Way (our galaxy), the local group of galaxies (the Milky Way belongs to the so-called Local Group), the Virgo supercluster (the galactic cluster that contains the Local Group) and today the entire Universe. The progress made by humankind is tremendous, however, it is ironical that this progress led us to understand that we still know relatively little. For instance, we discovered that the matter we are made of, mainly baryons (particles such as neutrons and protons which are constituents of atom nuclei), is only a small minority in the Universe, only a few percent of its total contents. What a change of perspective within about half a



millennium, when the Earth used to be the centre of the Universe! All this came by steps, with an acceleration of progress starting with Galileo Galilei at the turn of the 16th century, when he used instruments to observe the moon, comets in 1618, and other objects in the sky, such as Jupiter's satellites, to verify the theory of Nicolas Copernicus, establishing that the Earth was indeed rotating and orbiting the sun. New ideas, even scientific ideas, are not always easily accepted by society, and in this particular case they cost Giordano Bruno his life for supporting them. Their revolution was a deep one, as observation became the basis for science and instruments were built that extended the reach of the human eye. It is characteristic of this new era of science how Galileo, armed with one of the first telescopes, was able to settle once and for all, for instance, the issue of the nature of the moon, which had been discussed endlessly by philosophers, as long as society could remember. He immediately realized that the structures he discovered on the moon through his new instrument were reminiscent of our mountains, and that the moon had obvious similarities with the Earth. It was not one of those perfect spheres imagined by philosophers before him.

Today physicists can observe the Universe over distances that vary by 45 orders of magnitudes (a factor  $10^{45}$  between the two extremes), from the smallest distance, reachable at the Large Hadron Collider (LHC) [3] (Figure - 1) at CERN,  $\sim 10^{-19}$  m, to the scale of the entire Universe  $\sim 10^{26}$  m, reachable with large instruments to observe



Source: Copyright CERN, Geneva, Switzerland

**Figure - 1: The LHC tunnel between points 1 and 8, showing some of the large superconduction magnets (1232 dipoles with a field of 8.4 Tesla) that constitute part of the 27 km underground accelerator structure**

the sky, such as the Hubble telescope or the European Organization for Astronomical Research in the Southern Hemisphere (ESO) Very Large Telescope (VLT) project, which will be the world's largest optical telescope array.

Another important revolution concerning our place in the Universe came with Albert Einstein, at the beginning of the 20th century, when he described an unexpected relation between space and time. It came as a great shock that two individuals could age differently, if one of them travelled. This completely changed our understanding of the Universe. Today, relativity is with us even in everyday life, when we observe, for instance, muons produced by primary cosmic-rays in the higher layers of the Earth's atmosphere, 100 to 200 km above us, reaching sea-level, which implies that they must have lived 100 to 150 times longer than a muon at rest, which lives only two microseconds on average. Even closer to everyday life, with the advent of new technologies, the Global Positioning System (GPS) would be totally unable to locate a car within a few metres without relativity corrections.

Einstein's revolution was soon followed by another one, made possible both by the understanding of the red shift of the light coming from distant galaxies, and by the availability of better telescopes, when Hubble realized, in 1929, that the Universe was expanding. Everyone remembers that it was even a shock to Einstein himself, who had desperately tried to find a static Universe solution to his general relativity equations. It is very ironical that today, with the observation that the expansion of the Universe is actually accelerating, cosmologists are tempted to include again in the equations the cosmological constant term (  $\Lambda$  ) which Einstein had taken out of his equations of gravitation [4], reproduced here because of their incredible conciseness, which some scientists refer to as "beauty":

$$\left( R_{ik} - \frac{1}{2} g_{ik} R \right) + \Lambda g_{ik} + T_{ik} = 0$$

Despite my natural bias towards physics and cosmology, I should not forget to mention Darwin's contribution with his theory of evolution by natural selection, which gave a new perspective of the place of humankind in the history of life. More recently, in the early 1950s, Francis Crick and James D. Watson, discovering the double helix structure of deoxyribonucleic acid (DNA), the fundamental molecule of life, bridged biology and chemistry, and opened the field of molecular biology. This actually gives me the opportunity of making an important comment on how various fields of science interact. There is often cross-fertilization between fields. Francis Crick and Maurice Wilkins, who shared the Nobel Prize in Medicine with James D. Watson in 1962, were physicists. The microscope, X-ray imaging, more recently gel electrophoresis which plays an important role in the study of genomes, integrated circuit techniques to study gene correlation with cancer cells, computers, large databases, etc. are all coming from physics and have allowed molecular biology to progress in a very spectacular way

in the past sixty years. This pleads in favour of a diversified research programme, which will create a general scientific environment that will stimulate all areas of research.

For politicians, it is not always easy to understand why they should invest in fundamental research. The practical results of fundamental research are not predictable, and the benefits often come on a long time-scale. It is certainly easier to explain to constituencies investing in the transportation system, or in the building of a new football stadium, rather than investing in research to discover the nature of dark matter in the Universe.

Actually, my own experience shows that when scientists make the effort of explaining their own research to the public, it always triggers a lot of interest and enthusiasm. CERN is currently submerged by visitors, and is foreseeing more than 60 000 visitors a year during the LHC era. Not that visitors can actually see much of the LHC itself, which is buried on average 100 metres underground, but because they are intrigued by the mysteries of high-energy physics, the scale of the experiments needed to tackle some of the smallest objects we were able to imagine as constituents of matter so far, and also because they are fascinated by the paradoxical connection between understanding the world at the smallest dimension scale and understanding the history of the Universe, described by the Big Bang model at the largest dimension scale.

The example of Michael Faraday, the prestigious English physicist of the early 19th century is an ideal case to illustrate the difference between fundamental research and applied research. His government had asked Faraday to also spend time doing “useful” things, whereby they meant “applied” research as opposed to “fundamental” research, which to them seemed a waste of time. Faraday was asked to solve the problem of lighthouses along the coast of England. England was at that time, and still is, heavily reliant on shipping for trade and could not afford the heavy losses due to shipwrecks when lighthouses failed. Michael Faraday took up the challenge, and with his brother, an engineer, understood that the main problem was the soot produced by the candle that was deposited on the lenses and on the light reflector. They invented a clever chimney system that controlled the soot and they took out several patents, which allowed them to make some money out of their invention. However important that contribution was at that time, today, if we remember the name of Faraday, it is because in his laboratory he was puzzled by the fact that when drawing an electric current through a conducting wire, it had an action on his compass needle. Faraday was curious and he spent his life studying this type of phenomenon, which led to the invention of the electric transformer, the electric motor, and made possible the deployment of electric lighting, etc. The impact of his fundamental research turned out to be far more important than improving candle lighting.

Today, the realm of fundamental research is broader than ever. The study of life in general expanded from botany and biology to molecular biology and to the search for

extra-terrestrial life. The study of the Universe can take so many forms, from the observation of the microwave background (COBE, WMAP, etc.) to the observation of type II supernovae to map the expansion of the Universe to accelerator experiments at the CERN LHC: ALICE [5] will explore the early Universe state of matter known as Quark-Gluon Plasma (QGP), that is presumed to have existed only during the first 10 microseconds after the Big Bang; ATLAS [6] and CMS [7] in addition to searching for the Higgs particle to explain the origin of mass, will try to find out whether supersymmetric particles could account for the dark matter that constitutes about 23% of the contents of the Universe; LHCb [8] will study the violation of one of the main symmetries of fundamental interactions, the product of charge conjugation by reflection in a mirror, so-called CP symmetry which might be related to the fact that the Universe is almost entirely made of matter, as opposed to equal amounts of matter and antimatter. Not only is the realm of fundamental research broad, but the possibility of building instruments today which are infinitely more powerful than ever before, makes the enterprise of fundamental research so exciting that I believe this might be one of the most gratifying occupations and a continuously exciting adventure for a man or a woman on our planet. Again to take my own field as an example, I believe that the Large Hadron Collider being commissioned at CERN has the potential for being one of the greatest scientific adventures of our times.

Besides satisfying our thirst for knowledge, fundamental research plays a very important role in society. History shows that it is fundamental research that drives the development and progress of a society and that the success of a civilization depends on its support of science. Examples are numerous but I shall mention only a few here: the Greek civilization of the 5th century BC, the first one to attribute value to the search for knowledge. I have always been impressed by Empedocles (492-432 BC), who, two thousand and five hundred years ago, was already asking the very same questions we are asking at CERN today: what are the ultimate or fundamental constituents of matter? What are the forces through which they interact? Of course, even though Greek Scientists invented the concept of the atom, they could not possibly get the right answer. To the first question, they answered that there were four fundamental elements, earth, air, fire and water, and that there were two fundamental forces, love

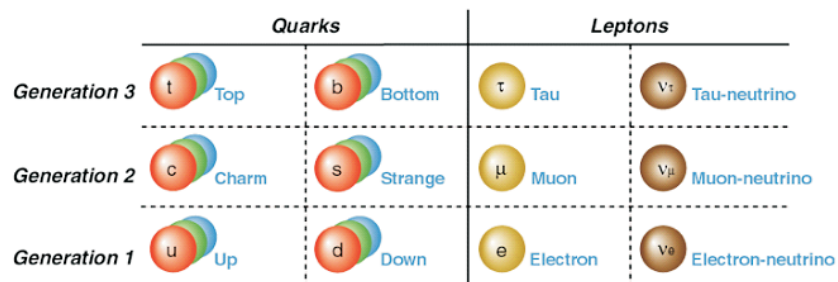


Figure - 2: Today's Three generations of fundamental building blocks of ordinary matter. In addition, for each particle of matter there exists a corresponding antiparticle

and strife, engaged in an eternal battle for supremacy. Today we know of 24 elementary building blocks of matter: 18 quarks and 6 leptons (Figure - 2), and of three forces: the electroweak, the strong and the gravitational forces, which are mediated respectively by the  $W^\pm/Z^0$ , the eight gluons and the graviton (yet to be discovered). A relatively simple and consistent picture well described by the so-called Standard Model of elementary particles and their interactions. The LHC will be searching for the ultimate piece in this construction, the Higgs particle, the quantum of a scalar field that might be generating the masses of the quarks and gluons.

The other well-known example is that of pre-medieval Arabic civilization, which was flourishing and of great influence throughout the world. Just at the time when they were supporting science: they had great mathematicians, astronomers, doctors, etc., but for various reasons, their enquiring spirit died and left modern Arab society greatly impoverished. Another interesting example is that of the 15th century Chinese civilization. The eunuchs wanted to explore the world, and Admiral Zheng had assembled, what would be the largest fleet for another five centuries, 300 ships, some of them 130 metres long. However, the confucianists won the debate: why explore the world, as nothing in their mind could be better than China, what was the point of going elsewhere? As a consequence, the fleet was destroyed. That was the time when the first Portuguese boats were sailing along the coast of Japan. Most likely, if the enquiring spirit had prevailed, Europe would have been discovered by China, and surely our history would have been quite different.

The fact that fundamental research drove innovation was even truer in the 20th century. Prof. Hendrik Brugt Gerhard Casimir, a physicist who became research director at the Philips Research laboratory, in a symposium on Technology and World Trade in 1966 listed a number of spectacular examples:

*"I have heard statements that the role of academic research in innovation is slight. It is about the most blatant piece of nonsense it has been my fortune to stumble upon.*

*Certainly, one might speculate idly whether transistors might have been discovered by people who had not been trained in, and had not contributed to, wave mechanics or the quantum theory of solids. It so happened that the inventors of transistors were versed in, and contributed to, the quantum theory of solids.*

*One might ask whether basic circuits in computers might have been found by people who wanted to build computers. As it happens, they were discovered in the thirties by physicists dealing with the counting of nuclear particles, because they were interested in nuclear physics.*

*One might ask whether there would be nuclear power because people wanted new power sources or whether the urge to have new power would have led to the discovery of the nucleus. Perhaps – only it didn't happen that way.*

*One might ask whether an electronic industry could exist without the previous discovery of electrons by people like Thomson and H. A. Lorentz. Again it didn't happen that way.*

*One might ask even whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.*

*Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way. They were found by Hertz who emphasised the beauty of physics and who based his work on the theoretical considerations of Maxwell. I think there is hardly any example of twentieth century innovation which is not indebted in this way to basic scientific thought."*

In practice, there are two basic ways in which fundamental research feeds innovation: (a) directly, as was for instance the case with Faraday's research which led to direct applications; (b) indirectly, from the tools developed for fundamental research. CERN provides many spectacular examples. A first image from a PET camera was made at CERN in 1977, in collaboration with the Hôpital Cantonal of Geneva. CERN ISOLDE provides hospital with radioelements for diagnostics. CERN patented the TARC idea to produce locally new radioelements, which would considerably reduce the dose to the patient, simply by using shorter half-life nuclides produced in the vicinity of the hospital where they will be used.

In the accelerator domain, the most spectacular development at CERN is the proposal by Carlo Rubbia to use a proton accelerator to drive a new type of nuclear fission reactor. It is subcritical, uses thorium-based fuel as well as transuranic elements from PWR spent fuel. Such a system would be very proliferation resistant, designed to remain subcritical under all circumstances, making a Chernobyl-type of accident impossible. It would moreover be able to destroy existing nuclear waste. It is in my view the only reasonable way we can imagine deploying nuclear energy today on the large scale needed to provide developing countries with the huge energy increase they need, while at the same time fighting global warming. At the time of writing of this book, Norway is showing interest in building the first prototype of such a system, which Carlo Rubbia named "Energy-Amplifier" [9]. Today, more than half of the particle accelerators of the world are used for medicine. For instance a proton cyclotron built by a physicist who trained at CERN is now used with spectacular success, for treatment of retina cancers, at the centre Antoine Lacassagne in Nice, France.

It also happens that innovation comes as a total surprise, as for instance in the case of the World Wide Web. Tim Berners-Lee, at CERN, for the need of the large experimental collaborations carrying out experiments at the LEP collider (the predecessor of the LHC), combined personal computers, networks and hypertext technologies into a global information system that was easy to use. As the Economist put it when awarding

their innovation prize to Tim Berners-Lee: “the World Wide Web has changed forever the way information is shared”; this contribution from CERN is having a huge impact on the entire society, but in 1954, when a few European member states created CERN, nobody could have predicted that such an important innovation would come out.

With the LHC in preparation, the needs for computing resources (storage and CPU power) are such that CERN abandoned the idea of constructing the required computing system at CERN. Instead, CERN is participating in the development of the GRID, to allow its physicists to tap resources distributed throughout the world, in a way somewhat analogous to tapping electricity from the electrical grid.

There is an interesting feedback mechanism between fundamental research and innovation. Innovation allows the construction of new and much more powerful tools, thereby allowing the exploration of new research territories. For instance, pixel detectors massively used by LHC experiments, were made possible by progress in semiconductor physics, and then developed by the microchip industry. Today, they are used at the LHC to improve the precision in the detection of charged particles produced in proton-proton collisions. The computer technology was based on elementary circuits invented by physicists. It was then developed by industry to provide processor chips to the public, imbedded in sophisticated toys or in personal computers. For comparison, CERN at the end of the 1970s had the most powerful computer in Europe, the CRAY/XMP, a very spectacular water-cooled machine. Today, the SONY PlayStation 2 uses a processor 2.5 times more powerful than the old CERN CRAY! These new generations of processors, developed by industry, are allowing molecular biology, particle physics, astrophysics, etc. to process amounts of data which would have been impossible to handle merely 10 years ago.

We can be sure that the new fundamental research projects, made possible today by the progress of technology based on previous research projects, will in turn produce their share of innovation, as has always been the case in the past.

How can we hope to increase the public’s awareness of the true nature and virtue of science? I believe that this cannot be accomplished quickly, but is a long-term goal, which can be achieved mainly by a better education system. Science must become an integral part of the general culture. Unfortunately, an insufficient number of students are going into the sciences these days (at least in the western world), maybe because science requires a particular effort, but mainly because our society is not fully appreciating the role science should play in our culture. For the large majority of people, believing in science is only a matter of faith. It is ironical that, while our society depends more and more on technological development, hence on science, scientific education seems to be decreasing drastically. The Russian Academician Lev Borisovitch Okun, in his address at the International High-Energy Conference in Marseille in 1993, remarked very correctly that:

*“The more illiterate people are, the more they hate the spirit of scientific curiosity, the*

*more irreversible the process of intellectual degradation will be.*”

It is, therefore, our most important duty to foster education, while at the same time using every opportunity we have, to explain why science is such an exciting adventure and why we should share with the largest number of people the unique excitement which knowledge can bring to us. It is our duty to write about science in popular newspapers; to talk about science on the radio; on television; to use every modern medium to convey our enthusiasm for science, so that the young people may learn that science offers hope for them and that the future may be bright. Scientists certainly have an overall moral obligation to inform.

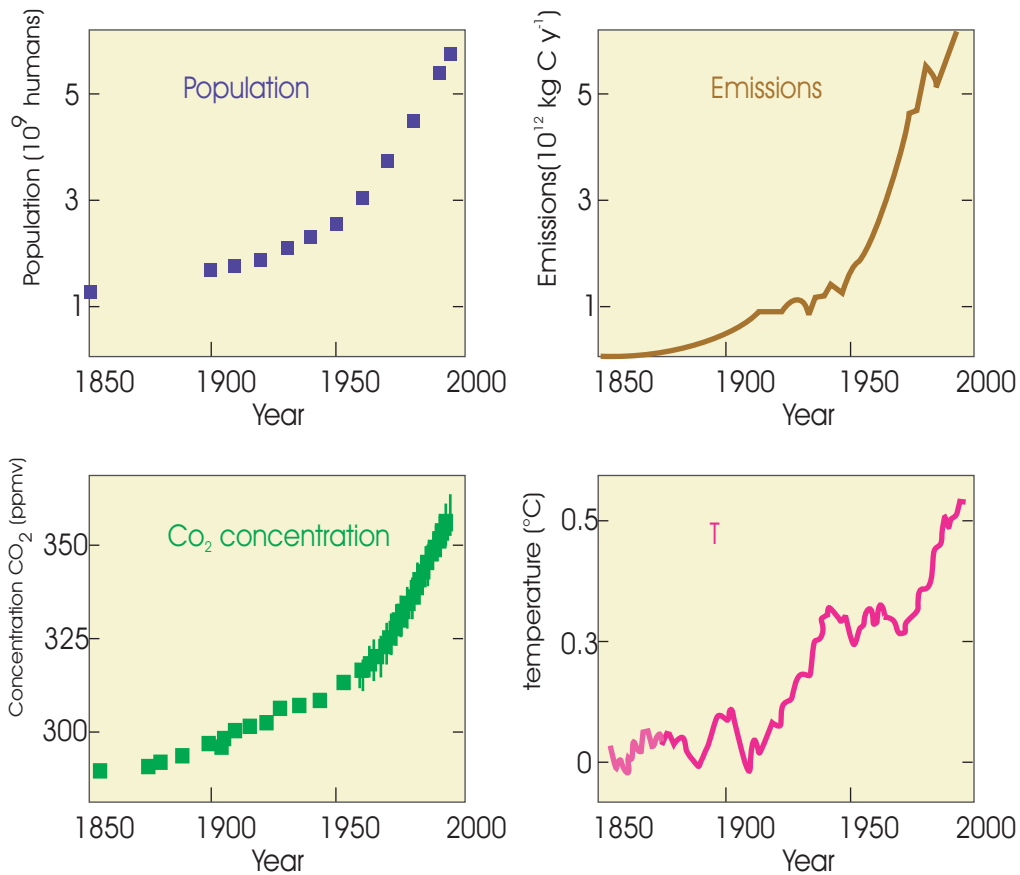
In this context, I believe that COMSATS could take the initiative, and use its unique access to a large number of developing countries to act in the area of scientific education. In Pakistan, an educational effort is already taking place under the leadership of Dr. Ishfaq Ahmad, who was the main initiator of collaboration between Pakistan and CERN. CERN has a lot to offer in matters of education, as a place to carry out Ph.D thesis research, a place with various graduate and undergraduate student programmes; a unique summer student programme, and a unique physics teachers training programme. International collaboration, in particular with CERN, can strongly boost scientific education in developing countries. Clearly, Pakistan has the opportunity to take a leading role in this area.

I would like to conclude by citing Dr. E. Sylvester Vizi, the President of the Hungarian Academy of Sciences, who wrote in 1993 [10]:

*“In the next century, more than ever before, the world will be shaped by science. Knowledge, primarily scientific knowledge will be the engine of modern society, it will provide the new raw material for prosperity of mankind. Science is able to change the world for the better, to improve the quality of life, but it is also true that its application can have adverse effects on the world. Therefore, the moral duty of the scientists is to call the attention of the governments to the actual problems and to help them in their attempts to find solutions for political, economical, ecological, social and moral problems.”*

The energy problem may well be among the foremost challenges to our civilization, because it is crucial to the prospects for sustainable and harmonious development. How can our civilization meet present and future energy needs without jeopardizing the ecological balance of the planet? How can we be sure that acceptable energy resources are distributed equitably among all nations, including developing countries? This is certainly a challenge for scientists to take up, as the solution can only come from innovation. Furthermore, a significant part of this challenge for scientists lies in providing politicians with the proper guidance, which is certainly not easy. It is rather clear that energy savings and maximum use of renewable energy sources will not be sufficient, by far, and that we must free ourselves, as soon as possible, from the use of fossil fuels, because of their strong environmental impact (chemical pollution





**Figure - 3: Historical increase of the world's population, the industrial emissions, CO<sub>2</sub> concentration in the atmosphere, and the increase of global temperature from 1850 onwards. This illustrates the correlation between human activities and the global atmosphere parameters relevant to global warming**

and release of global warming gases). Therefore, the ball is more than ever in the scientist's camp, they must find a new non-polluting energy source that can provide the huge energy production increase required on a relatively short time scale ( $\leq 50$  years) to avoid catastrophic and perhaps irreversible consequences for our planet and for our civilization. I strongly believe that the Norwegian Prototype of an Energy Amplifier for Clean Environment (PEACE) initiative is a very significant step in the right direction, and I hope it will soon turn into a global project that will associate developing countries, in particular COMSATS countries. Warming of the earth's atmosphere is a global problem (Figure-3) and it must be faced globally.

## CONCLUSION

It is vital for any country to strongly support fundamental research. This is a message that China has recently understood well. If the United States of America leads the world today, it is mainly because independently of which party is in power, their enquiring spirit has always been encouraged, offering some of the best research facilities in the world. As a result, today the pool of American researchers is dominated by foreigners. Encouraging fundamental research is a task of and must be a priority for governments, as it is not in the interest of private investors who require short-term profits, and who most naturally can invest in applied research.

In addition to cultural and educational contributions, to the innovations generated, fundamental research presents a universal character, which contributes to promoting peaceful international cooperation beyond cultural and political barriers. In my view, this is in itself a strong enough motivation for developing fundamental research, both on a national scale and on the international scale. Therefore, it makes sense for developing countries to contribute at the forefront of research, whatever the field, and nothing less than the forefront.

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