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Challenges and Opportunities for Physics Enthusiasts

B.T G. Tan
Department of Physics
National University of Singapore

Introduction

When Darren asked me to speak at today's Awards Ceremony, he thought that it would be appropriate and useful to highlight to our Award winners what kinds of challenges they might be expected to face in their future careers. Indeed, it may be worthwhile to ask our winners today where they see themselves and how might they have made a difference in perhaps 10 or 15 years time.

A career in research

I am of course hopeful that many of them will think in terms of a career in physics, and perhaps a career which includes research into physics or physics-related areas. If so, this will indeed warm the hearts of those of us in academia or in research institutions. However, it has to be said that research is not for everyone, and only the most dedicated, passionate and perhaps the most crazy people will want to spend their lives in research

pursuing some narrow topic which may or may not be earth shaking, but which is unlikely to make them a great deal of money.

Some of you will not go into physics or physics research, and that may not be a bad thing, as the kind of special skills i.e. the ability to analyse problems and solve them with rigorous, logical and systematic thinking which is (I believe) the hallmark of all good physicists and scientists, is sorely needed in all the other sectors which make up our complex society today. This includes engineers, the medical profession, lawyers, accountants and most importantly, politicians and the leaders of the nation.

The increasing pervasiveness of science

As a physicist, I am conscious of the need for the challenges and problems which face the nation to be dealt with in a scientific and logical fashion. When I was younger, I always assumed that as time went by, the world would become a place in which science was taken seriously and the tenets of scientific thinking became part and parcel of society.

As science and technology progressed rapidly in the 20th century, it did indeed seem that this would be the case. The rapid advances made during the Second World War in fields like computers, electronics, radar, communications and transportation technology soon spread into peacetime society, enabling the benefits of advances in science and technology to be enjoyed by the man in the street.

Over the later part of the 20th century, the influence of science and technology grew even stronger, and an education in disciplines based on science and technology was seen to be a prerequisite for success in life. I was quite confident then that society's progress would be increasingly guided by scientific and technological principles.

Misinformation and half-truths in science

However, since the start of the 21st century, I perceive that the influence of science and technology in society has not increased, but may even be waning. In particular, with the growth of the Internet, the propagation of and belief in pseudo-scientific principles and dubious technological predictions has increased tremendously. For example, the dissemination of supposedly helpful health and medical information on the Internet is virtually a daily affair. Members of the public with no recourse to accurate scientific and medical knowledge are perplexed and anxious about the half-truths and sometimes complete falsehoods bombarding them daily. Some of them may make erroneous and dangerous decisions based on such misinformation.

In the technological field, we also often come across predictions of engineering wonders which may come upon us in the near future. Many of these pronouncements are made by people who are themselves scientists or engineers, but who have a direct financial interest in the technology they are promoting. It is understandable for an enthusiastic proponent of a certain technology to overstate the claims for that technology. It is not right for claims which are downright unrealistic to be made for the purposes of

marketing a technology for financial advantage. Unfortunately, the frenzy to profit quickly from the tech industry has made this a common occurrence.

Policy decisions about science and technology

It is bad enough when ordinary consumers are confused and misled by dubious or incorrect scientific and technological claims. It is quite another thing when policy makers and governments make wrong decisions about science and technology which may have severe consequences for an entire nation lasting for generations.

You Award winners will become the future policy makers and movers and shakers in our society. If you become scientists and engineers directly driving the technological development of our nation, that is excellent! But even if you enter other careers which have less direct or little connection with science and technology, you will still have a direct influence on how our society utilizes science and technology.

If you become a politician, government minister, senior civil servant or policy maker, you have the grave responsibility of ensuring that all future decisions on your country's future science and technology - be it energy, the environment, climate change, natural resources or anything else critical to our survival - are made on the basis of sound science and technology.

Even as an ordinary member of society, your collective views are very important, as they can strongly influence our policy makers. Indeed, it is the duty of every citizen to ensure that he or she is sufficiently well

informed about all key issues of the day to ensure that as citizens, we collectively make the right decisions for our future.

History of science and technology

I have earlier alluded to the increasing pace of scientific and technological progress since the end of the Second World War, which transformed our society so dramatically. However, it was really in the 18th and 19th centuries that the transformation of society from a mainly agricultural society into the modern technological society we know today really took place. My own interest in the history of science and technology came relatively late in my career, as during my school days I was not fond of history as a subject, laden with dry facts and lists of dates to remember.

However, as I grew older and perhaps a little wiser, I began to realize that a knowledge of history is essential to understanding the present day, and also perhaps critical to understanding what the future might portend. Indeed, crucial policy decisions which affect the future usually require a good understanding of history for sound decisions to be made.

History of equal-tempered scale

The study of the history of science should of course include the history of science and technology in both the East and West. Many of you will know that I have been teaching a General Education Module or GEM in NUS for almost 20 years, called the Science of Music, in which I attempt to show the many close linkages between science and physics in particular, and music.

One of the topics I cover is the development of musical scales, which are the basis of the notes used in the music of a particular musical culture. I explain how the most universal scale in modern Western music, the Equal-tempered scale was derived to the accuracy of eight decimal places, not in Europe, but in China by a nobleman, Zhu Zaiyu (朱載堉), who was also a poet and mathematician. This shows that the scientific and cultural histories of East and West are closely intertwined and bound up, just as the Silk Road had done thousands of years ago.

Science and technology progress in tandem

The ancient civilizations of China, India and the Middle East very early in recorded history utilized the skills of scientists and engineers for key state functions, such as the making of accurate calendars and the prediction of the seasons for agricultural and ceremonial purposes. It is a rather unfortunate fact that the art of warfare and the need to prevail in battle were great drivers of technological advancement. More recently, it was the industrial revolution of the 18th and 19th centuries which transformed Western civilization from a mainly agricultural society into the highly technological and industrial society which it is today.

Indeed, the 18th and 19th centuries was a period of astounding progress in both science and technology during which many key scientific concepts and technological advances defining our modern world came into being. Science and technology advanced in tandem, but it was often the case that a

key invention was devised and built through sheer ingenuity, before the scientific principles underlying that invention were fully understood.

When these scientific principles had been elucidated, they often made an existing invention more efficient and hence more useful. In turn, scientific discovery was often greatly assisted by the availability of devices brought about by technological advancement. Hence science and technology fed on each other's advances during this momentous period of scientific and technological progress.

The pace of scientific and technological discovery in the 18th and 19th centuries proceeded rapidly, certainly in comparison to previous eras of history. We often believe that our current era is seeing the greatest rate of technological progress ever in history. However, this may be a debatable point, if we look at how some of the 18th and 19th century developments altered society and daily life much more profoundly than the developments of the 20th century.

The great inventions of East and West

China is justly proud of the four great inventions (四大发明) which she gave to the World – the compass (指南针), gunpowder (火药), paper making (造纸), and printing (印刷). These four great inventions of China certainly profoundly affected society at that time. Looking at the technological progress of the 18th and 19th centuries, what were the most significant technological advances and inventions changing society then?

If I had to pick four such inventions, to mirror the four great inventions of China, I would select these four: the steam engine; the electric telegraph; photography; and the incandescent light bulb. No doubt each of you would have your own favorites, but my reasons for these four are as follows:

1. The steam engine liberated mankind from its dependence on the motive power of nature and of animals.
2. The electric telegraph made possible communication over long distances within a matter of minutes or seconds.
3. Photography provided a means of faithfully recording visual information without the capricious interpretation of artists.
4. The incandescent light bulb freed mankind from the darkness of night without the need for illumination by fire or flame

<u>The steam engine</u>

If I had to name one single invention as the most significant of this period, I have no doubt that it would be the steam engine. Prior to its invention, mankind had to rely on natural forces like river currents or wind, or on the strength of animals like the horse, donkey or buffalo, to supplement human muscle power. Indeed, the steam engine spawned the Industrial Revolution which brought mankind from the agricultural to the industrial age.

The steam engine not only gave rise to the Industrial Revolution, but utterly changed the face of transportation. Sailing ships which had hitherto been totally dependent on the vagaries of wind and weather were replaced by steamships, which travelled much more rapidly than if driven by wind power. An entirely new class of transportation – railways – was able to

spring into existence as a result of the availability of motive power not dependent on animal traction: the steam engine.

Physics and railways

Indeed, my interest in the steam engine and the history of its development came about because of my long-standing interest in railways and trains, an interest which was revived by the recent issues in our MRT system. It struck me that while the development of railways was a technological subject, it had quite a lot to do with physics. This is apparent in the three major areas of railway technology:

1. The physics and kinematics of steel wheels on steel rails, which determines the stability of trains.
2. The physics and technology of the motive power driving trains – steam, diesel and electric engines.
3. The signalling systems preventing trains from colliding with each other.

I was especially interested in how physics principles had been so important in the development of the steam engine, which had its genesis in the 18th century, a period when the gas laws were also being formulated. The first practical commercial steam engine invented by Newcomen in the early 18th century made use of the formation of a vacuum by condensing steam, and so allowing atmospheric pressure to move a piston against this vacuum. James Watt later in the century vastly improved Newcomen's engine by condensing the steam in a separate chamber.

The adaptation of the steam engine to railways only became possible when Trevithick in the early 19th century invented a practical high-pressure steam engine which was powerful and compact enough to drive a railway locomotive. The Stephensons by the mid 19th century built steam engines for their locomotives so advanced that their designs formed the basis of all subsequent steam locomotives. At around the same time, Carnot was formulating the thermodynamic cycle named after him which permitted the proper analysis of heat engines.

Throughout the development of the steam engine we see the parallel development of thermal physics and thermodynamics which in turn made superior heat engines possible. The diesel engine and electric motors which power modern trains also have close linkages to physics. With all the interest in the current state of our MRT system, perhaps these connections between physics and railway technology will inspire some of you to apply your physics knowledge to improving the MRT system!

<u>The Second World War</u>

Many of the most important scientific and technological developments of the 20th century which have profoundly shaped our society today, were the result of the Second World War. I have already mentioned some of them, such as computers and radar. Perhaps the most significant such development bequeathed to us by that war is the development of nuclear energy. As is so often in wartime, nuclear science and technology were

basically driven by the need to create advanced weaponry, so as to enable the war to be won decisively.

The development of nuclear weapons was indeed made possible by significant advances in the understanding of the atom and its nucleus. The birth of quantum physics and relativity gave physicists new tools for the understanding of the atom and the tremendous energy which it could release, both for destructive purposes as well as for the generation of energy for the use of society. The Manhattan project which gave rise to the atomic bomb was driven mainly by physicists, and indeed comprised perhaps the most distinguished group of physicists ever gathered together to work on a single project.

Nuclear energy

Fortunately, physicists were also instrumental in showing and demonstrating that the immense powers of the atom and its nucleus could be harnessed for the good of society. This is a powerful reminder to us not only that physicists can make a great impact on society, but also that this impact can work for vastly different purposes.

As you may know, Singapore has opted not to utilize nuclear power at this juncture in time. We hope that in the future, advances in nuclear technology will create sources of nuclear energy more appropriate for our rather unique situation as a very small nation with a high population density. In the meantime, we are building up our national expertise in areas of nuclear physics and technology in order to safeguard our nation from possible

radiation hazards due to incidents which may occur internally and externally.

Some of our near neighbours may adopt nuclear energy in the near or medium-term future, and we need to be prepared for any eventualities. Hence Singapore will need physicists who are trained in various aspects of nuclear and radiation science, and I hope that some of you will seriously consider entering this field of study, as we have not had many people in the past interested in entering this field.

Other exciting fields of physics

Nuclear physics is of course just one of the many fields of study for future physicists wanting to contribute to Singapore's development. Another exciting area is that of quantum computing, in which Singapore has gained an international reputation within the last decade or so. If some of the current developments reach fulfilment, we may see enormous changes in high-performance computing, as well as in communications technology and cryptography.

Another expanding field is that of materials science, in which physicists are making tremendous advances in the understanding of the behavior of physical materials at the quantum level. These advances will undoubtedly lead to new materials which will transform entire areas in electronics, communications and transportation. A case in point is the whole field of 2-dimensional materials which was opened up by the discovery of graphene, a

material with truly amazing properties, and which is the subject of much research effort in Singapore.

Some of you may have the great responsibility of teaching physics at school, college or university. You will of course be as up to date as possible and be on top of all the latest developments in physics and technology, ensuring that your students are as well informed as possible. You will be aware that it is important not just to convey physics principles and facts, but to imbue in your students an understanding of the scientific method and the values of the scientific community in upholding the integrity and trustworthiness of science.

Science and the citizen

No matter which areas of physics you may embark upon, and even if you do not choose a career in science or technology, I very much hope that each of you will keep yourself abreast of every important development in science and technology, and help to propagate and promote a good understanding of science in our society.

This is of utmost importance so that when our nation has to make important decisions in the future which are crucial for our future, these decisions will be made by our policy makers and by society as a whole on the basis of a sound understanding of the scientific issues involved. If we do so, we can avoid catastrophes arising from an unsound or erroneous understanding of science, and ensure a better society for our future.