CANDLES, COMMITTEES, AND NOBILITY: THE FUTURE OF NANOSCALE BIOLOGICAL SCIENCES

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DEAR FRIENDS AND COLLEAGUES – THANK YOU FOR COMING.

It is a great honour to be here and to have the opportunity to present my Inaugural Lecture.

When I was first told about this lecture, I asked David Blank what it was all about and his response was basically ‘tell people what you do and what you think and have some fun’ – so I will try to do that.

My comments today reflect 40 years as a researcher and 19 years as a university and research administrator – two years as Associate Dean of Graduate Studies, one year as Associate Dean of Research, five years as Chair of a Chemistry Department, one year as Associate Vice-President Research, nearly three years as Vice-President Research, and 7 years as Director General of the National Institute for Nanotechnology.

Part of my agenda today is to reflect on whether we should be optimistic or pessimistic about the future of emerging technology fields.

I worry that science in particular and research in general is at a crossroads and that the future of our research endeavours will depend on how we manage science funding and science programs, particularly those that require strong interdisciplinary teams working in emerging technology areas – such as nano-bio-technology or nanoscale biological sciences.
On the one hand, I fear that Robert Fulford may be proven right if we continue down a path of ‘excessively planned’ research -

On the other hand, I believe that Lincoln Steffens will be proven right if we can maintain independence in our research agendas1.

But more about that later -

First, let me briefly set the stage for the concepts of nanoscience and nanotechnology so that we may better understand the future of nanoscale biological sciences.

Nanoscience is about exploring the properties of materials and devices at a small scale where these properties actually depend on the size. This is not a new concept – in fact the foundations for this were established over a century ago in disciplines like colloid science, quantum mechanics, x-ray scattering – but what is new is our ability to use these properties in new and fascinating ways, and that leads us towards nanotechnology – which is about the application of nanoscience to develop new materials, devices, and products that exploit the special properties of the nanoscale.

Astronomy fascinates us because we don’t understand it. Thinking about the universe forces us to consider concepts and numbers beyond our daily experiences – it is hard to fathom what is going on at such a large scale.

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1 Interestingly, Lincoln Steffens wrote this in a letter in 1919 after having seen what he considered the success of a planned society in Russia.
Let us consider some numbers in the context of the constellation Orion:

1 meter is about the distance from the tip of your nose to the tip of your finger
1,000 meters is about the distance from here to FC Twente stadium
1,000,000 meters is about the distance from here to Vienna
1,000,000,000 meters or $10^9$ m is about twice the distance from here to Vienna
1,000,000,000,000,000,000 or $10^{18}$ meters is about the distance to the moon
1,000,000,000,000,000,000,000 or $10^{24}$ meters is about the distance to the star in Orion
1,000,000,000,000,000,000,000,000 or $10^{24}$ meters is about the distance to the edge of the universe

$10^{24}$ is also approximately the number of stars in the universe – a number so large that it is hard to imagine

Yet

$10^{24}$ is also approximately the number of water molecules in a sip of coffee – that is a lot of water molecules in a small volume – they must be very small.

Today we study molecules individually – and that is the realm of nanoscience and nanotechnology

Let us go in the other direction

.001 meters is the thickness of your nail
.000 001 meters is the thickness of a small bacterium
.000 000 001 meters is the thickness of many molecules –
and 0.000 000 001 meters – a nanometer – is the distance between the two silicon atoms at the tip of the arrows on this surface of silicon – the surface on which almost all electronic devices are built today.

This is the scale of nanoscience and nanotechnology – from atoms and molecules up to about 100-300 nanometers.

Let us look at another aspect of this scale:

Think about a grapefruit – it is about 12 cm across – or 0.12 meters. It would scale to a 1.2 nm gold nanoparticle by about 100,000,000 times or put another way a small gold nanoparticle would compare to a grapefruit as the grapefruit compares to Earth – which is about 12,000 km.

Along the same lines, a cell membrane – my favourite topic for more than 40 years – compares to a pad of paper as that pad of paper would compare to Mount Everest, or three times the height of the Rocky Mountains close to where I live.

So nanoscience and nanotechnology deals with small things – but that is not enough – more importantly, nanoscience and nanotechnology deals with objects for which size matters - principally because of two things:

- The effect of more surface and less volume as we get smaller
- The effects of confining electrons in small volumes – quantum confinement

- let me explain both very briefly
Surface effects become important because the surface to volume ratio changes dramatically as items get smaller. You actually all know this very well and I will illustrate it with some coffee beans:

If you take a cup of coffee beans – as I did here – the surface area of the coffee beans is on the order of the size of my cutting board – or a napkin.

If I grind them in a normal coffee grinder, the surface area becomes much larger – in fact, the same cup of coffee now has a surface area as large as my living room carpet – and we know that the ground coffee makes better coffee than the beans because we can extract more flavor more easily because of that extra surface area. Note that the volume has not changed – the surface to volume ratio has.

If I was able to grind these coffee beans to the size of nanoparticles, their surface area would increase to cover several football fields!

So the surface properties of materials become dominant for small particles. And surfaces are different because molecules at the surface only have neighbours on one side while those in the middle have neighbours all around them. This larger surface area affects the fundamental properties of materials.
For example, gold has a melting point of 1064 degrees centigrade. If we take a piece of gold and cut in half, the melting point does not change – in fact the melting point of a material is an **intrinsic property** of that material, a property that does not depend on how much material we have – it does not change with the size of the sample.

Still, if we make smaller and smaller nanoparticles then as the particles decrease in size the surface becomes more important – the atoms on the surface dominate the behaviour of the whole and the melting point drops – the material properties change!

So why is this important? It means that we can – at will – manipulate the size of an object and change its properties – **we can make new materials from old materials**.

Another example of the effect of high surface to volume ratio is found in the residue of clay, oil, and water in tailing ponds, such as those in the oil sands of Alberta – but they are also found with other mines around the world.

Because of their small size, the surface is very active, and the clay holds on to the water and the oil very strongly. The particles are also so small that they will not settle by gravity alone.

Cleaning the tailing ponds in mines is ultimately a nanotechnology problem.
The other effect of size arises from confinement of electrons to small volumes. This effect has been known for a century and is explained by quantum mechanics as follows: Any object – an electron for example, but also a tennis ball – is only allowed to occupy certain energy levels. This is akin to you being in a building where you can only be at certain elevations above ground level as determined by the floors in the building – you effectively occupy a higher (potential) energy state on the tenth floor than you do on the first floor – which would be very evident if you were to jump out the window! As you know, you cannot stand between floors (except on the stairs or in the elevator – both of which serve to get you from one state (of potential energy) to another state).

In the same way, electrons are only allowed to occupy specific energy levels, and they can only go from one level of energy to another if there is an external influence – such as shining light on the material. What is important for electrons – and what we learn from quantum mechanics - is that they occupy the space available in a particular way – namely as a wave that is zero at the walls. This is like a skipping rope forming a standing wave between the hands that hold the rope – the wave is zero at the edges of the rope.

Clearly, if the hands are further apart, the wavelength is longer. Likewise, if the edges of the box the electrons are in are farther apart, the wavelength is longer.

Longer wavelength corresponds to smaller energies. In a small box, the levels are farther apart.
So why is this important? It means that the energy levels of electrons depend on the size of the particle they are in!

Nanoparticles of different sizes will have different colours!

This is illustrated very well with nanoparticles made of a combination of Cadmium and Selenium – Cadmium Selenide quantum dots:

- 1 nm particles emit blue light if excited
- 3 nm particles emit green light if excited
- 6 nm particles emit red light if excited

So we can change the colour of a material by simply changing the size.

Sometimes we can change the effective size by bringing nanoparticles together into clumps. For example, if we coat goal nano-particles with an antibody that recognizes a particular protein, then when that protein is present,
the gold nanoparticles will attach to the surface and form clumps. When they do so, they change colour – in this case they become red rather than blue - and we can see that with our bare eyes – as is the case in this pregnancy test where the small band –T– that forms is a result of the association of gold nanoparticles because there is a small amount of a particular protein – the beta subunit of hCG or human chorionic gonadotropin – present in the urine very early in pregnancies.

This is a clear example where nanoscience (colour changes associated with aggregation of gold nanoparticles) has been applied as nanotechnology (a product that relies on a nanoscale phenomenon). [The second line is a control to show that the test is working.] We have used nanoscale phenomena for a long time – in fact the colour of red stained glass windows used hundreds of years ago were generated by colloidal gold – nanoparticles in action – so why is nanotechnology such a hot topic today?

Because we can understand and know how to manipulate the nanoscale world; because we can

**Visualize** – we can see really small things really well  
**Design** – we can apply engineering principles of design because we know how things work  
**Control** – we can control how molecules are arranged or assembled

We are thinking about this small world in different ways. Let me illustrate how:

If we want to make an object we have two choices:  
- we can take some material and cut away the unwanted parts to create the final object  
- we can assemble components to create the object
In the world of nanoscience and nanotechnology we call these the top-down and the bottom-up approaches. Both are equally useful, depending on the problem that needs to be solved.

**Today,** the entire electronics industry relies on a top-down approach to making fine wires in circuits.

They:
- Visualize the circuit of interest
- Design a mask and imprint it on a substrate
- Control the etching of the parts that do not form the circuit

**Tomorrow,** we may follow the principles of Jillian Buriak at NINT:
- Visualize the circuit of interest
- Design molecules that will assemble to form the pattern of interest
- Control deposition of the material that forms the wires in the circuit
Why change?

Because the newer approaches may be done on a table top whereas current approaches require large clean rooms in Billion$ fabrication facilities.

A real example: Xerox EA Toner Particles

Xerox traditionally made their toners by grinding down dye particles (top-down technology) and sorting them into relatively uniform sizes. After adopting a self-assembly protocol (bottom-up technology), they were able to produce more homogeneous particles with much higher fidelity in printing - and at half the cost.

This is one of the first successful commercial applications of nanotechnology by design.

Hopefully I have given you some sense of the broader field of Nanoscience and Nanotechnology. What then is Nanoscale Biological Sciences?

There are really two aspects to this:

**Bio-nanotechnology** - the application of understanding of biology to create new nanoscience

**Nano-biotechnology** - the application of nanotechnology to understand biological systems
While perhaps an arbitrary distinction, it underlines the fact that we can learn from nature, where almost all systems rely on the principles of working on a small scale often through some assembly process – we can learn how natural engines work to create or utilize energy, we can learn how natural systems assemble into functional organelles, we can learn how biological systems interact to regulate function.

And at the same time, we learn about nature by applying the tools of nanoscience – we learn about structures by electron or light microscopy, we learn about function by using spectroscopy, we learn about interactions by pulling or pushing on molecules.

An example of learning from Nature:

DNA strands assemble into long chains by very specific interactions between different components of the DNA molecule through hydrogen bonds – a juxtaposition of an oxygen atom and a hydrogen atom in a very specific linear geometry. Each hydrogen bond is weak, but when properly aligned, many of these will add up to form very strong and very specific interactions – this is the basis for transmitting our genetic code – without many errors.
Hicham Fenniri at the National Institute for Nanotechnology in Edmonton has now adopted the principle of specifically oriented hydrogen bonds to create new structures – in this case rosette nanotubes – with unique and novel properties. These can be designed to act as adhesives on surfaces to promote bone growth or to adsorb metal particles to act as catalysts or electric wires.

My own work qualifies as ‘nano-scale biological sciences’ for two reasons:

I have always been interested in an biological membranes or their mimics – and these are large flat sheets about 4-8 nm thick – nanoplates is the new terminology, so they are truly nanoscale in one dimension.

I have applied tools, such as atomic force microscopy, developed in the nanotechnology area to study the properties and functions of membranes and membrane analogs.
During my 40-plus years as a researcher, I have contributed to four general questions:

1) Is a curved membrane different from a flat membrane?
2) What determines the mechanical properties of cell?
3) Do proteins in the membrane cluster?
4) Why do lung surfactants fail?

During the early 1970’s it was for the first time understood that the membrane was a dynamic system where molecules could move fairly freely in the plane of the membrane and a lot of tools were applied to understand how molecules moved and with what speed. In addition, a new model system of small liposomes, or vesicles – spherical bilayers – was developed to study the dynamics since they were reproducible and easy to work with.

However, a great debate arose as to whether the curvature of these small vesicles would affect the dynamics – would the chains wiggle more or less because of the curved surface?

My doctoral research helped address this question by combining the information from a number of different spectroscopic measurements to show that indeed, the lipids in small vesicles were more disordered than those in large flat membrane systems. This is now the accepted view and it turns out the curvature of membranes can have significant functional roles – for example destabilizing the membrane during fusion events or allowing increased concentrations of specific molecules at the curved sections during the cell division in bacteria.
As it became clear that the membrane was a dynamic liquid system, it also became evident that if the membrane that envelopes a cell controls its shape, then the natural shape of cells should be spheres – since that creates the lowest energy for the membrane. Very few cells are in fact spherical, so one of the questions that arose in the late 1970’s and early 1980’s was: what controls the cell shape if it is not the membrane? My post-doctoral work was designed to address this question by creating a device which could probe the mechanical properties of cells by poking on them and measuring the force required to deform the cell surface. With the invaluable help of Bill McConnaughey, we succeeded in designing and building the Cell Poker - which consisted of a fine glass fiber attached to a fine wire that could bend. When the tip of the glass fibre touched the surface, the resistance to deforming the cell caused the fibre to bend and we measured the bending with a precision of 20-30 nm to determine the forces on the cell. We combined these measurements with treatment of the cells with drugs known in vitro to cause changes in the state of polymerization of intracellular structures known as microtubules and microfilaments to show that these structures contributed significantly to the stiffness of the cells and that this stiffness varied with position on the cell. We now know that these structures act much as the bones and muscles of the cells and control not only their shape, but also their ability to move.

The recognition that the membrane is fluid led to the hypothesis that proteins in the membrane could diffuse and associate with each other and that this in turn would control their functions. Specifically, it was proposed that when a hormone or small protein binds to a specific
membrane protein – a hormone receptor – it leads to an association of the receptors to form dimers or small clusters within which further chemical reactions take place. This raised further questions: how rapidly do they move? What controls their movement? What is the state of clustering of proteins on a cell surface? Does it change? These questions led us to study the dynamics of lipids and proteins in model membranes and in cell membranes using a set of fluorescence microscopy tools.

Fluorescence arises when a molecule absorbs light at one wavelength, for example blue, and emits light at another wavelength, say green. This fluorescence emission can be detected in a microscope and it allows us to locate the molecule on a surface with some precision – approximately 300 nm depending on the wavelength. Since we can locate it we can follow it by a number of approaches to determine where it goes, how rapidly, and what factors influences its motion. We decided to see if we could determine from these microscopy methods whether the proteins were clustered, whether they would interact with themselves or with other molecules, and how quickly they moved, so we developed a new set of tools to do this by analyzing variations in intensity of fluorescence emission as a function of position across an image of a cell surface.

This set of tools we called **Image Correlation Spectroscopy**.

We showed that the fluorescence image could be analyzed by a particular function – called a correlation function – and that the height of this function would be a quantitative measure of the number of clusters on the surface.
This allowed us to characterize the density of clusters for a number of proteins – particularly receptors such as transferrin receptors; epidermal growth factor receptors; platelet derived growth factor receptors; and more recently bone morphogenetic protein receptors.

Subsequently, we showed that if we measure two images representing two different protein molecules on the surface of the cell, we could determine the density of each of the proteins and the fraction of each protein that would associate with the other. This way we were able to show that certain receptors (transferrin and platelet derived growth factor receptors) would associate with coated pits on the cell surface (through which they would be taken up into the cells), while others (epidermal growth factor and bone morphogenetic protein receptors) would preferentially associate with caveolea (through which they would internalize).

We are now working on using sets of three images to determine the extent of association of three different proteins, which will perhaps allow us and others to understand in more detail the mechanisms that control signaling between cells.

Finally, we showed that measuring images as a function of time would allow us to determine how quickly the clusters of receptors moves on the surface. We used this to demonstrate that clusters move about 100-1000 fold more slowly than monomers, but that the monomers can rapidly exchange in and out of these clusters.

In the mid 1990’s I started collaborating with several colleagues to understand why lung surfactants fail to function after mechanical ventilation of lungs – a condition known as Adult Respiratory Distress
Syndrome. It was known that lung surfactant is a mixture of lipids and proteins that form a thin monolayer film at the air-water interface of the alveolar structures of the lung and that they are absolutely required for lung function since they reduce the surface tension of these small, and highly curved interfaces to a level where it is possible to breathe. Without these lung surfactants, the lungs fill with water – so lung surfactant failure frequently causes pneumonia.

Our collaborators were physiologists and biochemists who had shown that the only measurable change in the compositions of surfactant from lungs of rats that had been exposed to ventilation was an increase in the level of cholesterol. They showed that when they remove the surfactant from lungs of rats, the level of oxygen in the blood drops to nearly zero. If they reintroduce surfactant lipids, the oxygen level increases to normal levels and the rats recover. However, if they add more than a specific amount of cholesterol to the surfactant, the oxygen level recovers to a lower level.

They also showed that when the lung surfactant was extracted and studied in a model system, it fails to work properly when cholesterol levels are about 50% higher than normal.

These findings implicated cholesterol as a key factor in malfunction of the lung surfactant and the question was why and how? We and others had shown that the structure of the lung surfactant at the air water interface could be studied using a number of tools, including fluorescence, atomic force microscopy, and imaging mass.
spectrometry. It turns out, that as the lung surfactant is compressed during exhalation, solid domains of various sizes form within the monolayer, and these are critical for allowing the low surface tension. Using atomic force microscopy, we could determine that excess cholesterol led to additional phase separations within these solid domains, and using imaging mass spectrometry, we could show that the cholesterol preferentially sequestered in these solid domains. We therefore now believe that the action of cholesterol is to disrupt the formation of solid domains during exhalation cycle, leading to a higher surface tension, which in turn leads to failure of the lung surfactant.

Recently, I have become interested in a new question: How do cells interact with nanoparticles of different types. This arose because of a request from a small company that wanted to understand how their protein nanoparticles interact with dendritic cells – cells of the immune system. We were able to use our tools to track the fate of the nanoparticles, but since this was work I performed for the company, it is not published. We have developed a new system to study the general question using gold nanoparticles coated with a membrane. We present these to cells in culture to see whether they are taken up, how the cell responds, and whether they are excreted by the cells.

An interesting observation, which we are pursuing, is that these lipid coated nanoparticles seem to induce a response in the cells that sequesters the nanoparticles into structures that allow the cells to get rid of them. A specific example is the response of A549 cells, a lung epithelial cell type whose function is to process lipids by taking them up and excreting them through lamellar bodies to form lung surfactant. We see that the number of such lamellar bodies increases dramatically when the cells are exposed to our membrane coated nanoparticles, and that these nanoparticles specifically locate in these lamellar bodies. We have yet to determine how effectively they are excreted, if at all.
In the future we plan to study cellular processing of oligomers of alpha-synuclein – a protein that is implicated in Parkinson’s disease, and which is the focus of study of many here at Twente.

As you can see, over the years I have had an evolving set of interests, and I have been fortunate enough to have the freedom to pursue each of these at my leisure and with my own objective. While I will not claim to have changed the world, I feel I have made some useful and important contributions to our understanding of membrane dynamics and perhaps cell biology.

The concern for the future is whether we will continue to have the freedom to choose our own subjects of study and the ability to change course when we believe the science demands it.

I am convinced that the nanoscience and nanotechnology based work will continue to flourish based on three observations: it will be pervasive, it will be persistent, and it will be powerful – economically and socially. Nanoscale biological sciences will be a core driver as well.

It will be **pervasive**, since it forms the foundation for applications in almost all fields – health, communications, manufacturing, agriculture etc etc. Already we are seeing hundreds of products on the market and the trend is growing.
It will be **persistent**, since nanoscience and nanotechnology represents new approaches to thinking about science through visualization, design, and control, as I described earlier.

It will be **powerful**, since it will provide new economic opportunities – already there has been significant growth in that part of the economy that is enabled by nanotechnology materials, devices, and products – as much as 25% compound annual growth rates and it is predicted to contribute in excess of 3 Trillion dollar annually to the economy at the end of the decade.

And we are just beginning. According to the US National Nanotechnology Initiative, the first phase of application of nanotechnology is deployment of passive materials – materials that strengthen or form permeability barriers; the second phase uses active materials – materials that promote reactions or interactions; the third phase deploys smart materials – materials that respond to their environment, and the fourth phase will result from the convergence of nano-scale biological sciences with information sciences and cognitive sciences.

There are, however, going to be hurdles and I would like to briefly address three – in the context of three key words – words that are heard more and more in the academic circles

**Transparency**  
**Accountability**  
**Innovation**

and that will perhaps justify that part of the title that refers to Candles, Committees, and Nobility.

**Transparency** is a critical component of the future of nanoscience and nanotechnology for a number of reasons:
1) There are concerns for health and safety and the potential environmental impact of new nanotechnologies –
   a. We make new materials with new properties – do we know enough about them?
   b. We create new devices that very few of us understand – can we explain them?
2) There are concerns of ethical applications of new technologies, particularly those related to biological sciences
   a. We may create new drug delivery systems – can we control them?
   b. We may be diagnosing diseases better and faster – can we afford to treat them?
3) There are unlimited areas of application that can generate wealth and fame
   a. Are we prepared to address the secrecy surrounding these developments?

To deal with this, I think it is essential that researchers adopt the old code of “Noblesse Oblige”

Researchers and scientists are privileged in society: we generate new knowledge, we understand new technology better than most people, we work towards and implement novel applications of our research, and we have the freedom to pursue our passion. As a consequence, when we explore the new worlds of emerging technologies, I believe we have an obligation to each other and to society as a whole to be honest and
transparent about all of what we learn, to ensure that we ask all of the right questions about the new technologies, and that we explain the answers or the unknown as clearly and as completely as we can to the public at large.

If we fail in transparency, we will ultimately face public opinions that are negative towards any form of emerging technologies and we will have no way to regain credibility.

In other words, we must act nobly.

**Accountability** is a necessity, but we have to make sure we do it right. I am concerned that we are going overboard in our interpretation of what accountability in science is all about.

On the one hand, we all recognize the need for appropriate and detailed financial accountability – if we get a grant to perform research, we must account for our expenditures – are they appropriate expenditures, are they used for the projects that they were intended for, are they essential for the success of the project and so on. So, financial audits are both necessary and important.

On the other hand, we are seeing more and more of what we might call scientific accountability – did we do the research we were funded for? Did we do it in the manner in which we said we would do it? Did we generate the data we proposed to generate? Did we deliver the impact we promised was possible?
From some perspectives, this is an important development. We do write proposals in which we promise to conduct certain research based on some hypothesis or on some concept, and we provide a detailed rationale as well as methodology on how to conduct our research. We are assessed by peers who determine whether our proposed work is novel, unique, and feasible, among other things. And our success is largely based on our ability to convince our peers that our work was worthy of dissemination in respectable journals - our publication record is our scientific audit.

But the questions raised in a scientific audit go further and presuppose that the research is predictable and that the only thing that stands between the proposal and the impact is the actual execution of the work as stated. The questions assume there are no uncertainties. This type of thinking I fear will lead us to more and more low-risk research, research that only very incrementally increases our knowledge. It will inhibit transformative research that creates emerging technologies – research that is purely explorative and that is performed simply because we don’t know the answers.

Of even greater concern to me is the trend towards what I will call ‘scientific accountability in advance’ – the trend that it is not good enough that we describe what questions we want to address and how we want to approach it, but that we must also describe – in detail and in advance - when each of the steps will be taken and when each of the results will be created, and when each of the impacts will be felt – the incorporation of milestones into research proposals is diminishing the opportunity to make newdiscoveries, to pursue new avenues that arise and ensures that only the most predictable research will be undertaken.

Moreover, and here is the rub, the assessment of whether we successfully meet such milestones are not performed by peers, but by
employees of funding agencies who understand process, but who do not understand science or research.

This unfortunate trend of “scientific accountability in advance” is creating environments in which we downplay the importance of individual initiative in the investigative phase of research.

We must encourage individuals with ingenuity, individuals willing to take risks, individuals who can think outside the box since they create new concepts, they discover unknown and unimagined new worlds, and they create new opportunities.

We have to be careful that we do not get research planned by committees.

Let me quickly clarify, that in this emerging technology world, we also need individuals who can collaborate with others. It is imperative that we join expertise from multiple disciplines – engineering, science, social science, business to name a few, but groups must grow organically by like-minded people finding common causes, rather than by artificially creating groups of researchers and forcing them to interact. Many programs today – in the US, Canada, and I believe in Europe, enable researchers to come together and apply for group grants and that should be encouraged. But, increasingly we are also seeing organizations, such as universities and institutes that focus their attention on hiring by strategy rather than by excellence. This could become counterproductive if we are not careful.

The Government of Alberta, following its most recent budget, sent a Draft Letter of Expectation to the University of Alberta – first in Alberta and it was subsequently retracted, but it shows the intent:

“I have searched all the parks in all the cities – and found no statues of committees.”

(G.K. Chesterton (1874-1936 - English writer and philosopher).)
In working to fulfill the expectations set out in this letter, the U of A agrees to focus its resources in the following areas:

**Research:**
- Enhance alignment of Campus Alberta research priorities and capacity with the key outcomes and themes articulated in the Alberta Research and Innovation Plan.
- Demonstrate increased research and innovation system engagement and collaboration among Campus Alberta faculty and students, the Government of Alberta and industry to advance the knowledge-driven economy and create societal benefits.

My third word is **Innovation**.

There are many definitions, interpretations, and implementations of this concept. This web-site [http://freshconsulting.com/what-is-innovation/] compares 30 different statements and definitions and concludes that the common thread is that innovation refers to ‘something new that creates value’.

What is the role of the modern university in the innovation process?

If we consider the Merriam-Webster definition, the university and its focus on discovery research is at the core of innovation.

**The Business Dictionary: Innovation**

The process of translating an idea or invention into a good or service that creates value or for which customers will pay.

To be called an innovation, an idea must be replicable at an economical cost and must satisfy a specific need.

**Merriam-Webster: Innovation**

1) the introduction of something new;
2) a new idea, method, or device

If we consider the Business Dictionary definition, innovation is all about converting an existing
idea or invention into something for which people will pay. That is what a business is doing and the role of the university should be much more limited.

Universities started as institutions of higher learning, meaning that they were the place where people were taught and debated the state of human knowledge. At some point in time they transformed into organizations where new knowledge is created through research – this happened a few centuries ago in many parts of Europe, but only since the Second World War in Canada, and only in the last couple of decades in many other countries such as China and Russia where research was performed in separate and often specialized Institutes.

Integration of teaching and research is, in my view, an excellent development for two reasons: First, the teaching is based on the leading edge of knowledge and second the research is informed by the fresh minds of the next generation.

However, integration of teaching and research is challenging since they often require different skills and personalities. Both require a lot of time – but in different ways: teaching in classes is tightly scheduled but an experiment needs unbounded time for completion – perhaps an hour, perhaps five, perhaps more. Nevertheless, most universities and individuals in universities have found ways to balance the two with great success.

What then about innovation in universities? Do we in the future try to integrate innovation, in the context of the business language, into the university so that it becomes a teaching, research, and innovation institution? Will it be possible to balance those three activities in a meaningful way? Is it appropriate? Will the added innovation agenda diminish the role of teaching or will the teaching be enhanced by the entrepreneurial component? Will the need to ‘create value’ diminish the research role of parts of the university, such as the humanities and
social sciences?
I am not convinced that it is the best combination, and interestingly, we are seeing a trend across the globe towards establishing stand-alone institutes without teaching, where research and innovation can be more integrated.

Whatever the organizational principle of the future, the push towards innovation is leading us towards more planned research – research that is aimed at solving a specific, well-defined problem – research that is predictable – and therefore by necessity low risk.

If we embrace this philosophy, and let innovation based research take over at the expense of discovery based research, I fear that we will stagnate. We will focus on problems with known solutions rather than on unraveling the unknown and on being inventive.

This is a particular concern in emerging technology areas, such as nanoscience and nanotechnology, which is all about exploring new territories and discovering new principles.

So let me counter the push towards excessive focus on deliberate research by quoting a colleague of mine:

“**Innovation is not the result of thinking differently. It is the result of thinking deliberately (in specific ways) about existing problems and unmet needs.”**

“One can agree that no amount of research and development on candles would have brought us electric light” Yunjie Xu (2012)

If we keep this in mind, and continue to support research into novel ideas and new concepts, then I believe we can be optimistic about the future like Lincoln Steffens—although for very different reasons—he embraced the principles of planning to get a better society.

I suggest we need less planning and more free-roaming research by bright individuals who understand their obligations to society as researchers and scientists.

Thank you very much.
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