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130TH ANNUAL ACADEMY MEETING[1]

Presidential Plenary Address by Arden L. Bement Jr.[2]

"CONNECTIVE PATHWAYS IN SCIENCE"

INTRODUCTION

I have chosen "Connective Pathways in Science"' as my topic this morning for a particular reason. Just as dark matter drives the acceleration of the expansion of the universe, connections are the driving force for accelerating the pace of scientific and technological advancement. Such connections make available exchanges of a broad diversity of opinions, concepts, and perspectives; stimulate new discoveries; create still more knowledge; and drive still more scientific and technological advancement. It's an autocatalytic process that makes us all more knowledgeable.

An appropriate starting point for this presentation is the mission of the Indiana Academy of Science, which is now 130 years young:

- Promoting scientific research and diffusing information connects the various science communities in Indiana and also connects these communities with the public at large;
- Encouraging communication and cooperation among scientists promotes collaborations and the discovery of new concepts; and
- The improvement of education in the sciences provides generational connections between Academy members and aspiring young scientists.

CONNECTIONS IN A CONTRACTING WORLD

The world is shrinking figuratively due to advances in communications and information technologies and the ease of international travel. An increasing number of the world's universities aspire to become international universities. In the United States the growth in international students, foreign-born faculty members, study abroad programs, international collaborations, and joint publications has already accomplished this.

Furthermore, the growth of large-scale, virtually-connected, research facilities; the open exchange of information and courseware; and the harmonization of curricula and degree programs support growth in the international connectivity of STEM fields.

Most countries in the world now view science and technology as an engine for economic growth and have increased investments in higher education and research. The BRIC nations and emergent economies in Central and South America, Africa, The Middle East and the Far East are beginning to 'get it'; that it is far more important to build their own higher education and research base in order to solve their own problems than to rely on foreign assistance.

Universities in these countries are increasing their numbers of PhD faculty to increase research capacity. Their governments are increasing research grants to support academic research at home and collaborations with top researchers and members of their diaspora at leading world universities. The overall strategy is to both broaden their economic base beyond a current primary dependence on natural resources and export more high-value added products.

As a result the fraction of the world's research being done in the U.S., which is now estimated to be about 30%, is expected to decline to about 20% by 2020. Likewise, the number of U.S. universities ranked in the top 100 of the world's universities, now about 50, will likewise steadily decrease, especially those that are STEM intensive. Therefore, connectivity with the top researchers and universities in the world will be an imperative to avoid becoming 'blindsided' to important new scientific discoveries and technological innovations occurring abroad. As mentioned in my introduction it will also be a key driver for scientific advancement in the U.S.

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CONNECTIONS IN ADDRESSING GRAND CHALLENGE GLOBAL ISSUES

Global issues abound in the world today. A few examples include sustainable energy, global warming, disruptive natural events, world hunger, pandemics, loss of biodiversity, invasive species, and failed states (Yemen being the latest example).

Each of these global issues is highly complex. The interrelationships among them compound this complexity. For example, sustainable energy is connected with sustainable ecology and a sustainable economy. The growing intensity of weather events is connected with global warming, which in turn is connected with carbide dioxide emitted from fossil fuel burning to generate electric power. Food production and processing to meet the needs of a burgeoning world's population is energy intensive, challenged by invasive species, and consumes 70% of the world's available fresh water. Likewise, growing high-water-content crops, such as tomatoes and cucumbers, and raising livestock in arid countries using water obtained by energy-intensive desalination is not as economically viable as importing these foods from other countries where water is plentiful.

Solutions to these problems by technical approaches alone are insufficient. One must also consider a wide range of social, behavioral, historical, and economic contexts. For example, the chlorination of water is resisted in some societies where water is regarded sacred. Also, pumping potable water is not helpful if it is stored and consumed in contaminated containers where sanitation training is lacking. Scientists and engineers who advocate normative approaches to these problems without taking contextual factors and safeguards into account do a disservice to society.

These are so-called 'nasty' or 'wicked' problems because long-range predictions are unlikely … only projections over limited time steps. Also, there may not be a 'best' solution but several competing solutions that may require political choices.

CONNECTIONS IN RESEARCH AND LEARNING

For three or four decades the major emerging technologies worldwide have been information technology, biotechnology, and nanotechnology. Lately, neurotechnology has been added. One now finds a number of new fields of science and engineering emerging from the interdisciplinary connections among these technologies; such as biometrics, bioinformatics, nanobioscience, nanobiotoxicology, and many more.

However, I should note as director of the National Science Foundation during the first decade of this century when I asked visiting ministers of science and education what their priorities were they invariably responded info-, bio-, and nanotechnologies. However, as the world recession set in their priorities shifted to innovation and entrepreneurship.

As educators began wrestling with the problem of teaching these subjects, they found that mentoring students by seasoned innovators and entrepreneurs through activity-based, self-based, and peer-based learning was far more effective than instructor-based learning solely in the classroom.

Some universities, Purdue University included, are now inverting their approach to STEM education by better integrating all modalities of learning. Students now study pre-distributed instructor's lectures augmented by self-learning on the Internet in their pajamas. They do their homework in class in a team setting mentored by their instructor and teaching assistant to stimulate peer learning. Students no longer have to pretend to be awake in the classroom or lecture hall.

CONNECTIONS IN COGNITION

The reverse engineering of the brain is one of the fourteen grand challenges for the 21st Century identified by the National Academy of Engineering. This challenge may be closer to realization than most people might suppose. With the near advent of exoflop, quantum, and synaptic computing, it will soon be possible to 'cyber-model' the human brain down to the synaptic level.

Synaptic computing based on a neural network chip introduced last year by IBM and the synthesis of 'Big Data' using tailored algorithms and parallel servers have already demonstrated some attributes previously reserved to the human brain; such as, self-awareness, pattern recognition, and prediction.

It might soon be possible to discover natural pathways between the human brain and high-capacity computers, smart devices, and anticipatory controllers to accelerate coupled analysis, decision-making, and conceptualization. Also, through applying 'Big Data' tools designed for open innovation, the self-organization of more effective teams and organizations for tackling education, research, and innovation challenges can result.

With the resulting time compression made possible by these new methodologies, the pace of creativity and innovation might outpace even the imagination of science fiction writers.

CONNECTIONS AMONG THE FORCES OF NATURE

In March of 2014 scientists who had been observing the cosmic microwave background with a microwave telescope at the South Pole announced the discovery of gravity waves that formed in less than a quintillionth of a second after the 'Big Bang'. This observation not only pointed to connections between quantum theory and the general theory of relativity but also the unification of the gravitational force with electromagnetic, strong nuclear, and electroweak forces before the highly dense seed of our universe became unstable and erupted into the 'Big Bang. It further provided indirect evidence of multiple universes.

This discovery would be an automatic candidate for a Nobel Prize. However, since the announced level of confidence of this discovery, although encouraging, has been challenged several research teams around the world are actively conducting experiments to either confirm or refute the claim. We should soon know their findings.

A year earlier, in March of 2013, the discovery of the Higgs boson, the key to unlocking some conundrums in sub-atomic physics, was tentatively confirmed by CERN. Unfortunately, supersymmetry or 'Susy' particles, which should have been observed at the then existing collision energy were not observed.

Supersymmetry theory is a key link for connecting quantum physics with classical physics. It provides needed credibility for string theory and an elegant pathway for explaining electroweak symmetry breaking and the high energy interactions among weak, strong, and electromagnetic forces, all important to the 'Theory of Everything' advanced by Stephen Hawking. If 'Susy' particles exist, especially the neutralino', the big sister of the neutrino, they would be prime candidates for the 'dark matter' driving the accelerated expansion of the universe.

Unfortunately, 'Susy' has been in the hospital waiting for a doubling of the LHC collision energy to renew the search for her particles. This search will recommence this spring. Discoveries of 'Susy' particles will not only provide needed confirmation for the connections just mentioned, they will lead to the greatest connection between theoretical and experimental physics in the history of science.

But … what if Susy particles are not discovered under experimental conditions where they certainly should be? In this case 'Susy' will make a short trip from the hospital to the morgue and theoretical physicists around the world will have to push a 'reset button' and start over.

FINAL REMARKS

With this short list of connections I am not trying to demonstrate that scientists are living in interesting times. You already know this from your own fields of interest. Rather, I am trying to drive home a different point.

Scientists and engineers in Indiana such as you are making important connections in science, such as I outlined in this talk. For example our membership over the past decade has included two Nobel Laureates and a Medal of Technology and Innovation Laureate:

- The late Elinor Ostrom from Indiana University received her Nobel Prize in Economic Sciences for advancing our understanding of resource management, the governance of local public institutions, and the 'tragedy of the commons'.
- Ei-ichi Negishi from Purdue University received his Nobel Prize in Chemistry for developing chemical reaction pathways for synthesizing complex organic compounds used in a broad range of applications.
- Rakesh Agrawal also from Purdue University received his National Medal of Technology and Innovation for improving the energy efficiency of gas liquefaction and the separation of industrial gases from air, which resulted in over 500 international patents.

Physicists at Purdue University have also made important contributions to the design and operation of the CMS detector at CERN, which was key to the discovery of the Higgs boson.

Likewise, your many scientific achievements have not only contributed to a better understanding of nature by Indiana citizens, but also addressed Indiana's grand-challenge issues and inspired young aspiring scientists throughout the state.

I am inviting you to increase the strength and representation of our sections by inviting into our ranks such remarkable scientists, colleagues, prospective young aspiring scientists and classmates who understand the importance of connective pathways in science and what they can mean for our future.

I joined the Indiana Academy of Science because I wanted to be connected with scientific developments in Indiana and to meet young aspiring scientists as they present their research and make connections that might prove valuable in their career.

I hope you will invite prospective members to visit our web page. The value proposition of what the Academy can do for them and what they can do for the Academy is clearly explained on the application form. By helping to build our membership you will be strengthening its connective driving force for the 21st Century.

Thank you

Arden Lee Bement, Jr., PhD, 2014–2015 Indiana Academy of Science President. Arden L. Bement, Jr. is an American engineer and scientist and has served in executive positions in government, industry and academia. He is a former Deputy Undersecretary of Defense for Research and Advanced Technology, Chief Technical Officer of Technical Resources and of Science and Technology (TRW), Director of the National Science Foundation (NSF), and Director of the National Institute of Standards and Technology (NIST). Following the end of his six-year term at NSF, he became the founding director of the Global Policy Research Institute and Chief Global Affairs officer at Purdue University. He is currently serving on the Science Advisory Council of the Skolkovo Foundation, the Board of Trustees of the Skolkovo Institute of Science and Technology, the Board of Visitors of the National Intelligence University, and the Board of Trustees of Radian Research Inc. He is also a retired lieutenant colonel of the United States Army Corps of Engineers.