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Killam Annual Lecture 2007

Published by the Trustees of the Killam Trusts

2007 Killam Annual Lecture

"More Data … Less Insight
The New Imperative of Quantitative Literacy"

Dr. Peter J. M. Nicholson, CM
President
Council of Canadian Academies

FOREWORD

The elegant and recently restored Capitol Theatre in Moncton, New Brunswick was the setting for this year's Killam Lecture. It matched perfectly the elegant phrasing employed by Dr. Peter J.M. Nicholson, CM in this remarkable Lecture – remarkable not least because Dr. Nicholson's ideas about the importance of computational literacy was instantly accessible to even the least numerate among his listeners.

Dr. Nicholson is uniquely qualified to deliver his timely message, namely that in every sphere of modern life we are lost if we do not embrace the compelling need for "computational literacy" – not quite "numeracy", but a cognate concept. His qualifications derive from his immersion over a lifetime in a whole range of disparate callings: university teaching, banking, business, high tech, economics, public policy (and two of its offshoots: public inquiries and elected politics), and, finally, the academic think tank. Indeed it is hard to think of many Canadians – if any – who have direct experience of such an eclectic array of callings, and at such a high level in almost every case.

Dr. Nicholson is a deeply thoughtful observer of the intellectual and academic scene in Canada. Whenever such a person adds to this a profound personal knowledge of the practical requirements of hard-headed business people, the urgent call of practicing politicians for programs to meet the demands of a fickle electorate, and the pressing needs of senior civil servants for policies to meet the nation's long term needs, that person is certain to have something very worthwhile to say. Such is the case with Dr. Nicholson's Killam Lecture.

The central role of the Council of Canadian Academies is to advise the government of Canada on the full range of policies and programs it should embrace so that Canada and Canadians will be better able to face the future as a world leader in both intellectual

and commercial enterprise. We are lucky indeed that Peter Nicholson heads up this vital organization, and thrilled that as a Killam Lecturer he has shared with us all his wisdom and insight on one of the key ingredients of that future: computational literacy.

Dr. Nicholson's lecture can be downloaded in audio and text formats from our website, or you can request additional hard copies by writing to the Administrative Officer of the Killam Trusts. Both addresses are found on the outside back cover of this booklet.

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For copies of this lecture and others in this series (listed at the end of this booklet), go to our website: www.killamtrusts.ca or write our Administrative Officer at the address on the back.

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The Killam Trusts

The Killam Trusts were established through the generosity of one of Canada's leading business figures, Izaak Walton Killam, who died in 1955, and his wife, Dorothy Johnston Killam, who died in 1965. The gifts were made by Mrs. Killam both during her lifetime and by Will, according to a general plan conceived by the Killams during their joint lifetimes. They are held by five Canadian universities and The Canada Council for the Arts. The universities are the University of British Columbia, the University of Alberta, the University of Calgary, the Montreal Neurological Institute of McGill University, and Dalhousie University.

The Killam Trusts support Killam Chairs, professors' salaries, and general university purposes; but the most important part of the Killam program is support for graduate and post-graduate work at Canadian universities through the Killam Scholarships. In each of the Killam universities and at the Canada Council, they are the most prestigious awards of their kind.

The Canada Council also awards five Killam Prizes annually, in Health Sciences, Natural Sciences, Engineering, Social Sciences, and Humanities. Worth $100,000 each, they are as a group, Canada's premier awards in these fields.

To date over 5,000 Killam Scholarships have been awarded and 88 Killam Prize winners chosen. The current market value of the Killam endowments approaches $400 million.

In the words of Mrs. Killam's Will:

> *"My purpose in establishing the Killam Trusts is to help in the building of Canada's future by encouraging advanced study. Thereby I hope, in some measure, to increase the scientific and scholastic attainments of Canadians, to develop and expand the work of Canadian universities, and to promote sympathetic understanding between Canadians and the peoples of other countries."*

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November 2007

Dr. Peter J M Nicholson, CM
President and Chief Executive Officer
Council of Canadian Academies

Dr. Nicholson became the inaugural President of the Council of Canadian Academies in February, 2006.

A native of Halifax, Nova Scotia, he holds a BSc and MSc in Physics from Dalhousie University and a Ph.D. (Operations Research) from Stanford University, as well as honorary doctorates from Dalhousie University, Acadia University, and the Université du Québec (INRS).

Dr. Nicholson joined the Computer Science Department at the University of Minnesota in 1969 where he taught for four years before joining the Government of Canada in 1973. There he served in a senior policy advisory role in the Departments of Urban Affairs, Transport, and Regional Economic Expansion.

In 1978, Dr. Nicholson became Vice-President of H.B. Nickerson & Sons, a major fisheries company. In 1982, he joined the Taskforce on Atlantic Fisheries established by the federal government to restructure the industry which had been financially devastated by the 1981-82 recession.

In 1984 Dr. Nicholson became a Senior Vice-President of The Bank of Nova Scotia in Toronto, advising the Chairman of the bank on a broad range of strategic issues, including, in particular, the resolution of the Latin American debt crisis in the late 1980s.

Between March 1994 and September 1995, Dr. Nicholson was the Clifford Clark Visiting Economist in the federal Department of Finance. In this senior advisory position to Canada's Minister and

Deputy Minister of Finance, he participated in the key decisions that led to a dramatic and sustained turnaround in Canada's fiscal position.

From September 1995 to June 2002, he was Chief Strategy Officer of BCE Inc., Canada's largest telecommunications company.

Between June 2002 and July 2003, Peter Nicholson was Special Adviser to the Secretary-General of the Organization for Economic Co-operation and Development in Paris. Between December 2003 and January 2006 he served in the Office of the Prime Minister of Canada as Deputy Chief of Staff for Policy.

Dr. Nicholson has served in a voluntary capacity on several organizations dedicated to the furtherance of science and technology in Canada. He was appointed in 1986 by Prime Minister Mulroney as an inaugural member of the National Advisory Board on Science and Technology. He was the founding Chair of the Fields Institute for Research in Mathematics; a Governor of the National Research Council; a Director and a member of the Research Council of the Canadian Institute for Advanced Research; Chair of the Canadian Institute for Telecommunication Research; and the inaugural Chair of the Members of both the Canada Foundation for Innovation and the Millennium Scholarship Foundation.

Dr. Nicholson is a member of the Order of Canada, awarded in recognition of his contribution to business through both the public and private sectors.

More Data … Less Insight

The New Imperative of Quantitative Literacy

Synopsis: Today's society is rich in data to the point of deluge. And the growing ubiquity of computers and embedded sensors can only bring us more without limit. Whether in the workplace or in one's role as citizen, we are more than ever challenged to think critically with, and about, numbers and their significance for things that matter in daily life – whether risks we face; the benefits and costs of medicines and procedures; our financial choices; or coming to an informed view on big policy questions like climate change, immigration, health care spending, taxation. Competence to address issues like these demands a degree of "quantitative literacy" that too few Canadians possess. Why might this be the case? And, more important, what can be done about it?

As a Nova Scotia boy, and a proud graduate of Dalhousie University, I grew up more aware than most of the nation-building accomplishments in business and education of Izaak Walton and Dorothy Brooks Johnston Killam – accomplishments which thanks to the Killam Trusts, will continue indefinitely to build a strong future for Canada through the support of higher learning. So it is a particularly great honour to have been invited to celebrate the Killam legacy through delivery of this thirteenth Killam Annual Lecture.

Of course "13" is not a very auspicious number for those who perceive in the pattern of numbers a certain occult intention. Fortunately, I am not one of those. Instead, I have learned to glean from the pattern of numbers a perspective on the world that is both illuminating and empowering. That is why, in these remarks, I will argue the case for a sharper focus on "quantitative literacy" because I believe that a basic ability to apply quantitative concepts is increasingly a prerequisite for competence as a worker, a consumer, and as a citizen. I will try to enliven the topic with a number of ex-

amples that illustrate the substance of quantitative literacy. I hope these examples will entertain as they inform. In conclusion, I will offer some broad policy-oriented observations as to what I believe is needed to foster a more quantitatively literate Canada.

In taking up this subject, I realize I am departing somewhat from the traditional Killam Lecture focus on matters related directly to university research and its support. But I hope to demonstrate the relevance of quantitative literacy to the broader aims of Canadian universities and the research community, as well as to the society they serve.

Let me begin with an anecdote. The recent Ontario provincial election included a referendum question asking whether the province should change its electoral system from "first-past-the-post" to a hybrid form of proportional representation, dubbed Mixed Member Proportional, or MMP. A few days before the vote, the editorial cartoon in the Globe and Mail depicted your average voter, staring in bafflement at a "salesman" for MMP who was holding up posters filled with mathematical hieroglyphics, allegedly explaining MMP. In the days previous, a pamphlet that described MMP in pretty simple language had been distributed to virtually every household in Ontario – and, true enough, it required some simple grade school math and a bit of logic to figure out how the seats would be allocated. But I am sure the Globe and Mail cartoonist captured the widespread reaction – it was just mathematical gobbledegook.

No surprise – the people of Ontario overwhelmingly rejected the MMP proposal. And while there were good reasons to be sceptical of such a fundamental and little-discussed change in the electoral process, it was also the case that no one I spoke to in casual conversation could explain precisely how MMP worked. The cartoon said it all. It spoke to a widespread quantitative illiteracy, and drew a chuckle. But was it really so funny?

Quantitative literacy and why it matters

In simplest terms, quantitative literacy implies a comfort with numbers and other mathematical objects, together with the set of skills needed to handle effectively the quantitative situations arising in everyday life and work. Sometimes this is called "numeracy" by obvious analogy with prose literacy.

Quantitative literacy is most definitely not higher mathematics. Indeed, it bears the same relationship to what professional mathematicians do as prose literacy does to what Margaret Atwood and Michael Ondaatje do. Of course, we are expected to enjoy Atwood and Ondaatje, whereas very few would ever think of spending an evening curled up with Newton or Euclid!

So while quantitative literacy requires mastery of basic math at the grade school level, it is the application to everyday life that will be the primary focus of my remarks. I will argue that quantitative literacy should be as routine a capability of an educated person as the capability to read and write. That is far from the case today.

For evidence, consider that the latest International Adult Literacy and Skills Survey (in 2003) showed that fully 55 per cent of Canadians between the ages of 16 and 65 do not possess the basic numeracy skills required to function really effectively in today's knowledge-based economy. Only in Saskatchewan, Alberta, and BC was more than half the working-age population above the threshold of adequate numeracy. The survey also assessed prose literacy, and while those results were troubling as well – 42 per cent of Canadian adults fell below the "Level 3" proficiency considered necessary to cope adequately with written material – a much larger deficit relates to quantitative literacy.

Quantitative literacy should be as routine a capability of an educated person as the capability to read and write.

Quantitative literacy matters because we are confronted increasingly – for some fundamental reasons I will explain in a moment – with quantitative information and associated logical structures. That is why quantitative literacy is needed to meet the requirements of today's workplace, and even more so tomorrow's. And that is also why we need to be quantitatively literate to behave effectively as consumers, as savers and investors, as voters and, quite simply, as informed and aware individuals. In the words of Professor Lynn Arthur Steen, one of America's most articulate advocates of quantitative literacy: "An innumerate citizen today is as vulnerable as the illiterate peasant in Gutenberg's time."

Beyond the functional motivations to become quantitatively literate, I believe there are important cultural reasons as well. That is because an instinct for logic and the sense of number are as much a part of being human as the power of language. The capability of quantitative reasoning has underpinned the evolution of science and technology, and therefore of society itself. Though even a cursory discussion would be well beyond the scope of these remarks, let me open a very brief parenthesis here and mention just a few examples of the enormous philosophical and cultural contributions of mathematics through the ages.

In the 16th and early 17th centuries, Copernicus and Galileo settled, once and for all, the great theological question as to whether the sun orbited the earth, or vice versa. Then Isaac Newton, in one of the greatest conceptual achievements of all time, reasoned mathematically from Johannes Kepler's observations that a universal, invisible force called gravity could explain both why the apple fell from the tree and the planets described elliptical orbits around the sun. Newton's monumental Principia Mathematica, published in 1687, became the model for a mathematical analysis of natural phenomena, the broad philosophy of which persists to this day.

Fast forward to 1864 when the great Scottish natural scientist, James Clerk Maxwell, predicted, purely by mathematical reasoning, that electric and magnetic forces would combine to generate waves that propagated through space at a speed that turned out to be the speed of visible light – or an astonishing 300,000 km per second. And thus was born a theory that has enabled human beings, through generations of ingenious radio and television engineering, to encode sound and pictures on electromagnetic waves.

One can multiply these examples almost endlessly. Einstein's famous "E = mc2" described the wonderful and terrifying possibility of extracting prodigious energy from the atom. The quantum theory of matter, developed in the first half of the 20th century, has given us the ability to engineer lasers and microchips. The mathematics of the "bell curve" has enabled the measurement – and then the management – of uncertainty; and so on, and on.

I believe that an amateur's acquaintance with these monuments of mathematical achievement should be no less a part of everyone's cultural education than history, literature and philosophy. In fact, an appreciation for the great historical achievements of mathematics illustrates our common humanity in a way that few subjects do. Great mathematical truths transcend all national, linguistic, religious and cultural divides. The square on the hypotenuse equals the sum of the squares on the other two sides of a plane right-angled triangle, everywhere and always. It is an enduring truth, the ancient discovery of which by Pythagoras reflects the essence of human reasoning.

A personal anecdote explains my own journey toward quantitative literacy. At the age of sixteen, I spent several evenings on the couch at home with my lawyer father reading together a book he had been given in 1946 entitled "Physics and Philosophy" by the celebrated British physicist, Sir James Jeans. Professor Jeans described

*...society's **material** progress depends ultimately on the cumulative development of science and technology, the language of which is quantity, logic, and mathematics.*

how, according to Einstein's theory of relativity, a moving yardstick contracts in length; a moving clock runs slower than a clock at rest – and how, according to the quantum theory, what appears to be solid matter can only be understood at the sub-microscopic level as "waves of probability."

My mind was completely bent by this shocking picture of a reality so outlandishly at odds with my most basic intuition. I decided, then and there, that I simply had to understand how Einstein's and Bohr's view of the world could be so out of synch with mine. And so began a university career in physics and mathematics that had absolutely nothing to do with job prospects or learning how to evaluate personal investments, but had everything to do with a pure quest for understanding.

Of course, for most people, the cultural and philosophical side of mathematics is either of no intrinsic interest, or else is assumed – usually incorrectly I believe – to be completely beyond them. So while the cultural aspects of quantitative literacy are important, and deeply gratifying, they are the frosting, not the cake.

The motivation for most of us will be largely functional – What does quantitative literacy mean for me? How could more of it add value to my day? To answer these questions requires some explanation of the increasing ubiquity and significance of quantitative information in the modern world. From this comes the "new imperative" in the title of my remarks.

The twin drivers of quantitative information

There are two factors primarily at play – one socioeconomic, and the other technological. The socioeconomic factor derives from the fact that society's material progress depends ultimately on the

cumulative development of science and technology, the language of which is quantity, logic, and mathematics. Human beings have progressed materially because we have learned to exercise increasing control over nature – for better or for worse. And to control nature requires that we must be able to predict nature's behaviour, at least to a decent approximation. And prediction requires an understanding of natural processes that is developed painstakingly through measurement of cause and effect, or circumstance and behaviour. Quantitative forecasts can then be made, on the basis of which our understanding of the world is continuously and cumulatively refined via the cycle of "theory, prediction, experiment, and revised theory." This cycle is the essence of scientific method.

As the technology of measurement and the means of analyzing data have been continuously enhanced, more and more phenomena have fallen within the scope of this method. The extraordinary success of the quantitative sciences of physics and chemistry has stimulated the extension of quantitative methods to biology, medicine, psychology, economics, political science, sociology, even the humanities, and, not least, to the management of business processes and the "science" of marketing.

More than a billion computers linked via the internet (and expanding every second) now amount to a global "cyber nervous system" – an analogue at planetary scale of the human central nervous system.

So as technical progress unfolds, more and more numbers, together with their complex relationships, unfold with it. This then is the first source of the increasing quantification in our lives. It explains much of the growing vocational importance of quantitative literacy.

The second factor is purely technological – based primarily on the microchip and its miraculously expanding capacity to capture and

process symbolic information. The pervasive influence of the computer derives from the fact that it is a general purpose information processor that amplifies the capabilities of the human mind. More than a billion computers linked via the internet (and expanding every second) now amount to a global "cyber nervous system" – an analogue at planetary scale of the human central nervous system.

I would argue that the most transformative technologies throughout history have been those that amplify a key human capability. Thus machinery amplifies muscle; the radio amplifies our hearing; TV our vision; and the internal combustion engine our legs. Computer and communications technology, by amplifying the mind, and instantaneously connecting potentially every mind on earth, puts us into a different realm altogether.

The power of networked computer technology is nowhere near its limits. The capability of the technology, relative to its cost, has increased more than a million-fold since the 1970s. During almost four decades, the amount of computer power you could buy for a dollar has doubled roughly every eighteen to twenty-four months – a regularity that has been dubbed "Moore's Law" after Gordon Moore, the co-founder of Intel Corporation, who first predicted this regular doubling more than three decades ago. A million-fold improvement in anything is almost impossible to imagine. If, for example, an analogue of Moore's Law applied to automobiles, then a BMW that might have cost $20,000 in the 1970s could be purchased for a couple of pennies today!

So as the cost of gathering, processing and storing data continues to be driven down exponentially by successive waves of technological innovation, the amount of data being produced will inevitably continue to increase exponentially. The fruits of this digital data explosion, whether bitter or sweet, are all around us:

- The digitization of the human genome will soon be able to give us our own genetic blueprint for under $1,000.

- Medical imaging will only become more adept at finding what you never knew you had, and probably don't really want to know about.

- Computer models of climate change will become more reliable and more location-specific.

- The size and sophistication of the world's capital markets – which today depend entirely on instantaneous computer communications – will continue to steer capital globally to its most profitable allocation.

- Google will become even more remarkable at finding whatever you might be looking for – and perhaps less of what you aren't. The same goes for eBay, Amazon, Facebook . . . you name it.

- And as for the cell phone – which is really just a computer attached to a radio – today's multi-functionality will seem positively primitive in ten years time.

The message is that a powerful combination of pervasive economic and technological forces will continue to drench us in quantitative information even though – just like the unseen binary code coursing through the "veins" of our computers and cell phones – it may not be apparent on the surface. Nevertheless, basic competence in understanding the quantification of our economic and socio-cultural environment is becoming required for success as both individuals and nations. In particular, more and more of the good jobs will be going to the quantitatively literate, whether here in Canada or in other far off places like China and India where mathemati-

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cal predilection has been part of the culture for centuries. Indeed, in his just-published memoir, "The Age of Turbulence," former Federal Reserve Chairman, Alan Greenspan, blames the stagnation of middle-class incomes in the U.S. largely on the failure of America's schools to properly teach math and science.

Quantitative literacy in everyday life

There is another dimension of our life – quite apart from the vocational – where quantitative literacy is equally relevant. We are all consumers, savers and investors, and citizens of a self-governing democratic society. Quantitative literacy is increasingly important in all of these non-vocational roles. The requirements range from the quasi-ridiculous, like converting currencies (do I multiply or divide?), to the relatively sublime tasks of making savings and investment decisions; or making sense of the latest media hype on medical risks and miracle cures.

Of course one can always turn to the pros for advice in handling the more arcane tasks like purchasing an investment product. But who are they working for? Better to have some basic savvy yourself. Let me give you one simple example.

We've all seen the ads for the mutual fund manager that's beaten the market six or seven years in a row. Pretty impressive – she must know something the other managers don't. Better buy her fund.

Well maybe. But if you start with, let's say 800 mutual funds to choose from then, on the basis of chance alone, about half of them will beat the market average in any given year and half will not.

So after one year, about 400 funds will have outperformed the TSX. Of those 400, pure chance says that about half will beat the market average the next year. So after two years, about 200 funds will have out-performed two years in a row. And so it goes, with the lucky ones being cut in half each year. Even after seven years, chances are that about six of the original 800 will have beaten the market seven years in a row – not because of any special skill, but simply because of the laws of probability. And those are the funds that will be taking out the ads trumpeting their remarkable financial acumen. Now I would not claim that there aren't some financial managers who have the skill to outperform the market, but academic studies have shown that they are extremely rare. More often than not, chance alone explains a run of out-performance in the stock market. This is a valuable lesson to bear in mind.

A point I would emphasize repeatedly is that quantitative literacy does not require proficiency in higher mathematics. In terms of the mechanics, it's mostly just adding, subtracting, multiplying and dividing. Admittedly, analysis of medical information and investment decisions may be somewhat more involved than converting from dollars to euros, but still there's no higher math required. What is needed, though, is a sense of how numbers and logic fit together. A calculator or your laptop can do the rest. But if you don't know whether you should multiply or divide, a calculator obviously does little good! So, quantitative literacy is really not about the mechanics of calculation – we now have tools for that. Quantitative literacy is about the skills needed to apply those tools to gain insight and solve practical problems in the unstructured circumstances of daily life.

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Quantitative literacy and citizenship

I have already suggested that there is an important linkage between quantitative literacy and competent citizenship. Virtually every major public issue – from healthcare, to energy and the environment, to economic policy – depends on data, projections, inferences, and the kind of systematic thinking that defines quantitative literacy. My anecdote about the MMP referendum in Ontario is a case in point. Let me illustrate further, with one more example, the linkage between quantitative literacy and democratic accountability. This linkage is not widely recognized, and the consequences for public policy can be quite serious. If issues are not understood by the public, or by journalists, we all become victims of the political or corporate spin doctors whose function is to sow confusion, not to convey insight.

A cautionary tale is provided by the bitter and confusing debate over the feasibility of meeting Canada's Kyoto Protocol commitments to reduce greenhouse gas (GHG) emissions by six percent below their 1990 level over the five-year period beginning next year. The public debate over Kyoto has been all about symbolism – are you green, or aren't you? – with scarcely any heed paid to the actual numbers and their implications. But the Kyoto Accord itself, and what would be needed to meet Canada's commitment, are actually very much about numbers. Yet how many Canadians are even remotely aware of the quantitative facts?

A society that is unwilling, or unable, to analyze its data will, ultimately, not be able to govern itself wisely.

Canada's GHG emissions, as we speak, are probably about 760 million tons (megatons), about two percent of the global total. Our Kyoto target is 563 megatons – a huge gap of roughly 200 megatons. To meet the Kyoto target, Canada would need to somehow achieve an absolute cut, relative to trend, averaging well over 200 megatons per year over the five-year period starting next year.

To put that in some perspective – all the cars in Canada generate roughly 40 megatons of GHG annually. Take them all off the road and you would make-up less than one-fifth of the Kyoto gap. Or consider that all the electricity and heating needs in Canada, plus all the fossil fuel production, generated about 200 megatons of GHGs in 2005, an amount comparable to the Kyoto commitment gap.

You be the judge as to whether Canada's Kyoto target is still feasible at this late date. And your conclusion should have nothing to do with whether you believe passionately, as I do, that we have to come to grips with carbon emissions. Your conclusion should have everything to do with the arithmetic, not the sentiment.

The message of this example is certainly not that political decisions should be reduced to a dry set of figures. It is clearly the case that beliefs, values and seasoned judgment should be the basis on which societies decide. But surely the formation of our beliefs and political convictions must pay heed to the constraints of reality, and increasingly, those constraints reveal themselves in numbers. A society that is unwilling, or unable, to analyze its data will, ultimately, not be able to govern itself wisely.

Developing an intuition for magnitude

A big problem with numbers, large and small, is that most of us lack a real intuition for magnitude. The development of such an intuition is a key objective of quantitative literacy. For example, Canada's gross domestic product is about $1.5 trillion or $1,500 billion dollars. This number is simply unimaginable – completely meaningless. Unfortunately, because of that, most of us have no benchmark to judge relevance when it comes to government budgets or statistics about the economy. That matters.

But look at the $1.5 trillion dollar GDP this way. Imagine Canada as a very thick wallet, stretching from St. John's to Victoria – a really

enormous wallet, just over 7,500 kilometres thick. Now imagine it filled with hundred dollar bills, stacked face-to-back, just like bills in your wallet. Each one takes up about a half millimetre of the wallet space. In other words, 2,000 of these bills, representing $200,000, would make a stack one metre high. That wallet, stretching from St. John's to Victoria, packed with hundred dollar bills on edge, is what $1.5 trillion would look like. Still awfully hard to imagine, but you are beginning to get the picture. To hold a million dollars in hundred dollar bills would take a wallet about five metres thick, or about half the length of a large living room. To hold a billion dollars, the wallet would have to stretch to the other side of town. What about federal government program spending of $200 billion this year? Well, that would take a wallet a thousand kilometres thick – or hundred dollar bills, on edge, all the way from here in Moncton to somewhere near Montreal. Think about it the next time you take a long drive.

We also lack an intuition for really small numbers, and they count just as much as the really big ones. At the frontier of microelectronics, transistors can now be about the size of a virus. Modern electronics is the product of "thin film" technology. How thin? Today's state-of-the-art films, on which the micro-circuits of computers are etched, have a thickness about equal to the amount your fingernail grows – in two seconds!

What about the ultra fast? Well, nothing is faster than the speed of light or, equivalently, the speed of the electromagnetic signals that propagate through our global communications systems. They zip along at 300,000 kilometres per second – again, unimaginable. But this means that a pulse along a transoceanic optical fibre can travel from here to New Zealand and back in about one-tenth of a second, or roughly the time it takes my voice – chugging along at the speed of sound – to reach the back of this room.

These are more than catchy factoids. They are the kind of metaphors on which quantitative literacy depends. These happen to appeal to me because they are startling enough to be remembered. You can develop your own. The important thing is to carry around in one's head a few quantitative benchmarks against which to judge the confusing welter of numbers in the daily media and dinner party conversation. You actually don't need very many, but you do need to develop some facility in manipulating them, and recognizing when they apply.

The important thing is to carry around in one's head a few quantitative benchmarks against which to judge the confusing welter of numbers in the daily media and dinner party conversation.

Impediments to quantitative literacy

The kind of quantitative literacy that these examples illustrate opens up new windows on the world. It creates context and enables judgements to be exercised that are vital for aware and responsible citizenship. Unfortunately, too few people possess this type of quantitative literacy. Even those who may be "good with figures" in a mechanical sense, often don't integrate quantitative insight in their framework for understanding the world around them. Why is this?

It is certainly not because people lack the basic capability. While there is a small minority for whom numbers will always be truly opaque – much as the printed page is opaque for those suffering severe dyslexia – the vast majority of people are perfectly capable of acquiring the level of quantitative literacy we have been talking about. Indeed, the required quantitative and logical skills are no more inaccessible than what it takes to play bridge or crib or poker; to do a Sudoku puzzle; or make the measurements needed to hang three pictures in parallel on your living room wall; or to convert a recipe for four into a meal for seven. Millions of Canadians do these things every day and don't think a thing of it. But

talk about math or "quantitative literacy" and either they freeze, or their eyes glaze over.

Indeed, mathematical illiteracy is something many people are almost proud of, whereas an inability to read or write is a matter of almost universal shame. What explains the difference in attitude between numeracy and literacy? I believe it begins with a vast difference in the perceived utility of the two, and the reinforcement of this perception in daily life. We "practice" reading and writing every day. But too many of us don't practice even very basic mathematics once we are out of school. Our quantitative skills atrophy rapidly. So mature quantitative literacy, and its associated intuition, never develops. But for all the reasons I have advanced in these remarks, this is not a situation we can any longer afford to accept.

Achieving greater quantitative literacy in Canada

What is to be done? I will conclude with three observations germane to the challenge, but it would be presumptuous to give detailed advice to professional educators and policy makers worldwide who have been grappling with the vexed issue of quantitative literacy for many years. There is much wisdom in the literature and it should be heeded.

That said, it is clear that we should look first at the K-12 school system and ask how we are doing in Canada, measured province by province and against international benchmarks. The answer – which will be surprising to many parents and employers – is that Canada appears to be doing very well indeed.

The evidence is to be found in the performance of Canadian students on tests of 15-year-olds under the OECD's Program for International Student Assessment, or PISA. This involves the most sophisticated evaluation ever undertaken of student learning in the fields of reading, science and mathematics. The most recently

analyzed round, in 2003, tested more than 270,000 students in 41 countries and focused particularly on mathematical skills – not on rote learning to meet specific curriculum objectives, but rather on the knowledge and skills needed by the average citizen in adult life – or what I have been calling quantitative literacy. Approximately 28,000 Canadian 15-year-olds participated in PISA 2003. The results provide an enormously rich base of data, including a great deal of demographic and socioeconomic information about the students and the schools they attend.

...grade-school mathematics education in Canada is in good shape overall, though not uniformly so across all jurisdictions. . . we have here at home several world-leading systems – like those in Alberta, B.C., and Quebec ...

The results are very encouraging. Among the 41 countries, only two – Hong Kong and Finland – had clearly better results in mathematics than Canada. The provincial breakdown is particularly revealing. Students from Alberta were tied, within the statistical margin of error, with Hong Kong at the top of the world rankings. Students from BC and Quebec were not far behind. Those from the Atlantic Provinces had comparatively weaker results but all were at, or above, the 41-country average and significantly above the U.S. as a whole. While scores in Canada were found to be statistically related to an index of the socioeconomic status of a student's family, the degree to which socioeconomic status determines test results in Canada is less than in most countries, indicating that Canada's public education system is remarkably egalitarian.

My first observation in conclusion, therefore, is that grade-school mathematics education in Canada is in good shape overall, though not uniformly so across all jurisdictions. Fortunately, we have here at home several world-leading systems – like those in Alberta, B.C. and Quebec – and therefore a wealth of best-practices to be transferred and adapted among the provinces in a cycle of continuous improvement. If every provincial education ministry seizes this op-

portunity to learn from its peers, young Canadians everywhere can be provided with an excellent foundation for quantitative literacy.

The fundamental challenge, of course, is to create the conditions during the K-12 years that will produce sustainable quantitative literacy – which is to say a set of basic skills and a quantitative intuition that survive the passage from formal education to life in the work-a-day world. That is why numeracy skills must be taught and learned in settings that are both meaningful and memorable.

My second conclusion is that this will require an approach to the grade school curriculum that integrates the perspectives of logic and quantification well beyond the math class and into a wide range of courses. Only in that way will quantification become understood, from the earliest years, as a window on the world that is complementary to the perspectives provided by art, literature, and religion. This integrative approach can not be achieved overnight since it will require considerable innovation in curriculum development and, particularly, in teacher training. But a transdisciplinary approach to knowledge is the way of the future in both research and education. The universality of mathematics suggests that it should be in the vanguard of this movement.

Information technology is shaping how children learn and will alter forever the relationship between the individual and the accumulated stock of human knowledge.

My third and final observation returns to the theme of information technology. Our education system simply has to come to terms with the computer – not only in the context of mathematics to which it has always been naturally suited – but throughout the curriculum. Technology based on the microchip – whether in phones, video games, blackberries or whatever – is now part of the experience of virtually every child from their time of earliest awareness. For today's youngsters, these devices are simply part of the world as they find it.

Information technology, whether we like it or not, is therefore shaping how children learn and will alter forever the relationship between the individual and the accumulated stock of human knowledge. With resources like Google and Wikipedia at everyone's fingertips, simply mastering and retaining a body of facts becomes rather pointless. This is a strange new world for educators that must be profoundly disorientating. Because when it comes to information technology, the role of teacher and student today is inverted, with adults as the neophytes and children with the monopoly on experience. But just as knowing how to swing a hammer does not make a carpenter, the fact that packets of knowledge can be accessed instantaneously is not the same as knowing what to look for and how to knit it together in novel ways that respond to the challenges at work and in our daily lives.

Quantitative literacy in the future needs to be grounded in the skilled and intuitive use of information technology as a natural extension of one's own mental abilities.

What is called for, it seems to me, is a profound re-evaluation of the education paradigm to place information technology at the center. How else to remain relevant to a generation that is already there? More than that, information technology, properly employed, presents unparalleled opportunity. It must not be seen simply as a better tool to keep doing things the same old way – though that is a necessary transition phase as we grope toward something more profound. Ultimately, the goal must be to teach young people to use the microchip as a mind amplifier and not as a sly way to crib their essays off the web. Quantitative literacy in the future needs to be grounded in the skilled and intuitive use of information technology as a natural extension of one's own mental abilities. Only then will we be equipped to extract insight from the torrent of data that the computer itself will

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disgorge in ever growing volume. That is the new imperative of quantitative literacy, and both the challenge and the opportunity for the educators of tomorrow.

In Summary

I have argued that quantitative literacy matters, and that it will matter increasingly as science and information technology continue to inundate both the economy and society with data of every description. I have emphasized that quantitative literacy is not about higher math – it is about developing the basic skills and habits of mind that enable us to deal effectively with the quantitative and logical information that we will encounter increasingly in the workplace, in the marketplace, and in our role as citizens.

The evidence is that Canadians are falling short, and the result is costly for the individual and for society. If there is an adult literacy problem in Canada, there is an even bigger adult numeracy problem.

But there is also good news. The quantitative literacy of Canadian youngsters appears, on the whole, to be near the top of the world rankings, despite wide variations in performance from east to west. So we need to learn from the best systems right here at home and use their methods to lift the level of the nation.

We also need to integrate quantitative methods and insights through out the school curriculum so that students acquire a quantitative literacy that is relevant, and therefore sustainable.

Finally, we need to acknowledge that increasingly powerful information technology is changing forever the rules of learning. It is a challenge – but far more, it is an opportunity to extract unprecedented insight from the inevitable torrent of data in our future, and thus to achieve levels of quantitative literacy in Canada that were never thought possible.

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**NOTE: The positions held by the Lecturer(s) are stated as at the date the Lecture was given.*

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