Human Adaptation and the Ingenuity Gap¹

Thomas Homer-Dixon
University of Toronto

I have been working for many years on the problem of adaptation: how societies or organisms, species, or systems of various kinds adapt to complex and rapid change. In this paper, I will outline my theories and my thinking about adaptation as summarized in the book, *The Ingenuity Gap*. I will also highlight five aspects of education for the future: education for complexity and what that means; education for reconnection to the micro and macro scales around us; education that increases our respect for experiential knowledge; education that will encourage a recognition of our connectivity through time, from the present into the future; and finally, education to broaden our conception of values. I'll touch on each one of these points in my presentation today.

Let's start by going over the basic argument that I've been developing in books such as *The Ingenuity Gap*. I start by asking a number of core questions:

- Are we creating a world that's too complex to manage?
- Do the "experts" really know what's going on?
- Are we really as smart as we think we are?
- Then finally, the most important question, can we solve the problems of the future?

I'm interested in developing ideas and taking them to the general public, explaining or extracting some of the ideas and knowledge from isolated worlds of academe and then providing them for a general audience. One way I do that is to tell a lot of stories. So I will start my response to these four questions this evening by telling a story that comes at the beginning of the book. Now one of the mildly amusing things about this book is that when it first came out it was selling very well in airports across the country. I don't think people

Professor Homer-Dixon is Director of the Centre for the Study of Peace and Conflict at the University of Toronto, and the author of numerous books on the human and physical environment.

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realized when they bought the book and then settled into their comfortable seats on the airplane that the first thing they were going to read about was a horrific airplane crash. But I'm going to describe that incident today because it will motivate my subsequent comments in this presentation.

The incident occurred on July 19, 1989, during United Airlines Flight 232 between Denver and Chicago. About half-way through the flight, the rear tail engine on the DC-10 blew up. Now, there are three engines on the DC-10: a large one in the tail and one over each wing. When the rear tail engine blew up, the shrapnel from the explosion destroyed all three hydraulic systems in the plane. Those hydraulic systems were necessary for controlling the flight surfaces – the ailerons, the rudder, the flaps, and the slats that allowed the crew in the cockpit to direct the plane through the atmosphere. So all of a sudden, the pilot and the co-pilots sitting in their seats found that the wheels and columns in front of them were dead. They had no control over the direction of the plane.

Immediately the plane started turning into a rightward, downward dive, and about 15 seconds later, just at the moment that the plane would have been irretrievably lost, the captain tried something. He increased power to the right engine, and lo and behold, that brought the right engine up and stabilized the plane. At that point, he discovered that he could maintain some modest control over the airplane by increasing and decreasing power to the right and left engines - what they later called 'differential engine thrust' – and basically skidding the plane through the atmosphere like that. After the engine exploded, the plane described a series of rightward turns across the Iowa countryside, but that modest control enabled them to make one left-hand turn to line the plane up with the shortest runway at Sioux City, Iowa. At the last moment, just before they brought it down on the ground, they made one very tight rightward turn, dropped below radar cover, and then eventually brought the plane down.

There's quite a bit more to the story than that. Some of the details I'm giving you today are from a conversation with the captain, Al Haines, whom I spoke to when I was writing my book.

That period of time lasted forty-four minutes and the cockpit crew had some help. It turned out there was an extra pilot on board – somebody called a "check airman" – who was responsible for checking on the performance of United Airlines crews as they flew back and forth across the country. He happened to be off duty but he was sitting in first class and he thought something was wrong. The explosion had been in the back of the plane, so it had been fairly muffled, but he started to see the sun going from one side of the plane to the other, and he knew that wasn't right. So he thought that perhaps he should offer his help to the cockpit crew. He spoke to a flight attendant who

went up and talked to the captain, and the captain immediately called the check airman into the cockpit and explained what was going on.

There was pandemonium in the cockpit. It was clear that the captain, the co-pilot, and the first officer sitting behind them had too many things to do. So when the check airman asked, "What can I do?" the captain said, "Could you take over control of the two engines?" So from that point on, the check airman stood between the pilot and the co-pilot with a hand on each of the engine throttles and watched the bank of gauges in front of him and steered the aircraft. Eventually, he was able to bring the plane down on the shortest runway in Sioux City, Iowa. When the plane hit the ground, its right wing dipped at the last moment and caught the ground so that it crash-landed. The plane hit the ground five times hard, and broke into three sections. The cockpit broke off and rolled across the tarmac, compressed into a piece of metal about two meters high. The remainder of the fuselage broke into two pieces, both of which cartwheeled and exploded in flames. But despite all of that, of the 300 people on board, 200 were saved, and the entire cockpit crew survived. The rescue teams on the ground didn't even go and look at the cockpit for 35 minutes after the crash, because they saw it off in the distance and thought it was such a wrecked hunk of metal that nobody could be alive inside, but when they went over and looked at the cockpit, they found that all the cockpit crew was still alive.

Now this is a pretty dramatic incident, and I'd probably claim that I started the book with this story because I wanted to make sure that nobody would put down the book once they started to read it. But there was more to it than that. I wanted to draw some lessons, highlight some aspects of our world illustrated by this story that I thought were important. So I will identify four points of resonance or connections between this particular incident and the state of our world today.

The first is the problem of cognitive overload. When I first heard about this incident in 1989, I filed it away and forgot about it. But I came across it again about six years later because somebody had done a very detailed analysis of the information flows within the cockpit of the aircraft during this incident. He had taken the cockpit transcript, broken it down into chunks of information, and had then analyzed the flow of information between members of the cockpit and between people in the cockpit and crews on the ground, the air traffic control officers who were communicating with them as well as other aircraft. He discovered that at peak load, the people in the cockpit were operating at about five times the cognitive level or the information-processing level of people in normal aircraft operation at peak load, which usually occurs during a landing. So it turns out that the people in the cockpit were receiving information, processing it, communicating among themselves, making

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decisions, and then communicating information out of the plane to people on the ground as fast as humanly possible. They were at their maximum cognitive load, in fact, and sometimes if you read the transcript, it seems like they almost became one organism. It was as if their brains melded together as they were making decisions to save this aircraft.

I'm intrigued by this because I think that in the decision-making environments we've created for ourselves in this world, we're reaching our cognitive maximum in many cases. Especially in times of crisis, I would say that our leaders are finding themselves overwhelmed by the complexity of decisions they have to make, the amount of information they have to absorb, the range of decisions they have to take. It really is a much more difficult world to operate in, especially for our leaders, than it used to be. So that was the first connection point that interested me.

The second is a related point. It turns out that the cognitive load that these people faced was a lot higher because they had an inadequate knowledge of the nature of the system they were operating in. It turned out, after the National Safety Transportation Board had examined the wreckage, that the only thing controlling the direction of that plane was the differential engine thrust used by the check airman standing between the pilot and the co-pilot manipulating those engine throttles. But the pilot and co-pilot didn't know that. They continued to operate the wheels and columns in front of them because they thought they might have some residual control over the system. They continued to operate the plane as normal because they didn't know the nature of the damage to the system they were operating in. Therefore they had to spread their attention over a much broader range of things than they would have had to otherwise if they'd understood the system properly. Again, I think that resonates with our world frequently, in that we don't understand the complexities of the systems – ecological, technological, economic, socio-political systems – that we're living within; frequently we have to try everything in the hope that something will work. As a result, we spread our resources and our cognitive energy over so many things that we end up doing nothing very well at all.

The third connection point is the problem of time lags. Now Al Haines, the plane's captain, didn't know it at the time the explosion happened, but he sure learned quickly that a plane that has locked flight surfaces and can no longer steer itself but maintains power goes through an action that aeronautical engineers call a 'phugoid,' which is kind of a porpoising motion through the atmosphere – sort of like that. Now the key thing about a phugoid is that there is a time lag between the time that you change the engine thrust and the time that the plane responds in terms of changing its aerodynamic behaviour

– going up or going down. For a DC-10 the time lag is somewhere between 30 and 90 seconds, a long period of time. Now as that plane was coming down on the runway at Sioux City, Iowa, the right wing was dipping, the co-pilot was yelling at the check airman, “LEFT. LEFT. LEFT. LEFT. LEFT. LEFT. LEFT.” Because he wanted the check airman to increase power to the right engine so that the right wing would come up and they would land instead of crash landing. But of course the check airman couldn’t do anything because the plane was responding to commands he had given it 30 seconds before. He was powerless at that point.

When you look at the complex systems that we’re embedded in, you find that time lags are omnipresent, making management of these complex systems far more difficult. They’re especially present in ecological systems. For example, the carbon dioxide that we are dumping into the atmosphere right now won’t have its full effect on the global climate for another 50 to 100 years. The current warming that we see in the global climate has been caused in part by carbon dioxide that was emitted in the middle of the last century. But you also find this in economic systems. Probably the best example of a time lag that we’re all familiar with is the lag between the time when a central bank intervenes to change interest rates and the point at which the economy responds in terms of increasing or decreasing its output of goods and services. In the American economy, that’s assumed to be between six and nine months. We’re all wondering now whether Alan Greenspan got it right this last time around, or if he waited too long to increase interest rates, then increased them too high, then ultimately did not decrease them quickly enough, with the result that he has done serious damage to the American and ultimately the Western economies. Time lags make it much more difficult for us to manage in this world.

The fourth connection point between this story and the real world is the problem of experts, the inadequacy of experts. Shortly after the explosion, when the plane was stabilized a bit and they were using differential engine thrusts, the pilot turned around to the first officer and said, “Get SAM on the line.” SAM stands for ‘System Aircraft Maintenance,’ a group of designated engineers that United Airlines has to advise crews in crisis in the air. Within five or ten minutes, a group of engineers had gathered around a speaker phone in San Francisco and were talking to the first officer in United 232. First off, they requested a briefing on the situation, so the first officer told them everything. He said, “We’ve lost all hydraulic quantity and pressure. We don’t know what to do. We seem to have very little control over this plane except by using differential engine thrust.” The SAM engineers didn’t know what to make of this, never having heard of an accident that compromised all three hydraulic systems. In fact, they had the first officer flipping through a thick flight manual

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trying to find something that pertained to their situation at the time. After a few minutes, the SAM engineers said, “Look. We have to go and think about this for a while. So we’re going to sign off.” So they disappeared, and then about ten minutes later, came back on and said, “Could you just confirm that you’ve lost all three hydraulic systems?”

The first officer shouted into the microphone, “AFFIRMATIVE, AFFIRMATIVE, AFFIRMATIVE,” and then hung up. At that point, the crew realized that they themselves would have to generate the ingenuity to land the aircraft, and a remarkable job they did. There’s not an insignificant amount of luck involved in this event; after the crash, they programmed the incident into a flight simulator and in 45 attempts, including a number of attempts with the original crew itself, they never got anywhere near the airport.

Thus, issues that I investigate, such as cognitive overload, time lags, and adequacy of experts, suggest that in recent decades our world has changed in a way that makes these problems more acute for us. My central argument is very straightforward: that the complexity, the pace, and often the unpredictability of events in our world are soaring, as is the severity of environmental stress. If we are to meet the challenges we face in this new world, we need more ingenuity. But we cannot always supply the ingenuity we need at the right times and places, and the result is an ingenuity gap. That’s the basic argument.

Before I elaborate, what are some of the problems that I’m talking about? I divide them into three categories: problems at the global level, problems at the national or societal level, and problems at the individual level. One of the contentious claims I make is that there are common patterns across these three levels. In other words, the causes or sources of rising complexity and pace in our daily lives, at the personal level, can also be seen at the national level and at the global level. They are contributing to such things as international financial instability as in the Asian financial crisis of 1997-98. It’s these common patterns that I’m trying to identify in my work.

At the global level, I’m interested in climate change, a problem that will probably affect every person on this planet, quite likely sooner than most of us realize. To address it effectively will require us to develop the most sophisticated and complex institutions that humankind has ever developed. International financial crises can be caused by an international financial system tightly coupled with 1.5 trillion dollars of hot capital sloshing around in it on a daily basis and hence prone to flip between stable and unstable modes as we saw in with the Asian financial crisis. Chronic zones of anarchy in the developing world caused by converging stresses, very much like those pilots experienced in United 232 in that cockpit, where you find societies that are

faced with epidemics of tuberculosis and AIDS, diffusion of light weapons like rocket propelled grenades and assault rifles, rapid population growth, economic shocks from outside, weakened institutions inside these countries, and the convergence of all of these stresses and problems produce a breakdown of the process of economic and political development and ultimately a rise in violence. Over the last two years, we've learned that events happening on the other side of the planet in places where you have states breaking down and widespread social dislocation can penetrate right back into the core of our own societies.

At the national level, in Canadian society for instance, I'm interested in rising antibiotic resistance. This is a classic example of a race between our medical and epidemiological knowledge on one side and the pathogens that are affecting our species on the other, the bugs that are evolving faster than we can develop drugs to treat them. In many cases, it seems that those bugs are winning the race. Chronic health care crises – well, we know a lot about those in Canada. Persistent homelessness is an interesting problem: There is a widespread consensus in our society across all socioeconomic levels, across all classes to be crude about it, that this is a problem that needs to be solved, and yet for some reason our municipal, provincial, and federal governments cannot address this problem effectively. The data on the widening gaps between the super rich and everyone else are really quite astonishing. I don't think most people realize what has happened in the last 20 or 30 years, but I suggest that as the gap between the richest and everybody else widens, it will undermine our sense of identity and perhaps even lead to political instability in our societies.

In our daily lives, I'm interested in information overload. This is the thing that we confront every morning when we turn on our computers and find another 60 to 100 e-mail messages there. Many of us, especially those of us living in urban areas, now have the sense that there are simply too many stimuli, too many things coming into our lives, too many streams of information, that sometimes our brains literally feel overloaded. As you can see from my description of United 232, one of my arguments is that sometimes our brains literally are overloaded, that we are reaching our cognitive limits.

This is a pretty broad range of problems. How can I possibly link all of these together? I'm now going to sketch out the basics of what I call 'Ingenuity Theory' so that you can see how I bring all of these problems together and show the connections among these levels.

I start by defining 'ingenuity' and sets of instructions that tell us how to arrange the constituent parts of our physical and social worlds in ways that help us achieve our goals. Ingenuity is like recipes that allow us to take the stuff in our world, literally the stuff in the ground, and reconfigure it to make the things we need to solve our problems. My laptop computer, which has about as much

computational power as was available to the entire American defense department in the 1960s, is nothing more than reconfigured rock and hydrocarbons. We've taken stuff out of the ground, and through a long and elaborate set of recipes, we've reconfigured it into this remarkable device. It's equally true with everything around us in this room – the seats you're sitting on, the clothes you're wearing, lights overhead – all consist of reconfigured materials from our natural world. If you want to think how amazing that is go camping sometime and sit in the natural world and think about what would be required to take all the stuff around you and make it into the things like laptop computers. It's really remarkable; we're extraordinarily good at that.

In my work, I focus on the requirements for these recipes or sets of instructions, what determines the kinds of instructions we need and how many instructions we need at the same time, and what things impede the flow of those instructions when and where we need them. Also, I make an important distinction between technical ingenuity and social ingenuity. Technical ingenuity consists of ideas or instructions for creating new technologies, like a laptop computer or more comfortable chairs or better lights or better internal combustion engines. We're really good at doing that as a species. We're not as good at producing ideas for how we arrange ourselves into societies and groups and institutions. That's what I call social ingenuity - sets of instructions for creating things like governments, political systems, or markets. Now, it turns out that social ingenuity is more important than technical ingenuity, but not only are we not as good at doing it, we also don't pay as much attention to it, because we're really fascinated by technology. But institutions ultimately are more important than technologies because you don't get the technologies you want until you have the right institutions designed. In particular, you're not going to get the flow of neat technologies like laptop computers or whatever you want unless you get your markets organized right so that your entrepreneurs are rewarded for the risks they take. They have to get the right price signals. But markets are very complicated institutions that require things like limited-liability legislation, property rights, judicial, court, and police systems that enforce contracts, monetary systems that are stable, stable banking systems – all of these things have to be provided if markets are going to work effectively. You need those first before you get the flow of technical ingenuity. That's why I claim that social ingenuity is more important than technical ingenuity.

I also make a distinction between requirements for ingenuity and supply. I'll talk more about requirements in a moment. Let me just say one thing about supply. It's important to understand what I mean here: By "supply," I mean ideas, ingenuity or recipes that are implemented and delivered. I think of society as pipelines; at the beginning of this pipeline is a generation stage

where ideas are produced. That can happen in all kinds of places: in corporate laboratories, in government bureaucracies, in universities, in non-governmental organizations, or in local community groups trying to solve local problems. But then those ideas have to move along the pipeline to the implementation and delivery stage, and they're not supplied until they have been implemented and delivered. Unfortunately, you often get powerful special interests along that pipeline, acting to block the delivery, especially, of institutional reform, because when you change institutions, you change the power balance and the distribution of wealth within society. Powerful groups don't like that. So they intervene at various points to make sure that that doesn't happen. One of the results I have studied is how our political systems are changing to make it less and less easy for true institutional reform to occur. I'll return to that shortly.

We are left with a situation where I would argue that in certain circumstances our requirement for ingenuity shoots up faster than we can supply it. Not in all circumstances; sometimes in certain areas and with certain problems there is no ingenuity gap. We solve the problems quite satisfactorily. But in the kinds of problems I talked about earlier I would suggest there is a significant gap. Note one thing here: The supply is not leveling out, it's not flattening off. This is not an argument about limits to science or some kind of inescapable cap to human creativity. Human creativity is extraordinary and I believe our ability to innovate is still very strong. It's just that in some cases, we can't keep up; we're creating problems that are too hard for us, that are developing too fast and are too difficult.

Given this model, these basic concepts, we can ask some fairly straightforward questions. First of all, is our requirement for ingenuity rising? Second, if it is rising, can we supply the ingenuity we need? Third, if we can't always supply the ingenuity we need, what do those ingenuity gaps mean for our future? What are their implications? Fourth, what do we do about it? How do we fix this problem?

I argue that there are three principle forces driving our requirement for ingenuity, making our world more complex, faster paced, and sometimes more unpredictable: larger human populations; higher resource consumption; and more powerful technologies for the movement of people, material, energy, and especially information. These three changes together sharply raise the density, intensity, and pace of our interactions with each other and with our surrounding natural environment.

We can think of the world as consisting of networks. We are embedded in a set of systems - ecological, technological, economic, political, and social systems - each of which can be thought of as a network consisting of nodes or entities connected together with links. A node can be people,

corporations, technologies, even whole nations. Over time, especially in the last two or three decades, we've seen a highly significant increase in the number of nodes in our networks and therefore a dramatic increase in the density of linkages among them. We've seen an absolutely exponential increase at the rate at which we can push energy, material, and especially information along those links. That causes the increasing density, intensity, and pace of our interactivity within these networks.

About a century ago, the French sociologist, Emile Durkheim, wrote about the inexorably rising dynamic density of societies. The concept is similar, except that in the last thirty years, we've seen a dramatic qualitative shift in the nature of human social systems. They have become complex in a way that's truly novel and has significant implications for our ability to survive. This is called a 'Complexity Transition,' and will be elaborated further later on.

Two of those three factors, larger human populations and higher resource consumption, have greatly increased our burden on Earth's natural environment, and the third factor, more powerful technologies, has shifted power from national and international institutions to individuals and sub-groups. I call this the "power shift issue." If you want a dramatic demonstration, September 11th, 2001 showed that small groups of individuals can now destroy large groups of individuals. Within ten years, we may see that small groups can destroy whole cities. Thus, individuals now have access to unprecedented kinds of power – power to communicate, power to destroy, power to make things. That change has fundamental implications for the manageability of our societies. All these developments – increasing dynamic density, increasing burden on our natural environment, the power shift from large institutions to small groups – imply that we must cope with more complex, urgent, and often unpredictable circumstances. "Complexity" here means something specific: Complexity theorists talk about certain characteristics of complex systems: feedbacks, synergies, non-linearities, unknown unknowns, time lags. I'm not going to discuss all of these; you've heard about time lags in United 232. Let me just talk about a couple. Unknown unknowns arise when the system has become so complex that you don't even know what questions to ask anymore. You're ignorant of your own ignorance. It's like the problem I get when I look at my car engine now. I used to do a lot of work on cars when I was a teenager and understood them pretty well. But then I didn't own a car for a long time, for almost seventeen years. Then a couple of years ago I bought a new car - a nice European car, very fast, very sporty - and when I picked it up, the salesman came out and we opened up the hood. We looked at the engine and he said, "You can look at this but you can never touch it." For me, that engine, in its density of tubes and modules and wires all over the place where I

couldn't even see the manifold anymore, represented a cluster of unknown unknowns.

The other concept I'd like to illustrate is the idea of non-linearities. Complex systems have the capacity to flip from stable to turbulent modes, often with very little prodding, with only a small permutation. In fact, complex systems often have multiple equilibria. They can sit in a number of stable states and move from one to another, often in very unpredictable ways. We see non-linear behaviour around us all the time, but don't pay much attention to it because it's rather bothersome. It doesn't fit into our standard operating procedures very well. The collapse of the cod fishery off the east coast of North America is a good example of a non-linearity. The opening up of the Antarctic ozone hole is another non-linearity. The Asian financial crisis is a non-linearity in our international economic system. The exploding fan disk on U232 was a non-linearity. The dot-com implosion was a non-linearity in the stock markets. If anything characterizes complex systems, it's their capacity for non-linear behaviour, surprises that we can't anticipate. The one thing that shouldn't surprise us about the future is that it is going to be full of surprises. In this environment, we must generally make more and better decisions in less time than ever before, because the management of our relationship with this new world requires immense and ever-increasing amounts of social and technical ingenuity.

A couple of stories will illustrate what I mean. I'm going to talk about the climate because it's a good example of a non-linear system, using data derived from the Greenland ice sheet. As you know, Greenland is covered by a very thick ice sheet formed by the accumulation of snow that has fallen over thousands and thousands and thousands of years. As that snow has fallen, it has been compressed into layers of ice by the snow that has fallen on top of it. If you drill down and extract an ice core, you extract an archeological record of past climates. Scientists have examined the amount of snow accumulated each year and found that the warmer the climate over Greenland, the more snow falls. That is because warmer air holds more water, and as it still precipitates out as snow, you get more snow. We have evidence of an event around 11,500 years ago with a dramatic increase in snowfall at a point that's called "the end of the younger, driest cold event;" it's basically the end of the last Ice Age. That change in snowfall represents a 7-degree Celsius warming in a thirty-year period. Seven degrees Celsius in a thirty-year period. The difference between the current average temperature on the planet and the coldest period of the last Ice Age 18,000 years ago is 5 degrees Celsius. This is a monumental change in global climate. It turns out that at that time, there was a wholesale reorganization of atmospheric and ocean circulation systems all around the

planet. We think we know why that happened, and we're concerned that if we push the temperature higher on this planet by another degree to a degree and a half, we could see that kind of flip in the organization of ocean currents in the North Atlantic which could trigger reorganization elsewhere on the planet. The key thing about this is that it is hard-core evidence of the non-linear behaviour of the global atmosphere. Don't assume that as this planet warms up over the next century it will be a nice easy ride into the greenhouse future. It's going to be characterized by sharp sudden shifts which will make adaptation vastly more difficult.

For the second part of the story, we go to the other pole of the planet, to a lake in Antarctica called Lake Vostok which is all frozen except for a little bit of water at the bottom. In the 1980's, Russian and French scientists started drilling into the ice sheet over Lake Vostok to extract an ice core. Later, American scientists finished the drilling, extracting an ice core that was almost four kilometers long and stopped just above the water. That whole ice core represents 420,000 years of time. The scientists made some very interesting discoveries, because they were able to extract air bubbles from each year's layer of ice and determine the carbon dioxide concentrations of various years as they went back into the past. So they had a record of carbon dioxide concentration going back 420,000 years, and using some clever chemistry, they were able to determine the temperature of the atmosphere at the time the snow fell. They found a very close correlation between changes in carbon dioxide concentration and changes in temperature. Now, we all know that correlation doesn't necessarily mean causation, but as lawyers would say, this is good prima facie evidence of a causal relationship between the two factors.

A sharp, sudden change has happened in the last 150 years. With industrialization, we have increased the concentration of carbon dioxide in our atmosphere by about 30%. The temperature is increasing too; we've seen an increase in temperature of almost one degree Celsius since 1900. This is where we're going in the future, and that's locked in, guaranteed, within the lives of our grandchildren. That represents just over a doubling of carbon dioxide in the atmosphere from pre-industrial levels, probably by about the year 2050. Now, although our atmospheric models of global warming are organized around a doubling of CO₂, most atmospheric scientists say we're not going to stop at a doubling. Given current development patterns on this planet, we're going to triple or quadruple our carbon dioxide concentration, and in that case, I would suggest that we're going to see some pretty dramatic effects on this planet in the next little while.

What's the point here? The point is that human beings are now, in an unprecedented way, major actors on this planet. We move as much dirt and

rock on this planet on an annual basis as nature does itself. We have doubled the amount of reactive nitrogen in the atmosphere and increased the amount of carbon dioxide by 30%. We are major actors. We don't know the implications of that and the only thing we can be certain of is that it will make our problems harder in the future. We're going to need more ingenuity to adapt to this new world.

Can we supply that ingenuity? I break this question into four parts; in my book, I devote a chapter to each one. I'm interested in brains because brains are the engines of our ingenuity supply, where all those ideas start. We need to go back and look at the evolution of the hominid brain over three million years and ask, "Are the characteristics derived from that evolutionary heritage suitable for the kinds of problems we've produced for ourselves today?" I deduce that in some cases, we don't have the right kind of brain for today's kinds of problems. Science and technology are very important if we're going to solve our problems, but we shouldn't assume that they will always solve our problems. Many people seem to think that science and technology will rescue us, that if we have climate change, we'll put mirrors in space or dump iron into the ocean and create phytoplankton blooms that will suck carbon dioxide out of the atmosphere - or something. But science and technology don't always solve our problems when and where we need them solved.

One of the best examples of this is cancer. We've invested 40 billion dollars in cancer research since Nixon declared his war on cancer in the early 1970s and we all still know people who are getting cancer. Necessity is not always the mother of invention and we shouldn't assume that science will save us at some point in the future.

Markets are important for the reasons I suggested before. We need markets organized so that they give the right price signals to our entrepreneurs. But frequently our markets are riddled with what economists call "market failures." They don't give the right price signals. The best example we have right now is gasoline prices. If we really cared about the future, about the climate future for our children and our grandchildren, our gasoline should be far more expensive now. It should include some of those future costs and then we'd conserve, we would invent new technologies that would allow us to reduce our carbon dioxide output into the atmosphere.

Finally, politics is important, because politics often determines whether those important ideas to solve our problems actually get implemented or whether they get blocked in that ingenuity supply pipeline.

What does this mean for educators? The first point is that we need to put on a new set of conceptual lenses that allow people to see the world on a human scale, but including the micro and the macro scales. We don't see small

things anymore and we don't see big things, especially if we live in cities. Think of Hong Kong and Beijing. One of the things we do in cities, especially in the developing world, is to generate huge amounts of smog and haze. Haze now blankets a large part of the world, but that brown sludge you see on the horizon is not normal. We also generate staggering amounts of light in urban areas, so we seldom see stars anymore. We've all had the experience on a clear, dark, summer night in the country side when we've looked at the sky and at the Milky Way and thought, "Oh, my God. That's just an astonishing thing." When we see the Milky Way, the first thing we think of is "My God, we're small." But we've lost the sense of awe and prudence, a sense of our true place in the universe, and so we often misunderstand the character of the problems we face or don't even see the problems at all.

I'm going to give you a concrete example: frogs. We have a world-wide die-off of amphibian populations going on, especially of frogs, from Queensland, Australia to Costa Rica in Central America to California to Newfoundland. All over the world, we're seeing a precipitous decline in frog species. I had an ecologist from Newfoundland sitting in my office one day and he said, "It's astonishing. There are just no frogs any more." Well, the frogs are probably dying because of a combination of stresses: a thinned ozone layer that has increased ultra-violet radiation of the surface of the planet and weakened the reproduction systems of these frogs, pollutants in the environment that weaken their immune systems, harvesting for food, destruction of habitat – all of these things are happening simultaneously and one of the results is we're seeing a decline in frogs. But most of us don't know that because we're so busy living in our self-referential world that we don't see frogs any more. Most of us don't notice that there's a problem out there. Frogs are like a canary in the coal mine. They're busy chirping away but nobody's listening because we're so wrapped up in the big 'I'. It seems to me that this is something that educators must confront directly.

So what does the ingenuity gap mean for our future? I think it widens the gulfs between rich and poor and between powerful and weak people. All of us in this room are educated, wealthy, and adaptable enough to deal with the complex changes that our world throws at us. Most of us probably have rich social networks to draw on when the going gets rough. But for an increasing portion of our societies and of the planet, people are being left behind. On a planetary scale, five to six hundred million people in sub-Saharan Africa are completely off the radar screen now. Nobody is paying attention to them. A major famine is going on in sub-Saharan Africa right now in Malawi, Botswana, Zambia, and Zimbabwe that threatens 15 million people. Have you heard about it? Are people paying attention? No. Increasingly within our own societies,

some groups of people just can't keep up with the kinds of changes we're seeing. This produces a fragmentation of our shared reality. Never before have we been so connected together on this planet and never before have we been so far apart in our realities – with web-ware designers in Silicon Valley living right next to women in South Africa who have to walk five kilometers every day to get their water, with bond traders in the City of London living right next to slum dwellers in Sao Paulo living right next to us in this auditorium right now. Unfortunately, we've learned from the last couple of years that these different worlds won't stay isolated from each other. We're packed cheek by jowl on this planet now, so that the problems, dislocations, and issues that are arising on other sides of the planet are going to visit us in our own lives here.

So what should we do? This is where I get to my last three points. I draw first on the story of United Flight 232, because Al Haines identified a number of factors that allowed him to land that plane. The first was luck: The accident occurred in daylight, the weather was good, and there was an airport nearby. There also happened to be a check airman on board. Those things helped them get that plane on the ground. A second factor was planning: Just a couple of weeks before, the crews on the ground at Sioux City, Iowa had done a full dress rehearsal for the crash-landing of a wide-body aircraft on the shortest runway of that airport. Another factor was co-operation: Some years before, United Airlines had implemented a program of training of its crews to react in a crisis in a co-operative and not hierarchical way. So when that accident occurred, everyone within that cockpit instantly started to co-operate to solve the problem. The hierarchy was flattened. The captain had to make some final decisions in some cases, but he had been trained to listen. Al Haines says that this was absolutely critical to get that plane on the ground. Then the final thing, which Haines did not mention, but which I consider very important, was experiential knowledge. This is something we have to emphasize as educators.

According to the results of the simulation tests, if Captain Haines had increased power to that right engine a second earlier or a second later, he would have lost control of the plane. When I asked him, "How did you know when to do it?" he answered, "Oh, well, I guess it was just luck." I don't think it was luck. It was the fact that he had been flying those planes for tens of thousands of hours, until the DC-10 was like an organic extension of his body. He had extraordinarily rich understandings of that machinery – experiential knowledge. I think we need to do more to cultivate wisdom in our societies, the wisdom that comes from working with complex systems for long periods of time so that you can recognize their patterns of behaviour, so that you have an intuition for what they're going to do and how they're going to respond. We need, too, the wisdom that comes from integrating reason with emotion, because it's for a

purpose that we've evolved to have emotions. We've evolved to have emotions because they help us survive. Fear and awe and wonder and dread help us survive, helped us survive on those plains of Africa. But although we've left a lot of emotional responses behind, wise people are still able to integrate that extraordinarily rich emotional repertoire with their reason when solving the problems that we face.

My second concluding point is about sustainability: education for sustainability and the recognition of our connectivity through time. What does sustainability mean in terms of the ingenuity gap? We can think about it this way: If you're not living sustainably, you're not planning far into the future. Your time horizon is proximate, one or two years, or four years in the future perhaps at the most. If you've got a problem, such as for example, a declining fishery like Newfoundland's, how do you respond to it? Well, since you don't plan far into the future, you respond by increasing the size of your fleet of fishing boats, getting better sonar so you can track the fish, building better nets so you can catch them, and so that involves a slow incremental increase in ingenuity over time. But then the system breaks down. You have one of those non-linearities because you haven't been thinking far into the future. Just at that point where you see that sudden sharp rise you get a dramatic increase in your ingenuity requirement - perhaps an infinite increase. Perhaps you can't solve your problems any more. This is what sustainability means. We move our time horizons way out into the distance; we're concerned now about the well being of people a hundred, a hundred and fifty years in the future. We want to make sure that fish stock is still able to provide fish in that period of time. But that means we have to adjust our technologies and institutions in a major way now. We have to invest in thinking about how to live within the limits of that resource base. It's easy to see why sustainable development doesn't get done; it's because there's a big investment in the present. It means you have to challenge the vested interests in a major way in the present. But I think one of the things that we can do as educators is help people recognize the implications of our actions well out into the future and the importance of starting to make changes to our technologies and institutions in the present - moving those changes into the present just as that green curve shows.

I think the final thing we need to do as educators is to broaden our conception of values, because the difficulty and character of the problems we face in this world are shaped fundamentally by the kinds of values we adopt. For instance, if we decide that the kind of life we want, the good life as we define it, includes two SUVs in the driveway, a three-car garage, five bedrooms with four washrooms and yearly trips to the Caribbean, and we want to do that for all of the ten to eleven billion people we're going to have on this planet

eventually, that's going to take a lot of ingenuity. We're going to have to be very smart to squeeze all of those services out of the limited material resources on this planet – to reconfigure them in a way that will provide all the stuff for ten to eleven billion people. We're probably going to have to live by lots of regulations. We're going to need very good technologies, very constraining institutions in a lot of ways. But we might decide, 'Well, you know, maybe that's not what's really important to a good life. Maybe we can be really happy with less material stuff.' Then all of a sudden, other options start to open up because we don't need so much pure technical ingenuity to provide the material well-being.

Now, the last thing I want to consider is how we think about values, because I think they influence fundamentally how we're going to address the problem of the ingenuity gap. There's a tendency within our common discourse to think about values as what I call simple preferences. These are what economists would call "utilities." I like vanilla ice cream more than chocolate ice cream. Unfortunately, that's about where the discussion of values stops a lot of times. But clearly there are other kinds of values that are important - moral values, values that relate to how we deal with each other in our societies, issues of fairness and justice for example – those values are very important. They don't get talked about very much, but at least they get talked about a little more than this third category: the existential or spiritual values that relate to what we regard as the source of meaning in our lives, the relationship between us and the cosmos, what the point of the whole exercise is. We learn by the time we're about ten that we shouldn't ask these questions, and we learn quickly from the expressions on the faces of adults that we're supposed to go somewhere else, perhaps to religious institutions or something, to find out the answers to those questions. So we go to those places and we're not given a place to think; we're told what to think. Maybe if we're lucky, by the end of our lives as we start to get intimations of mortality, we start to realize, "Wow, these questions are pretty important." Then we go back to investigate them a bit. But for the most part they are entirely marginalized within our societies. And yet if we want to think about our notion of the good life – what is bringing meaning into our lives and ultimately therefore what kinds of material satisfactions we want, whether two SUVs for example are really important, the answers start at the level of existential values. That's where we need to start. Unless we talk about those issues among ourselves, we may never reach a real consensus. We have to talk about them to start re-thinking the point of our social existence and individual existence. If we never discuss those questions, then all that gets talked about are the simple preferences, and human beings become defined simply as consumers or more crudely as walking appetites – as people who are driven by

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their hedonistic desires for some things over other things. The economists essentially win the day.

I conclude that a highly critical requirement for us in education is to broaden our conception of values – to educate for a broader conception of values in the future. If we don't do that, I can't see how we're going to address a lot of the problems that I've discussed in this presentation today. Thank you very much.

Question & Answer

Question 1: With the problems of terrorism, can you see a reinvigoration of the nation state as a decision-making institution? What can we do to talk about democratic values with the military and especially the politicians who dictate the role of the military in society?

It's a great question. The state is really important. Sometimes I don't like where people take the state, but as an institution it's important because it generates the public goods that allow for our well-being. It solves what economist would call "collective action problems." We really need things like health systems, road systems, security, control of epidemic diseases and things like that, but none of us is really prepared to pay a large cost as individuals unless we know that everybody else is going to as well, so there's an inevitable free-rider problem. We always want to hold back and let other people take care of the problem. What the state does is co-ordinate action so that we're all part of it together and the problem gets solved. My concern is that we're seeing an inexorable weakening of state institutions because of the power shift I spoke about earlier – the increase in power due in part to communication technologies and in part to the diffusion of technologies to destroy. Now a lot of the time, the increase in communication ability is a very good thing because it allows us to participate more fully in democracy, to communicate and organize ourselves more effectively. There should be – a lot of people assumed there would be – reinvigoration of democracy as a result of the internet, for example, and all the new communication technologies from fax machines to cell phones and things. But I'm not sure it's going to work out like that. I think it's more likely that what we're creating is a kind of electronic cacophony or electronic gridlock. Decision makers within our democratic institutions are absolutely overwhelmed now by the flow of information coming in. In the United States, 1998 figures showed that representatives in the House of Representatives would get up to 5,500 e-mail messages a month, senators up to 70,000, and congress as a whole

80 million e-mail messages a year. Until six to eight months ago, they responded to every one. Policy makers are overwhelmed. Now we have a set of democratic institutions which are critical to the functioning of the state in Western society that were developed or evolved during the 18th and 19th centuries when people traveled at the speed of horses at a maximum and when information was transferred almost wholly by mouth because most people weren't literate. Now people can travel to the other side of the planet in less than a day, and they transfer information by the gigabit. We have hyper-empowered citizens and institutions from over a century ago – two centuries ago. A big ingenuity requirement is the need to rethink our collective decision-making process effectively so that we can decide how we're going to solve our problems and include these hyper-active and hyper-empowered citizens effectively within that decision-making process. We need to strengthen the state rather than weaken it. At the moment, many people are withdrawing as participants because they see that the system isn't working. It's losing its moral legitimacy, voting turnouts are going down, nobody interesting and competent of high caliber wants to go into politics any more, and so we're seeing a steady erosion of the quality of our political institutions and over time, an erosion of the strength of the state. That's really bad news. The other part of this, of course, is that when you have all of these hyper-empowered groups all over the place, it's very difficult to solve problems with collective action. It's very difficult even if you have a competent state to get everybody together to actually deal with something like climate change, as we can see in Canada right now. So my sense is that we've got a real problem here, and we have to start thinking really creatively about new forms of democratic participation in our societies.

Question 2: I want to ask a question about the economy and some of the problems you've raised. Do you think that we need to look for ways to develop alternative economic systems or do you think we can simply accomplish what we need to accomplish by regulating the capitalist mode of production?

I'd like to answer that question by referring to the data on income distributions from the United States over the last forty years. These are from U.S. National Census Bureau data on mean family income in 1997 dollars, so they're controlled for inflation. The population is divided into quintiles (5ths), from about 1967 to almost 2000. (The latest figures aren't out but they'll be about the same in terms of trends.) The bottom four quintiles - 80% of families in the United States - have seen very little or no real increase in their income. The bottom three are essentially flat, and the fourth is almost flat, but the top

fifth of the population has gained an increase of about 50% in its income, while the top 5% of the families have seen an increase of over 100%. This represents a pretty fundamental change in the structure of distribution in our societies.

I think, to answer your question, that it is fundamentally a function of the nature of capitalism. I'm not sure that it's essential to capitalism, but it means that to avoid this situation, which I think ultimately is very dangerous to our society, we have to watch what's happening very carefully and we need strong states to deal with it. Why is this bad news? Well, among other things, it's bad news because increasingly, you're going to find that the top portions of the socio-economic system of the distribution are not willing to contribute to the generation of public goods, because they can buy whatever goods they need privately. Parks, recreation, health care, roads, security – they'll just buy them privately. Increasingly, it undermines our common sense of identity and if there's one thing that we need to solve our common problems it's a sense of 'we-ness' – that we are together in these problems and need to solve them together. So over time, this is really bad news for ingenuity generation, for solving our problems, and even for political stability.

Why is it happening? One of the critical reasons is that in our modern capitalist economy, markets are so large that those who are best at producing whatever they produce can sell essentially to the whole planet or at least to very large markets. But everybody who is second-ranked or further down the ranks doesn't get rewarded. So you get a winner-take-all economy – rewards tend to go to the very top-echelon producers and everybody else suffers. Just to finish my comment on this question: This economic gap is one of the problems we have in the current global capitalist system because it is happening not only within the United States, Canada, and other Western countries, but around the world. We see this widening of the gap.

But we also have the problem of a capitalist system that seems to be pushing at the outer limits of the ecological thresholds of the planet. We have a system that has a chronic problem maintaining adequate demand. For example, one of the problems we've got is that the bottom four quintiles are not increasing their income sufficiently to maintain adequate demand within the economy. So what do we do in response? Well, we generate a psychology of hyper-consumerism, to turn everybody into walking appetites. We try to get them to spend all of their money; we don't want them saving any money, and we don't want the savings rate to go up in the United States because the whole world economy now depends on the American consumer. Well, so on one hand, we have to maintain through-put in the world economy because it's only stable if it's growing; if it isn't growing, these differentials are going to produce real political and social instability. On the other hand, that increase in material

consumption is producing problems like the Green House problem that I mentioned before. That is pretty close to a fundamental contradiction. We are on the brink of a deflationary spiral in the Western and the world economy right now. This is a new situation, what Paul Krugman calls the “return of depression economics,” and the way we solve it is by pumping up consumption. We want people to buy SUVs. At the same time, we’re having the worst drought that has ever been experienced on the prairies, and climate change is starting to show its face all over the planet. I think it’s reasonable to say the signal is appearing from the noise. This is a serious contradiction. I’m not sure whether it’s an essential contradiction in capitalism, but we certainly need to revisit some of the deeper principles of the economic system we’ve created.

Question 3. You talk about people being overwhelmed and indeed they often are, but they also seem to be “underwhelmed” in that the information they get is often summarized and seldom explained in depth. This isn’t really new; even in war-time, most news was summarized, but today it seems to be even more the case, and it’s something that as educators, I think we should be fighting against. You mentioned microcosm and so forth in doing that. Do you have any “help” as to how to combat this?

Well, one of the things – and this is not a bad way to conclude I suppose – one of the things that people have found frustrating about my book is that I don’t provide a checklist of answers at the end. In fact, it would be a bit odd for a book that’s an extended argument against arrogance to say at the end, “Oh, well, I’ve got all the answers.” I’m not sure of the answer to this one, but we do have a critical problem, rather like the one about the capitalist system. The problem is that we’ve improved our ability to transfer information practically infinitely, but our basic cognitive capability hasn’t improved. We have probably increased our information-transfer capability a hundred million fold in the last twenty years. Well, what do we do in that situation? Here we are sitting in this tidal wave of stuff that’s piling up at the front doors of our cerebral cortex. What do we do? We hyper-specialize, we task-switch, and we abbreviate. We all task-switch, this is what multi-tasking is all about, right? We all do a little bit of this, a little bit of that, go back and forth – it’s really inefficient, it lowers your cognitive effectiveness – all the tests show that you’re actually a worse driver when you’re talking on the cell phone. But we’re all doing it because we’ve got so many things going on, and this gets directly to your point. We abbreviate, we shorten our messages. We see it in e-mail messages. They’re staccato phrases; we lose the depth of communication with people. It appears from cognitive research on the size of the human brain and

looking at other hominids and things that the normal size of our cognitive community – people that we can reasonably know something about, given the size of our brains – is about 150. But now we can have infinite communities. People I haven't spoken to in thirty years are popping up on the internet, right? I publish a book and I do the stupid thing of having my e-mail address on it and anybody in the world can contact me now. We have a cognitive community that is essentially infinite in size. It can involve thousands of people, even for somebody who is not terribly active on the internet. So what do we do? We abbreviate. Everything is getting abbreviated. Information within our news systems is getting abbreviated. In the last 30 years – this is one of the statistics I quote in my book – the length of Time magazine cover stories has gone down 40%. The length of Scientific American research articles – their principle ones – has gone down 30%. New York Times opinion articles have gone down 25%. A New York Times article now averages 575 words. You tell me what you could say about the world in 575 words. We have a world that's more complex, that requires more sophistication of thought, more subtlety, more lines of information and evidence integrated to try to address our problems, and we have less and less time to talk about those things. Because what's happening? Editors are responding by shortening those articles. They're responding to what they know about their audience, that it has no time to read any more. Most people don't read long texts. "I've got five minutes between one thing and another, I can read 575 words, so I'll read this." You get a little snippet of an idea, a snapshot of information – that's not going to help us solve our problems. So somehow, if we're going to reinvigorate our collective institutions of the state and our democratic decision-making, we have to return to some deliberative mechanisms. We have to give people, communities, and societies the space in their lives to actually think about things, and the time to do so. Again, that's a big ingenuity requirement in terms of designing our collective institutions, and what I'm trying to do in this book is raise the issues so that we can work on them together.