



Spohrer: Book of Problems

Nano-bio-cogno-socio-techno convergence for enhancing human performance:

Perspectives on the great unsolved problems of learning

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October 24, 2003

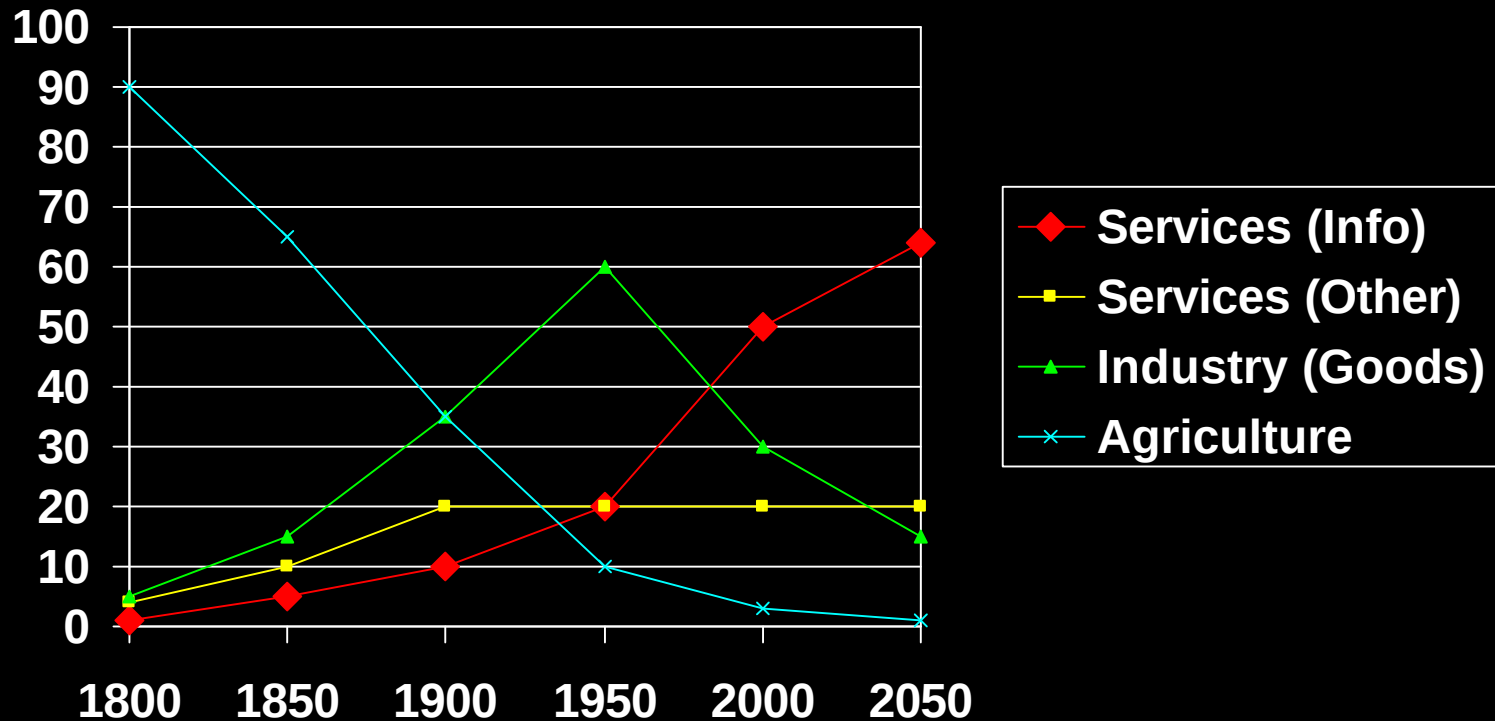
Six R's of Learning

- **Remind & Remediate – I knew it**
 1. Remind: Give me a hint
 2. Remediate: Give me practice
- **Receive & Reconstruct – You know it**
 3. Receive: Give me it fast (training)
 4. Reconstruct: Give me it deep (education)
- **Research & Reflect – No one knows it**
 5. Research: What's the right answer?
 6. Reflect: What's the right question?

Problems

- **Optimization and adaptation to environment**
 - Rate of change acceleration
 - Deciding to stop or change other aspects of the system
- **Knowledge transfer between agents**
 - Individual to individual
 - Organization to organization
 - Artifact to individual
- **Knowledge transfer across space**
- **Knowledge transfer across time**
 - Accumulation of knowledge
- **Knowledge transfer at lowest energy cost**

U.S. Employment Percentages by Sector



Estimations based on Porat, M. (1977) Info Economy: Definitions and Measurement, Augmented with recent data and projections from <http://www.bls.gov/>

Today's Talk

- **The Pioneers**

Enhancing human performance with information technology

- **The Science**

Nano-bio-cogno-socio-techno convergence

- **Business Implications**

The business of people

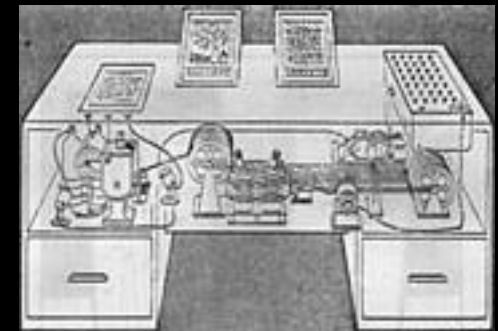
The evolution of businesses and organizations

- **Concluding remarks**

The Pioneers

Thanks to the pioneers whose early visions of enhancing human performance with new information technologies have helped to inspire many of us...

- **Vannevar Bush (1945) “As We May Think”**
- **J.C.R. Licklider (1960) “Man-Machine Symbiosis”**
- **Douglas Engelbart (1962) “Augmenting Human Intellect”**



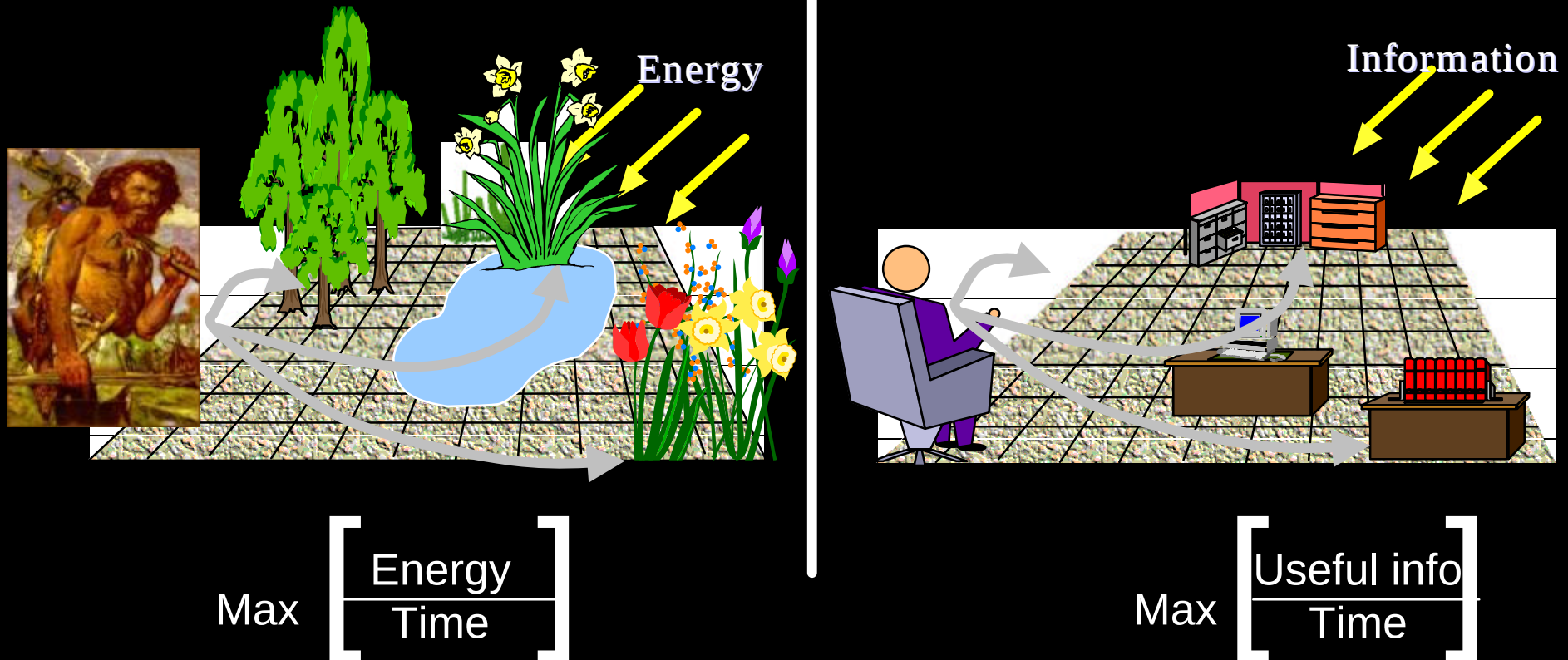
Original Source:
Atlanta Monthly 1945

The pioneers all clearly saw people adapting to a new environment... moving from a natural environment to a human-made information-rich environment.

The New Environment and Human Activity: Where does our time go? From the search for food to the search for information

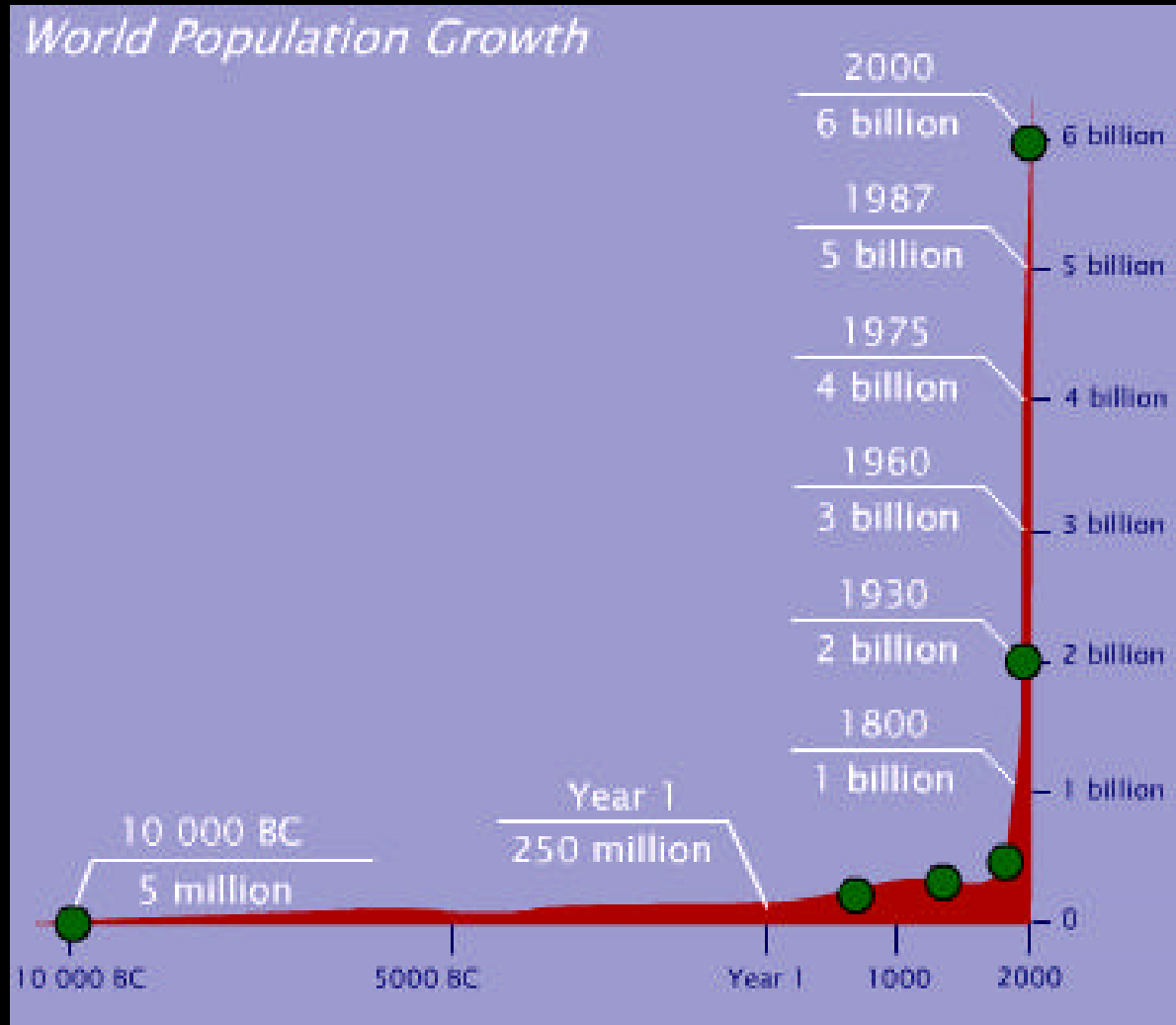
Humans as Informavore (Miller, 1983)

Source: Pirolli (2002)



Our environment is changing increasingly rapidly due to a positive feedback loop between population and information

Effects of Agriculture, Colonial Expansion & Economics, Scientific Method, Industrialization & Politics, Education, Healthcare & Information Technologies, etc.

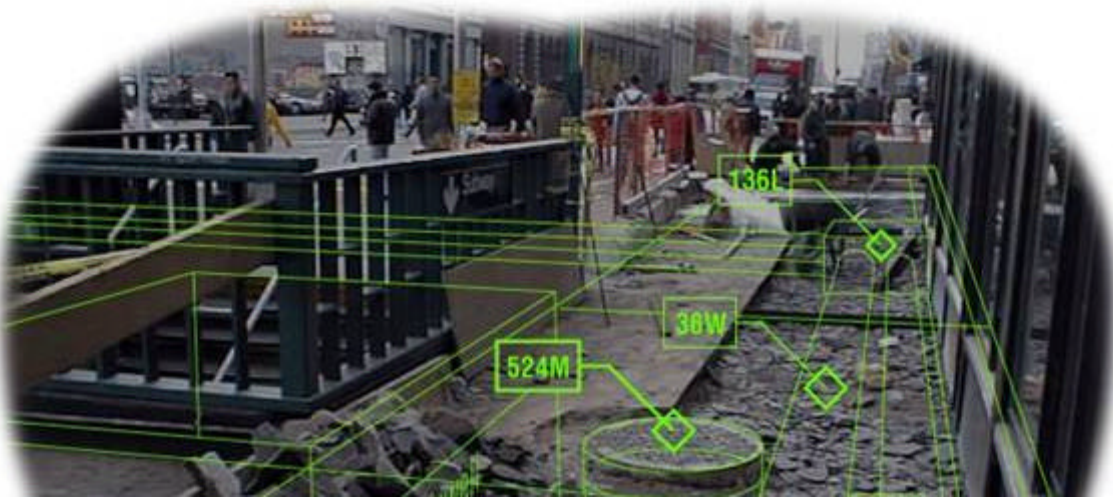
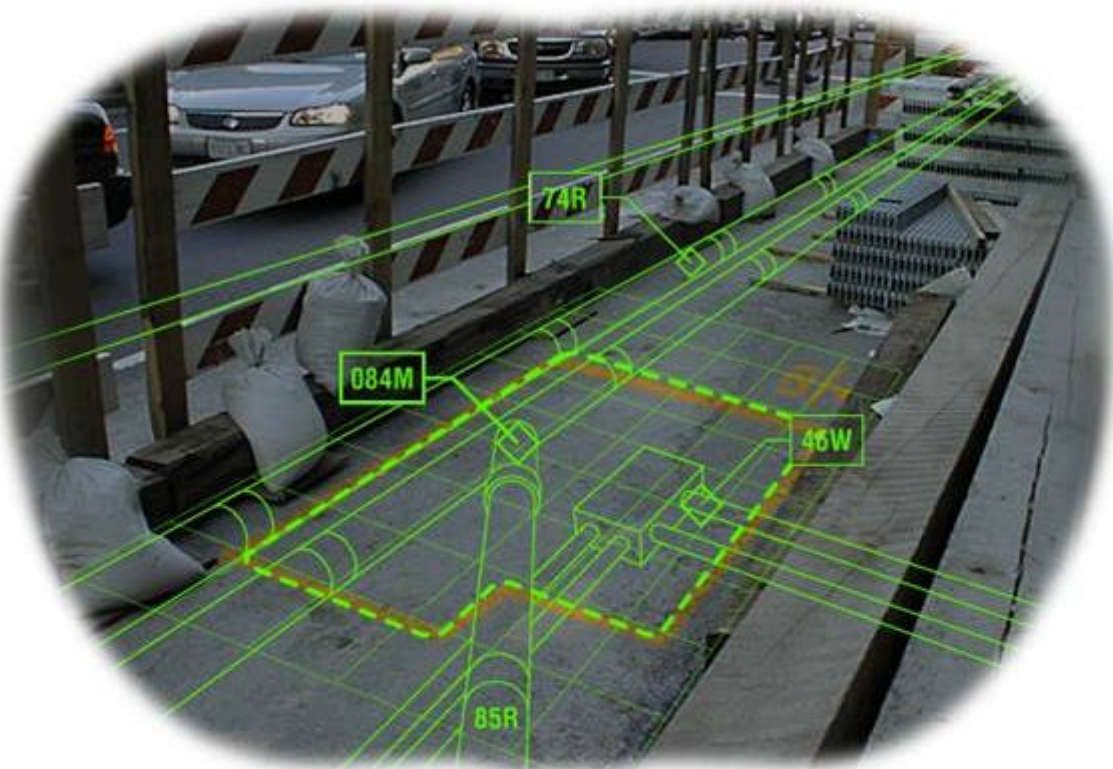


Positive feedback loop for the new environment
More people leads to more information
leads to more people...

6 Billion Human Beings: An exhibit from the Musée de l'Homme Muséum National d'Histoire Naturelle, Paris –France <http://www.popexpo.net/english.html>

WorldBoard: Learning Contexts

Art by Ian Bruce



Sutherland ('65)



IBM ('00)

Stage 1: Reach out and touch rocks, trees, natural atoms
 Stage 2: Reach out and touch table, computer human placed atoms
 Stage 3: Reach out and perceive information in places (WorldBoard) 21

The Science

The Science of Nano-bio-cogno-socio-techno Convergence

- **The Question:** Can we **understand and control to suit our purposes the different information** encoding, processing, and replication processes across multiple systems?

Natural Systems – Natural environment that people exist in

Information in Physical Systems (Matter & Energy Flows, Atoms Matter)

Information in Living Systems (Chemistry of Life, Molecules/Ecosys. Matter)

Information in Cognitive Systems (Brains, Neurons Matter)

Knowledge of the natural world and human made world

Human Made Systems – Human Made environment that people exist in

Information in Social Systems (Organizations, People Matter)

Information in Technology Systems (Tools, Machines Matter)

- **Implications:** As we get closer to a more complete answer, we can expect to realize many interesting, new capabilities that happen between the different systems:

artificial cochlea and retina (technology to cognitive)

terra-form Mars (physical to living)

The science: nano-bio-cogno-socio-techno convergence:
It's all about information – encoding, processing, replicating – in
different systems (ultimately all grounded in matter patterns)

Co-Evolution		System	Encoding	Processing	Replicating
	Nano	Matter (Nature)	Atoms & Molecules	Universe to Atoms	Galactic, Solar, Planet Systems
	Bio	Life (Nature)	DNA	Cells to Ecosystems	Evolution
	Cogno	Thought (Nature/Human)	Brains	Neural Nets	Evolution - Culture
	Socio	Culture (Human)	People	Organizations	Evolution - Culture
	Techno	Technology (Human)	Artifacts & Bits	Computers	Design- Factories

Rapidly increasing rates of advancement in each system area is creating cross pollination
Examples: FOXP2, Complex Adaptive Systems (CAS) – Variability, Interaction, Selection

The Scale of Things -- Nanometers and More



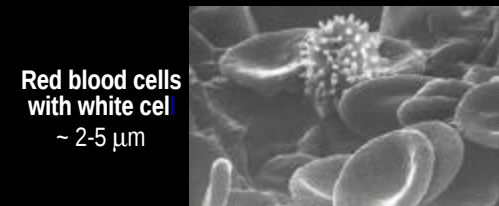
Things Natural



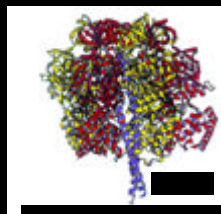
Dust mite
200 μm



Human hair
~ 10-50 μm wide



Red blood cells
with white cell
~ 2-5 μm



~10 nm diameter

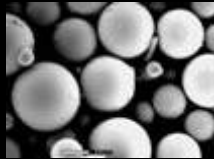


DNA

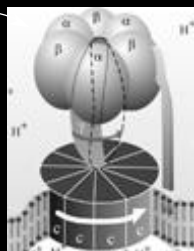
~141/2 nm diameter



Ant
~ 5 mm



Fly ash
~ 10-20 μm

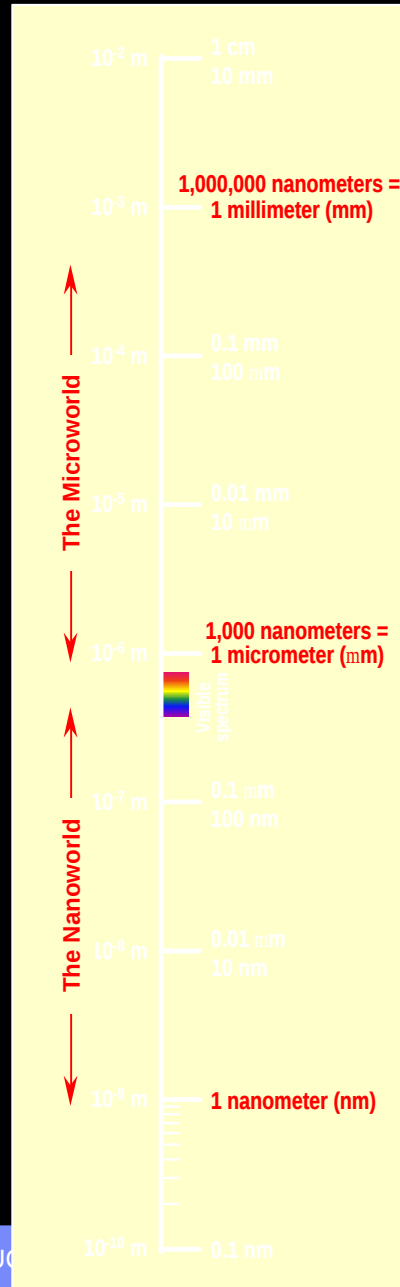


ATP synthase



Atoms of silicon
spacing ~ tenths of nm

Source: NSF website



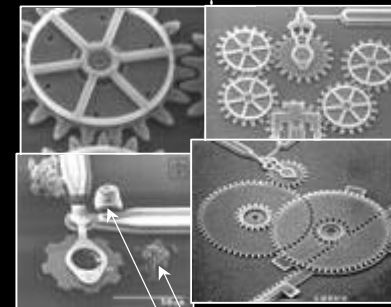
Nanotechnology Progress Generating New Excitement

Things Manmade

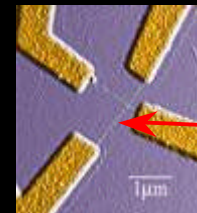


Head of a pin
1-2 mm

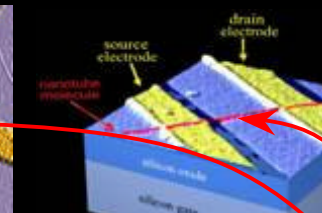
MicroElectroMechanical Devices
10 -100 μm wide



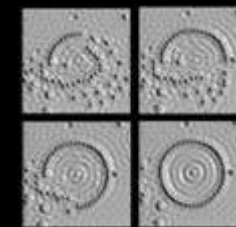
Red blood cells
Pollen grain



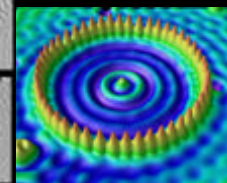
Nanotube electrode



Nanotube transistor

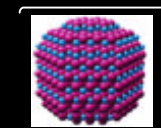
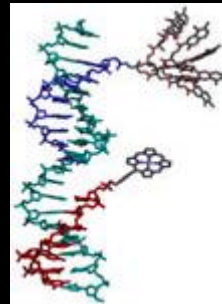


Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm

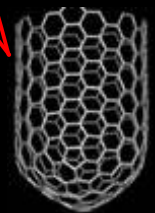


Carbon nanotube
~2 nm diameter

21st Century Challenge



Combine nanoscale building blocks to make functional devices, e.g., a photosynthetic reaction center with integral semiconductor storage



Brief History of Accelerating Change

Billion Years Ago	
12	Big Bang (EMST)
11.5	Milky Way (Atoms)
8	Sun (Energy)
4.5	Earth (Molecules)
3.5	Bacteria (Cell)
2.5	Sponge (Body)
0.7	Clams (Nerves)
0.5	Trilobites (Brains)
0.2	Bees (Swarms)
0.065	Mass Extinctions
0.002	Humans Tools & Clans Co-evolution

Generations Ago	
100,000	Speech
750	Agriculture
500	Writing
400	Libraries
40	Universities
24	Printing
16	Accurate Clocks
5	Telephone
4	Radio
3	Television
2	Computer
1	Internet/e-Mail
0	GPS, CD, WDM

Improving Human Performance: Outside-Inside Framework

Relative Position	Improvement Areas
External (outside the body; environmental)	Materials - Cost, Affordances, Dynamics
	Agents – Organizations, Bots, Animals
	Places – Real, Virtual, Mixed
	Mediators - Tools
External (outside the body; personal)	Mediators – Wearables, Mobile Tools
Internal (inside the body; temporary)	Ingestibles – Medicines, Foods
Internal (inside the body; permanent)	Organs – Implants, Sensor & Effectors
	Skills – Learning, New Uses of Old
	Genes – New Species, Devel. Process

Outside-Inside Framework can be used to analyze the past, and speculate about futures.

Outside-Inside Framework Applied: Past & Future

- **- 100,000 Generations: Speech**
 New Species (Kind of Agent)
 New Use of Old Sense (sounds -> symbols: language)
- **- 500 : Writing**
 New Mediator: Store symbols for later use (and New Skills = Scribes)
- **- 400 : Libraries, 40 Universities, 24 Printing**
 New Mediator, Places: Communicate/Distribute (and Agents = Organizations)
- **- 16 : Accurate Clocks for Navigation & More**
 New Mediator: Measure (and Agents = Organization)
- **- 5 : Telephone, 4 - Radio, 3 - TV, 2 - Computers, 1 - Internet**
 New Mediator: Communicate/Distribute (and Agents = Organizations/Businesses)
 New Use Old Sense: Stories (e.g., Why Honeymooners = Flintstones)
- **-0.5 :GPS/Sensors for Navigation & More**
 New Mediator: Measure (and Agents = Organizations/Businesses)
- **+0.5 : On-Demand e-Business (?business on demand?)**
 New Agent (Businesses become more automated, adaptive, resilient, responsive)
- **+1 : NBIC (?nano-bio-info-cogno convergence?)**
 New Material (Nanotechnology – first impact on materials, electronics, and life sciences)
 New Sense (Bionics - neural & biochemical interfaces cure deafness, blindness, organ failure)
 New Mediator (Information WorldBoard - planetary augmented reality system)
 New Agents (Cognitive robots or Bots - natural language interface to all human knowledge)
- **+5 : Utility Fog (?materials on demand?)**
 New Material (Utility Fog – billions of particles assemble on-demand to create macro-scale objects)

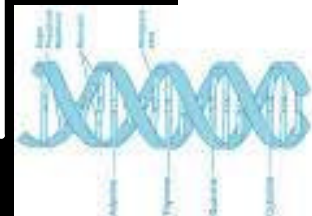
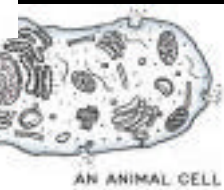
Business Implications: The Business of People

People science or human sciences increasingly driving technology and hence business

The Business of People – Healthy, Wealthy, and Wise

U.S. Census website defines quality of life metrics (health, material goods, info access)

	Science	Technology	Business
Group	Social Science, Economics, Org. Behavior	Science produces Data, drives Info Tech Tech underlies new Products & Services New Products & Services drive Business	Financial Services, Legal, Insurance, Government
Individual	Cognitive Science		Education, Communication
Brain	Neurophysiology		Healthcare, Public
Cell	Proteomics		Healthcare, Industrial
Gene	Genomics		Healthcare, Distribution



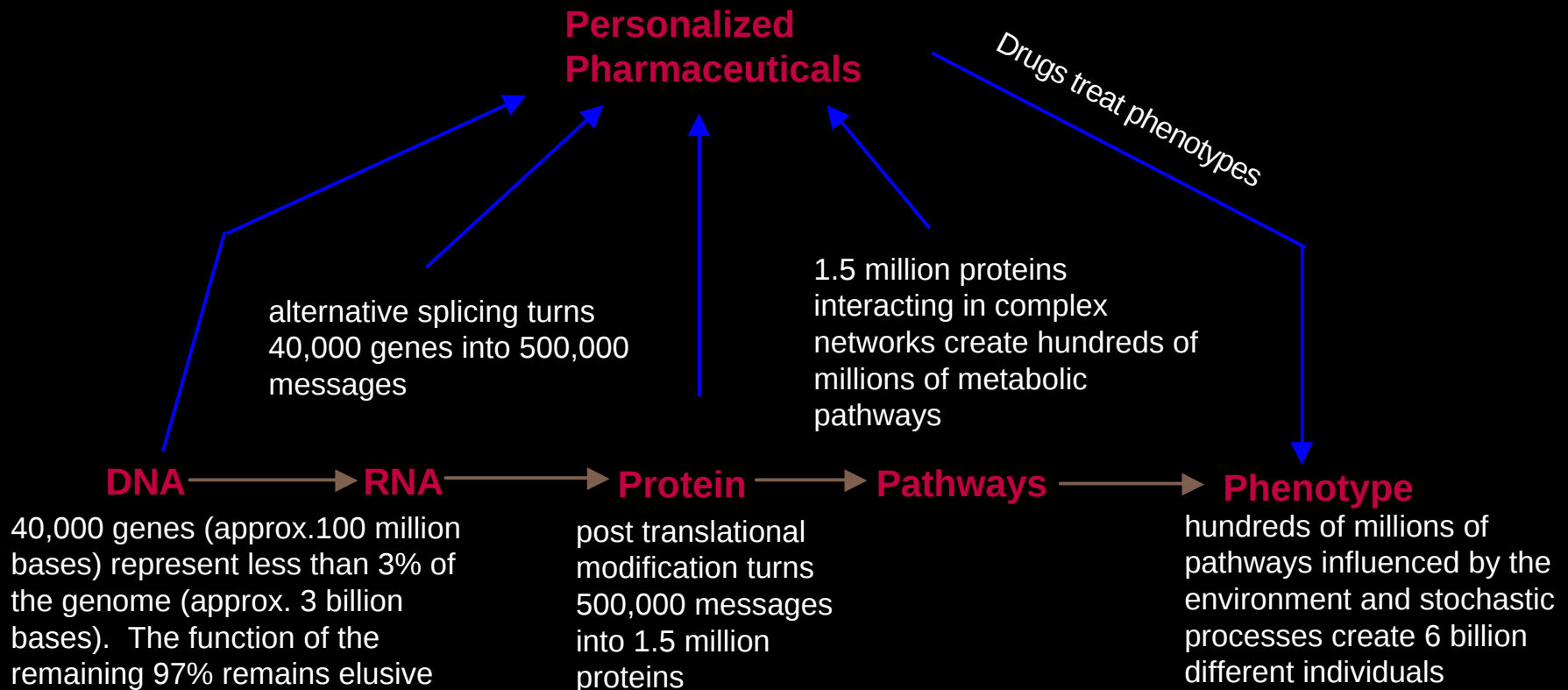
Business Implications: Three examples

- Healthy: Our Bodies & Our Environment
Someday Personalized Pharmaceuticals (nano for sensors, delivery, design)
- Wealthy: Our Material Goods (Sustainable, Cheaper, Stronger)
Someday On Demand Materials (nano for manufacturing materials)
- Wise: Our Thinking and Perception (Access to Information)
Someday Learning Conversations (nano for compute performance, interface)

Healthy

IBM Life Sciences Solutions

Rational drug development requires managing enormous complexity. Pharmaceutical companies are beginning to differentiate themselves on the power of their information technology platforms. IT Platform intellectual property is likely to be more valuable than content (gene sequences, metabolic pathways, protein structures, etc.)



Historically, 220 targets have generated \$3trillion of value. Industrialized genome sequencing has created a target rich, lead poor environment that will slowly reverse over the next several years as in-silico biology drives the discovery of new lead compounds.

DNA to Phenotype = 300 terabytes per person x 6 billion persons = 1800 billion terabytes of data

Wealthy

Material Goods

- Environmentally friendly, sustainable production
- Cheaper, Stronger, Lighter, Durable, Active, etc.
- Smart, polymorphic, chromatically active materials
- Clothing and Textiles – stain resistant
- Computing technologies – roll-to-roll manufacturing
- Cars and Vehicles
- Roads
- Houses and Buildings
- Furniture and Appliances
- Foods

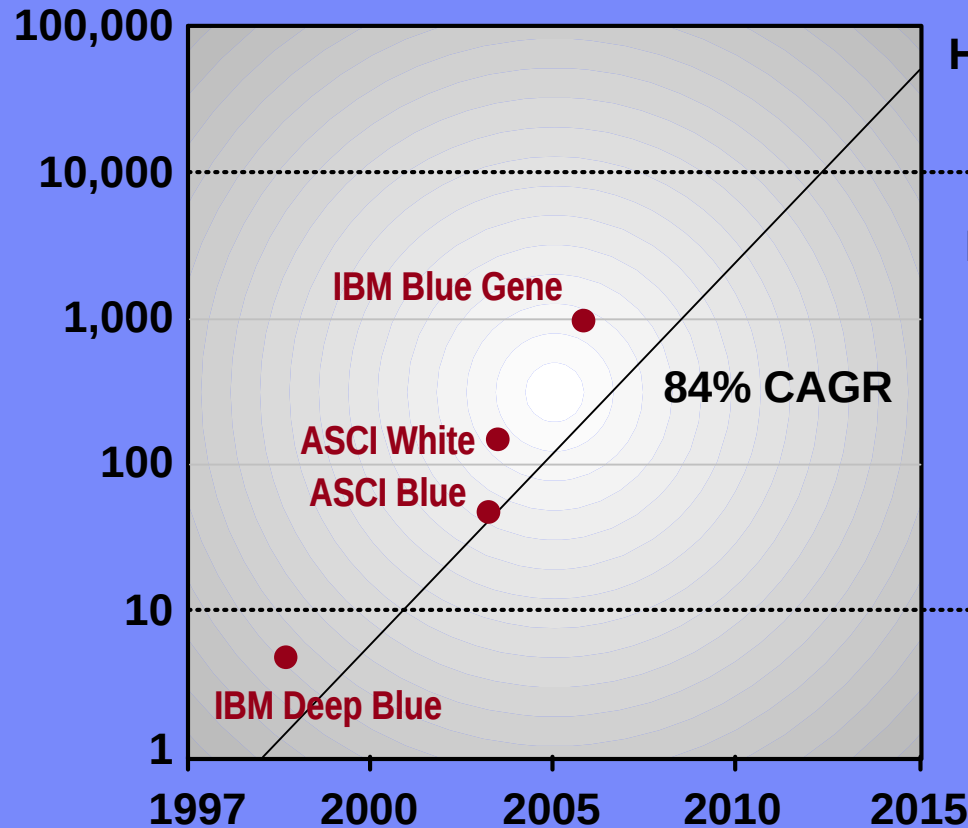
Wise

Access to Information

Semantic Web and Natural Language Capabilities

Learning Conversations

Trillions of Calculations per Second



APPLICATIONS

Human Like Behavior
"HAL"

Predictive Modeling

Protein Folding

Nuclear Simulation

Chess Playing

Source: ACSI Roadmap www.llnl.gov/asci, IBM Brain ops/sec: Kurzweil 1999, *The Age of Spiritual Machines*

Business Implications: Evolution of Organizations

On Demand Enterprise – the Evolution of e-Business

- **Sense & respond organizations**

E-Utilities, Web Services, Real Time, Adaptive, Policy-Driven, Product Lifecycle Management (PLM), Value-Driven to Profit Zone

- **Business Processes as the evolving DNA of business**

People (costs rising)

Labor Value Creation: Empowerment via tools and new organizations, Learning Technology (cost dropping)

Outsourced Services (cost dropping)

Labor Commoditization: Automation, Off-shore, Deskilling
External Regulations and Government Policy

- **Organizations as the fastest evolving “agents” on the planet**

Monetizing science is done increasingly rapidly as new products/services

New products/services accelerating science, new data, new technologies

People costs and ability to change are increasingly the limiting factor

Other examples of organizational evolution

- Governments

Settlements to Towns to City-States to Empires to Nations

Authority by Wisdom, Military Might, Divine Designation, Birth Right, Election

- Cooperatives

Robert Owens (1844), Charles Fourier, Granger Movement, Collective Farms, Communes

- Franchises

Chain stores, malls, retail brands

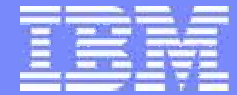
- On-line services

ISP (AOL), Portals (Yahoo), Retails (Amazon), Auctions (eBay)

- New Products and Services created by new kinds of businesses

Concluding Remarks

- The pioneers taught us that people are adapting to an increasingly information-rich environment
- The science of nano-bio-cogno-socio-techno convergence is about understanding information encoding, processing, and replication across multiple systems
- The sciences concerned with people (human sciences) from DNA, cell, brain, individual, and groups are on the rise, generating enormous amounts of data, and impacting the future of business
- Business (organizations) are the fastest evolving things on the planet, and while technology cost drop, people costs rise



Spohrer: Book of Problems

Thank-you for listening.

Suggestions, comments, and ideas are very welcome.
E-mail spohrer@almaden.ibm.com or
Jim Spohrer/Almaden/IBM.

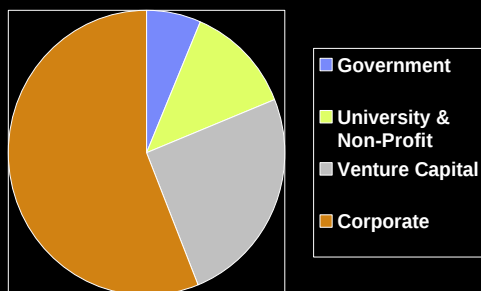
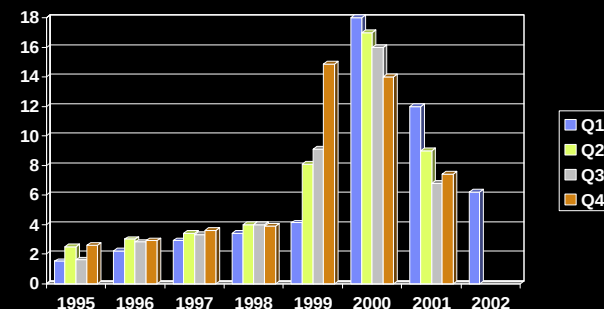


Spohrer: Book of Problems

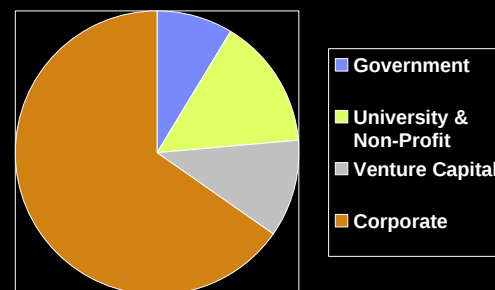
EXTRA SLIDES

Innovation Ecosystems

- U.S. Government R&D
- U.S. University, Non-Profit R&D
- U.S. Corporate R&D
- U.S. Venture Capital ----->



•2000, U.S. R&D + VC est. \$320B



•2002, U.S. R&D + VC est. \$290B

•Estimates from Venture Source & NSF, all numbers approximate

Repositories of Knowledge

- **Explicit Knowledge**

Structured Repositories: Databases (e.g., DB2)

Unstructured Repositories: Text (e.g., eClassifier, Project WF)

- **Tacit Knowledge**

People as Repositories of Knowledge: Tacit knowledge resides in the heads of people. An important category of tacit knowledge is relationship knowledge, knowledge about other people and ways of accessing their services. (e.g., IGS)

A study by the Delphi Group found that the largest segment of corporate knowledge resides in employees' brains (42%), followed by paper documents (26%) and electronic documents (20%). Quantifying the value of knowledge (e.g., relationship knowledge versus mere facts) is even more difficult to assess.

Sources: <http://www.powerhomebiz.com/vol21/knowledge.htm>, Delphi Group

EDUCATIONAL TECHNOLOGY HORIZON 2001-2010

Questions & Implications

HOW DO WE PREPARE FOR THE FUTURE?
 While the future of education is uncertain, it is clear that technology will play a significant role in shaping the future of education. We must prepare our students for a world where technology is a constant presence. This means providing them with the skills and knowledge they need to succeed in a technologically driven world.

WHAT IS THE NEW LITERACY?
 The new literacy is the ability to use technology effectively. It is not just about knowing how to use a computer, but also about understanding the implications of technology on society and the environment. It is a literacy that is essential for success in the 21st century.

WHAT ARE THE EDUCATIONAL CHALLENGES OF THE FUTURE?
 The educational challenges of the future are many. We must ensure that all students have access to quality education, regardless of their background or location. We must also ensure that our education system is able to keep pace with the rapid changes in technology and the needs of the workforce.

HOW CAN WE MEASURE THE IMPACT OF TECHNOLOGY ON EDUCATION?
 Measuring the impact of technology on education is a complex task. It requires a combination of quantitative and qualitative data. We need to look at things like student achievement, teacher effectiveness, and the overall health of the education system. We also need to consider the long-term effects of technology on society and the environment.

WHAT ARE THE ETHICAL IMPLICATIONS OF TECHNOLOGY IN EDUCATION?
 Technology in education raises a number of ethical issues. For example, how do we ensure that technology is used in a way that respects privacy and individual rights? How do we ensure that technology is used in a way that is fair and equitable for all students? These are questions that we must ask as we move forward with technology in education.

HOW CAN WE PREPARE OUR TEACHERS FOR THE FUTURE?
 Preparing our teachers for the future is a critical task. We need to ensure that our teachers have the skills and knowledge they need to use technology effectively in the classroom. This means providing them with ongoing professional development opportunities and ensuring that they have access to the resources they need to succeed.

WHAT ARE THE POLICY IMPLICATIONS OF TECHNOLOGY IN EDUCATION?
 Technology in education has significant policy implications. We need to ensure that our education policies are up-to-date and reflect the realities of a technologically driven world. This means involving all stakeholders in the policy-making process and ensuring that our policies are based on sound evidence and research.

HOW CAN WE ENSURE THAT ALL STUDENTS HAVE ACCESS TO QUALITY EDUCATION?
 Ensuring that all students have access to quality education is a top priority. We need to ensure that our education system is able to reach all students, regardless of their background or location. This means investing in infrastructure and ensuring that we have enough teachers and resources to meet the needs of all students.

WHAT ARE THE LONG-TERM EFFECTS OF TECHNOLOGY ON SOCIETY AND THE ENVIRONMENT?
 Technology has a profound impact on society and the environment. We need to be aware of these impacts and work to ensure that technology is used in a way that is sustainable and beneficial for all. This means considering the long-term effects of technology on things like the environment, social inequality, and the future of work.

HOW CAN WE PREPARE OUR STUDENTS FOR THE FUTURE?
 Preparing our students for the future is a continuous process. We need to ensure that our students are equipped with the skills and knowledge they need to succeed in a world where technology is a constant presence. This means providing them with a well-rounded education that includes both academic and practical skills.

WHAT ARE THE CHALLENGES OF THE FUTURE?
 The challenges of the future are many and varied. We need to be prepared to face whatever comes our way. This means staying informed about the latest developments in technology and the world around us, and being able to adapt to change. It also means working together to find solutions to the problems we face.

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LEARNING SPACES

Free Play
 Let the Kids Invent!

Opportunities

BEING BIOLOGY
 With the help of virtual reality, students can explore the world of biology in a way that is both fun and educational. They can see the inner workings of a cell, or they can explore the vastness of the universe. This is a learning experience that is truly unique.

LIVING HISTORY
 With the help of virtual reality, students can explore the world of history in a way that is both fun and educational. They can see the world as it was in the past, or they can explore the lives of famous historical figures. This is a learning experience that is truly unique.

GLOBAL PRODUCTIONS
 With the help of virtual reality, students can explore the world of global productions in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

SMART COMPANIONS
 With the help of virtual reality, students can explore the world of smart companions in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

INFORMATION IN PLACES
 With the help of virtual reality, students can explore the world of information in places in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

WOLF CAM/CRAV GRAPHS
 With the help of virtual reality, students can explore the world of wolf cam/crav graphs in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

Customized Learning

Supporting a Spectrum of Learning Styles

CYBER-SCOUTS
 With the help of virtual reality, students can explore the world of cyber-scouts in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

LEARNING CONCERNS
 With the help of virtual reality, students can explore the world of learning concerns in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

CUSTOM BOOKS
 With the help of virtual reality, students can explore the world of custom books in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

ONLINE MENTORS
 With the help of virtual reality, students can explore the world of online mentors in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

MASTER MUSIC CLASS
 With the help of virtual reality, students can explore the world of master music class in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

MODULAR, LINKED CURRICULUM
 With the help of virtual reality, students can explore the world of modular, linked curriculum in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

Orchestrated Learning

Connected, Multidimensional Classrooms

COMPETENCY GATEWAYS
 With the help of virtual reality, students can explore the world of competency gateways in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

HAND-HELD MEDICAL TEAM
 With the help of virtual reality, students can explore the world of hand-held medical team in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

BASICS BREAKTHROUGH
 With the help of virtual reality, students can explore the world of basics breakthrough in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

CONNECTED PARENTS
 With the help of virtual reality, students can explore the world of connected parents in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

SMART CLASSROOMS
 With the help of virtual reality, students can explore the world of smart classrooms in a way that is both fun and educational. They can see the world from a different perspective, or they can explore the lives of people from different cultures. This is a learning experience that is truly unique.

TECHNOLOGIES

Informated Appliances
 • Chips to everything
 • Smart-home power systems
 • Local area wireless networks

Filtering the World of Overload
 • Content recognition
 • Image recognition
 • Personalized filters
 • Geographically organized content

New Data
 • Multidimensional
 • Multidimensional
 • Multidimensional
 • Multidimensional

Global Tracking
 • GPS-enabled positioning system
 • Point-of-use content

Bandwidth to Burn
 • Wire & wireless
 • HFC-hybrid fiber-coax cable
 • DSL-digital subscriber phone lines
 • Wireless satellite

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 • Wire & wireless
 • HFC-hybrid fiber-coax cable
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INTERFACES

Data Trading
 • Peer-to-peer architectures
 • Social computation
 • Multidimensional authoring tools

New Realities
 • Visualization and simulation
 • Virtual reality
 • Augmented reality

Body as Security Device
 • Biometrics-fingerprints and retinal scans
 • Biomonitors

Mobile Media
 • Super cell phones
 • Interspersibility of devices
 • Agents & bots
 • Personalized programming

Ultimate Personalization
 • Eye-tracking interfaces
 • Sensory
 • Adaptive systems
 • Adaptive technologies for learning differences

THE SHADOW SIDE

Always On
 • Always On
 • Always On
 • Always On

Threats to Privacy and Security
 • Threats to Privacy and Security
 • Threats to Privacy and Security
 • Threats to Privacy and Security

Digital Divide
 • Digital Divide
 • Digital Divide
 • Digital Divide

Group Interfaces
 • Shared displays
 • Language translation
 • Privacy and encryption tools

Full-Body Contact
 • Gestural and haptic interfaces
 • Force-feedback sensors
 • Voice recognition

STAKEHOLDERS



INVENTING • GUIDING • INNOVATING • FUNDING • LEADING • PARTNERING • LEARNING • SUPPORTING • TEACHING • IMPLEMENTING • DEVELOPING • RESEARCHING

- How to Use This Map:**
- 1. Explore Technologies**
 Which do you understand and which puzzle you? Which are critical for learning in the future? What is missing?
- 2. Identify Opportunities**
 Which stories intrigue you? What stories would you add? Relate them to the learning spaces.
- 3. Discuss Questions & Implications**
 Identify which are most relevant to your district, your research, or your decisions regarding ed tech. Gather a group to discuss them.
- 4. Support Initiatives**
 Look at current research, developmental, or learning initiatives and see how they relate to the big picture.
- 5. Take Action**
 Use this map to build awareness and develop an agenda for investment and action.

Technology Innovations

COLLECTIONS
 The "Always On" Infrastructure

People and their intelligent devices will become increasingly interconnected, right from our mobile systems (PDA) and digital cameras (PDA) and right from our mobile systems (PDA) and digital cameras (PDA).

DEVICES
 The World of Smart Stuff

Desktop devices are no longer desktop devices. They are now portable devices. They are now portable devices. They are now portable devices.

DATABASES
 The Democratization of Information

The Internet will continue to evolve into a technology that will democratize information. It will democratize information. It will democratize information.

INTERFACES
 The Engagement of the Senses

Interfaces with intelligent devices and environments will use more than visual and auditory input. They will use more than visual and auditory input. They will use more than visual and auditory input.

BIOLINKS
 Biotech Meets Ed Tech

Biotechnology will transform technology. It will transform technology. It will transform technology.

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Meta Trends: Exponential Growth

- **Moore's Law** - Miniaturization - Continues
 - ➔ Processing, Storage, ...
 - ➔ Price/Performance 2X over 12-18 months
- **Metcalf's Law** - Interconnection - Continues
 - ➔ Value of a network increases as the square of the number connections
- **Gilder's Law** - Quantization - Continues
 - ➔ Bandwidth increases 3X every 36 months
- **Negroponte's "Law"** - Digitization - Emerges
 - ➔ Superiority of "bits over atoms"
 - ➔ Profound impact felt in "Knowledge Economy" where ideas are ultimate raw material

Key Megatrends Driving Venture Investment

Key Megashifts

Switching is shifting **from circuits to packets.**

Data, then voice; Backbone, then access

Transmission is shifting **from electronic to photonic.**

First long haul, then metro, then local access

Functions are moving **from the enterprise to the Net.**

IP universal protocol/ platform of choice is the Net

Offerings are moving **from products to services.**

"Utilitization" of processing, applications, storage, ... knowledge

Bioscience is moving **from *in vitro* to *in silico*.**

First Genomics, then Proteomics, ... nanotechnologies