CHAPTER 3: CHUNKS & MANTRA

CHUNKS

How many of these "files" can the brain handle at one time? It is common knowledge that humans have a difficult time concentrating on several things at once. George Miller published a landmark article in the *Psychological Review* in 1957, which demonstrated that in general the human mind will typically be able to search for context or differences in four "chunks." We all seem to have a workspace in our brains where up to four different pieces of stored information can be laid out next to some incoming stimulus in an attempt to form a linkage. We try to take some feature of the new piece of data, like one edge of a jigsaw puzzle piece, and find the best possible way to link it into one of the four regions of the puzzle that we have already completed.

Miller's theory is as pervasive as it is simple. His "four chunks" hypothesis is evident everywhere in human perception. Consider the following example: when you drive by a pasture, you can tell from your peripheral view in only milliseconds whether there are one, too, three, or four cows or sheep or horses standing in the field. However, if there is a small herd or flock of say, seven animals, none of us will easily and instantly be able to give an accurate number without focusing and counting the animals. If the number grows to twelve or more it gets even harder. We can tell when a duet is being sung, or a trio or a quartet, but beyond that number it is hard for us to distinguish the individual voices. An anthropologist friend of mine tells me that in primitive and illiterate societies, it is common that counting is performed as follows: One, two, three, *many*. (That's the extent of the numbering system).

Generally, then, we see that we poor mortals are limited by the amount of information we can parse quickly. Further, our experience shows us that it is difficult to build new contexts and to create new paths for information retrieval. We even see that we

must do creative work in our sleep as a byproduct of working difficult and possibly unresolved problems during our day.

Because it takes so much less energy to solve new problems with old mental skills and old patterns, as we gain "enough" experience we settle into comfortable habits at the expense perhaps, of innovative and creative new approaches to the problem. (We also sleep easier!)

FOUR CHUNKS OF MANTRA

Every person builds his or her own philosophy, and according to chunk theory, we all typically try to fit each piece of information to any one of four links at a time. Each of us has four initial pathways along which we generally try to find relevance and meaning for each encounter in our lives. I like to think of these first four options as to whether information has relevance as our "four chunks of mantra."

The trick is to make these philosophic chunks flexible and inclusive enough that we find peace and comfort with each new stimulus. To wit, the information must find a "home" in our network, without being rejected at the gate as being meaningless noise. If it doesn't fit somewhere, we're likely to reject it. The danger is that the philosophy might be inflexible to the point that we reject the vast majority of information, and only assimilate what we already know and believe. At this point, it is no longer mantra, but dogma.

As we grow very old, or if society changes too rapidly to let us build a set of connections, our decades-old mantra may begin to look more like the inflexible dogma described above. If our pattern of thinking is too rigid, we just may not be able to cope. It becomes increasingly likely that most of modern technology will be developed at a pace much faster than we are comfortable with. Society will be solving problems that had no place in our brain while we were forming our initial pathways. It becomes harder and harder for older citizens to really participate in the intellectual debates of the day, unless they keep active in lifelong educational

practices. In previous generations the pace of technology was slow enough, and life spans were short enough, that most citizens were actively engaged in their society's progress until their death. In the modern era, it has indeed become possible, and perhaps probable, that all us may outlive our time.

For my own mantra, I have tried to build a four-chunk framework (i.e., a philosophy) of life that should help me to grow with every new input over what I hope will be a long life. These memes have migrated to my brain from others. I believe that they first evolved in the minds of Marvin Minsky, John Nash, Lord Kelvin, and Carl Sagan, respectively. They thrive in my brain and in society because they are *good* ideas, and therefore are reinforced by providing a good philosophic match to almost every input. (At least, they have so far, but three of these concepts are only one generation old, and may be supplanted by *better* ideas in the future.) It would be a crime not to give them further chance to thrive, so if you care to transplant any of them to your own mantra, I'm sure that they would be happy to settle there.

MY MANTRA:

1) People evolve entirely by their accumulation of knowledge, and they pass that evolutionary gain on to their children. It is our *ideas* that are evolving, not us. Ideas are symbiotic with their human host. Ideas that fit the human environment survive, and those that don't fit do not survive. That environment is the human brain, and ideas need to be transplanted to other brains in order to guarantee survival.

2) People are inherently good, and try to make life better for what they perceive to be the scope of their society, not just themselves. When their scope is broad, society as a whole develops. When their scope is narrow, society locally may temporarily advance, but society as a whole may suffer. A person's scope is largely limited by the extent of their education and by his level of hope.

3) The laws of thermodynamics and of energy are pervasive, and ultimately they drive society. If something takes more energy than it needs to, it will ultimately reduce to a simpler, more efficient state. Such laws of nature will always win against the laws of humans.

4) We need to keep perspective of where we fit in the universe. We need to recognize that we are incalculably small compared to the vastness all around us, and accept humility for what we do not yet know, comprehend, or achieve. At the same time we need to recognize that we are monstrously big and influential—that all species on this planet are affected by what we do—and that we have the power now, or *will have* the power in the future, to affect everything on every scale, from the atom to the elephant, to our village, our country, our planet, and our galaxy.

CHAPTER 4: THE EDUCATION CURVE

ECLECTIC PAST

Now that you know my mantra, let me help you to *really* understand what makes me tick. I have had an excellent formal education, and for that I am forever grateful to my parents. However, a lot of people studied the same textbooks and attended the same classes that I did, so why am I any different than the next guy?

The answer is that I have a chequered past. I'm proud of it. Part of that past has taught me that the proper way to spell "chequered" is exactly the way I do! (It is a very uncreative mind that can think of only one way to spell a word.) I revel in the things that make me unique. Although over six billion people now live on the planet, I am confident that none of them has exactly my set of skills or perspectives.

I grew up in Canada, which by itself already differentiates my thinking from that of many Americans. Canadians use more commas than Americans do, they go to the theatre, not the theater, they keep to the right of centre, and they used coloured money long before we thought of it.

On top of that foundation, people have paid me to do some pretty diverse things, and I've volunteered for some even stranger tasks. I've been a circus clown, a mime, an opera singer, a hockey arena anthem singer, an envelope stuffer, a day care worker, a painter, a deck hand, a writer, and a public speaker. I've run cross-country races and have played basketball and hockey (all poorly).

I've sold popcorn, mowed lawns, been an Air Force ROTC cadet, an occasional preacher, and I've started three small businesses, a mission church of the United Methodist Church, and a nonprofit philanthropic organization. (Please visit www.ScienceNHS.org).

I know that I have had my share of luck. I've dived with the sharks and soared with the eagles. I once jumped out of an airplane. The parachute took its sweet time about opening…that was the last time I tried *that*. That wasn't the only heart-stopping time in my life. I once reached my hand into a crevice to try to catch a lobster, and found myself fingertip-to-eyeball with a Moray Eel. Once I stumbled into a safe robbery in progress, and had to wait to know (deduced from the lack of flying bullets) that the perpetrators were not armed.

For thirty stomach-disruptive minutes I have floated in weightless amazement (twenty seconds at a time) aboard the NASA KC-135 "vomit comet" aircraft. I've been a guinea pig for countless human ground-bound spaceflight experiments.

I've been a laser technician, a machinist, a fluids researcher, a movie extra, a photographer, an astronomer, a carpenter, a bone marrow donor, a pheresis blood donor and a donor recruiter. I've been a CAD specialist, a rocket scientist, a systems integrator, an international negotiator, and (at last germane to the education topic) a research assistant, a teaching assistant, an assistant professor, and a "knowledge engineer." It's in those last few roles that I've come to understand how we all learn things, and why we tend to learn them differently. We'll start into that stuff in another two paragraphs.

By now, you've probably reached the same conclusion I have, that it's unlikely that anyone else has had exactly the same set of experiences or perspectives that I have. However, I know that there are gaps in my education, too, and that millions of others have had rich experiences that I have not encountered. I've never skied, either downhill or cross-country. I've never golfed. Nor have I fathered a child. I've never run for political office, lived on welfare, broken a bone, or had any serious disease. I'm proud to say that I've never gotten a moving violation of any kind in twenty-three years of driving. I've never fought in a war, and I shall unfortunately never personally realize my dream of flying in space.

So, I have a unique perspective that is filled with individual strengths and notable weaknesses. You too can build a similar list of eclectic experiences that collectively are yours alone, making you unique in all the world. However, as we shall see, our experiences are just the *inputs*. How we link them in our brains is the basis of our philosophy, our mantra, and all our problem solving, and is the stuff of which souls are made. How we problem solve—that is to say, our *output*—is how we help our children to evolve.

COGNITIVE SCIENCE

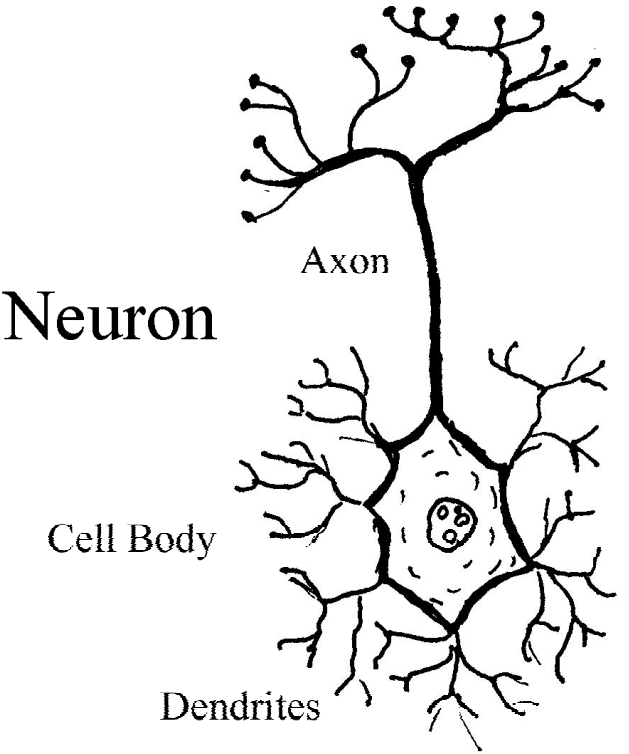
A computer has very regimented ways of storing, indexing, and accessing its data. So does a human brain. We name the process of storing and linking our information "education."

It has been well shown in the literature that people reason by analogy, and store information by connecting it to pieces of knowledge that they already have. George Miller's chunk theory shows that we seem to be able to do this along any one of four paths at once, whether in response to sensory stimulus or abstract thought. How do we do that? Somehow the real world gets represented in that mass of tissue called a brain. Here is (approximately) what may be happening in there.

The human brain weighs approximately one and a half kilograms (2% of the body) and consumes 20% of all the body's oxygen, which means that about 20% of all the body's energy is expended there: ten times more than "its share." It is mostly nerves, suspended in a fatty tissue that serves to support and to protect the nerves along with blood vessels that deliver the oxygen. The brain is bathed in a limbic fluid that helps to transport nutrients, regulating chemicals, and oxygen, all inside a limbic membrane. Two of the literally dozens of regulating chemicals ("*neuroregulators*") are dopamine and serotonin, which respectively encourage faster reaction and moderate it as required. Women seem to naturally have more serotonin and less dopamine than men. This may partly explain why men love to channel surf, and

women want to stop to absorb a little more before changing channels.

The brain has several identifiable geographic features, layering out from the intersection with the spinal cord in patterns that show a steady evolution of advanced cognitive capability from reptilian brain at the center, to mammalian traits, and then to elaborate reasoning areas called the cortex that are proportionately larger in humans than in any other primate.



Neurons grow and multiply in the brain until late adolescence, and then stabilize in number. There is strong evidence that the neurons in the brain form *permanent* physical

pathways that connect the individual packets of information. These "packets" are each one or more points where neurons touch each other, called a *synapse*. One cell's side of the synapse (called a *axon*) is able to send an electric signal, and the other cell's side (called a *dendrite*) is able to receive it.

This model of thought requires that the nerve itself must persist for your lifetime, unlike any particular skin cell, which can die and be replaced). Each of these neurons (or centers of neurons) has links of varying strengths to other memory packets, probably quite nearby. There are estimates that the human brain has over one trillion neurons, and each of them has approximately one thousand connections. We are therefore capable of storing a maximum of one thousand trillion (one quadrillion) bits of information, or one petabit. This dwarfs even the most powerful of today's computers.

Ideas and concepts are thus "hardwired" in a logical network. Each thought is an activation of a few of these electrical synapses. The neurons whose dendrites make these synapses activate several or all the synapses that their own axons make, building a kind of electric circuit. There are, of course, thousands of possible directions for the circuit to progress once any one synapse has been stimulated. The brain selects one to four paths to follow, triggering synapses down the line. The "train of thought" is kept open until a match is found for relevance. If no relevant region of the brain is found, then the brain backs up the "thought train" a neuron or two, and activates other possible routes from one of the connected axons. Once a match is found, the electrical pathway between the two packets of information is allowed to relax, enabling *new* thoughts to occur.

How then do we remember that we linked two concepts, after all that effort? Aftereffects of the chemical process of triggering the synapse essentially weaken the resistance slightly between the dendrite and axon. If you trigger a synapse many times, it strengthens, just as a muscle builds up if you use it a lot, or

like a path through an open field if you often walk along it. More heavily-traveled routes *stay* that way by minimizing the electrical resistance between connected dendrites and axons. Thus, certain pathways are activated more and more automatically to link related ideas. We call this *memory*.

Gradually, our response to any stimulus results in traveling in the most obvious and well-worn path directly to a behavior that has been shown through experience to be our most appropriate response. When this becomes instantaneous and subconscious, this instinctive and automatic "hardwired" connection between stimulus and response is called a *skill*.

When we are young of course, we do not have such skills built in. (Those very few skills that *are* built in are called "instincts."[1]) Until our middle adolescence we humans spend a large fraction of our time gathering experiences and linking them into a personal perspective or context. Anyone who has ever seen a frustrated student trying to make sense of her world will recognize that this process is quite hard. It takes tremendous energy and mental focus to lock such experiences away in our internal network. By contrast, once the experiences are there and locked in, it becomes a relatively trivial matter to connect the stimulus and the response.

In a young child, this linking of dendrites and axons is a natural occurrence. They are constantly building permanent new pathways in their brains in response to the sea of new information presented to them. Child psychologists expect to see a regular pattern of development of a child's mind that covers many years at a typical, expected pace. Sometimes these patterns are slow to develop, and the child is diagnosed with a learning disability. These

[1] One of the fascinating aspects of human and animal development is the concept of instincts and of imprinting. We have yet to understand how some behaviors emerge already hardwired in our brains, such as the tendency to grasp when touched. Somehow, the data encoded in our genes passes a minimum set of architectural information on to the neurons it forms in each new child.

disabilities can often be corrected or compensated for, and are really just a natural statistical variation around an average: nothing to be concerned about. In a few cases, they are chronic and severe, even though the mechanical difference in neural function is likely *very* small among a "normal" brain, a genius, and an abnormal one.[2]

Since we burn energy in all these synapse activations each time we try to find relevance, we grow weary of the constant effort it takes to uniquely file each new piece of information. It gets easier and easier to simply catalog each new bit of information either as immaterial noise that we do not care about, or as an example of something we already know and understand. We build a certain philosophy of life that allows us to be familiar with new information, and to avoid the stress of trying to make it fit somewhere in our brains. As you will recall, this automatic patterning of all our inputs is our mantra.

The trick is to keep linking the information in, and not filtering it out as "already known" or "irrelevant." Linking it in takes energy. Albert Einstein once said, "Things should be made as simple as possible, but not simpler." It is dangerous to reduce your entire understanding of a philosophic issue to words that can fit on a bumper sticker. Keep your mind open, or your mantra will turn into dogma.

DREAMS

As we go through our day constantly assimilating new experiences and inputs, we *try* to match these inputs to problems that we have already solved. Ask any schoolchild—thinking is hard work. Anyone who has ever searched frantically through stored paper records for one key document can understand the amount of

[2] There is a fascinating new study from the University of San Diego that indicates that autistic children may, in fact, make the permanent connections and pathways in their minds at a much faster rate than other children. This phenomenon hardwires their brains into lifelong patterns long before they have had a chance to assimilate all the social norms.

anxiety and frustration that builds as countless immaterial files are searched.

The same is true in our minds. Imagine that your brain is sifting through its own file drawers at a rate of one file every 30 milliseconds. A few at a time, we bring mountains of previous facts in to our mental workspace, where we compare it to the problem at hand for a possible "fit" of relevance. Every fact that we bring is electrically stimulated at the far end of a long neuron chain. Whenever we do find an excellent match, a little pathway is built between the new problem and the old fact. It is the purpose of our brain to make those electrical connections. We feel satisfaction and relief when the connections are made.

What then happens to all those snippets of information, facts, and responses that are excited in our little workspace, but which are *not* found to be relevant to the problem of the day? We don't solve every problem that comes our way. Those unmatched patterns need to be relaxed somehow, or we will build stress and anxiety by having so many excited but unresolved problems lying around. I personally believe a theory of dreams that postulates that humans sleep so the mind can ignore all external stimuli, and instead work to relax all the excited regions of the brain that had not previously found a new link.

Normally, we do not remember our dreams. There's no reason to…their *job* in life is to clear out the recent memory banks. When we do remember them, we find that they typically center on people, places, and things that were recently in our thoughts, although the stories we recall are fantastic and sometimes nonsensical. This theory of dreams implies that we have written a story for ourselves that links these disjointed thoughts in a whimsical tale that flows in a line like a necklace of discarded beads. Because a link has been made our minds can relax all those excited regions. Because it is a nonsensical (albeit a very creative) story, we are unlikely to ever travel that particular pathway again. The weak paths we create between these disjointed thoughts are

just enough to walk back to a relaxed state, but not enough to establish any route for the brain that we might travel again.

CREATIVITY

Creativity is the process of connecting ideas in ways that others have not seen before. While it is not necessary to have a broad education in order to be creative, it certainly helps. The mere fact that there are more ideas and concepts somehow connected within one brain makes it more likely that a direct link between two previously unrelated ideas might be stumbled upon. As Dean Keith Simonton has said, "Creativity is favored by an intellect that has been enriched with diverse experiences and perspectives."[3]

The human mind is *naturally* creative, and constantly seeks ways to map its stored information into a more and more cohesive whole. It is like the assembly of a jigsaw puzzle: it is one thing to have all the pieces lying on the table—it is quite another to enjoy the experience of linking the pieces together. Each link brings satisfaction and builds a greater sense of accomplishment as the integrated picture comes into view.

There is a theory of humor that states that every comic event is based upon some measure of surprise.[4] Consider a well-told a joke. As the punch line is reached, the entire audience sees a link among the story elements that had previously been hidden. There is a sudden outburst of relief (that we call "joy") as the final connection is revealed. The joke only works if every member of the audience sees the link and understands why the disjointed pieces are related. Tension is violently released from the body in the form of laughter, as the pieces of the puzzle are linked.

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[3] Dean Keith Simonton, from *Origins of Genius*

[4] Slapstick is the lowest form, where some outrageous event happens to an unsuspecting victim: i.e. the victim is surprised. Many comedians resort to language and concepts that are inappropriate for normal social behavior. Each utterance evokes surprise in the audience, in the sense that the dialogue exists in a realm far outside of their daily experience.

So too does the human mind rejoice in finding new links. We love to see things in context because it relaxes the tension in our minds. We stay in a state of awe after a magic show, whose surprises entertain us, but leave us giddy with excitement, rather than exhausted with laughter. After a magic act, we feel the surprise, but have hundreds of loose ends that we cannot tie together at the end of the act: "*How* did they *do* that?"

NO-CONTEXT EDUCATION

There are some things in modern society that each of us find incredibly frustrating only because we have no context for the information that we must incorporate into our lives. Don't you hate it when you get a new credit card or other account and the bank insists that you remember a new string of four numbers to use as a password if you ever need automated service? Where do you store those numbers in your brain? What mnemonic will instantly bring those from memory in a time of need? We have no context for remembering where these numbers are, or how they are to be used.

One of the most frustrating examples of "lack of context" is the lack of inputs into devices such as remote controls for television, pagers, and cellular telephones, which each provide us with many dozens of functions, with sometimes as few as one or two buttons to enable us to communicate our needs to the gadget. We older generations are used to the idea of only one function per button. Preferably, that button should be clearly labeled.

These days, it is impossible to label the button, because we'd run out of space to define what it is the button does. While we may not be comfortable with this multi-functionality of buttons, children today have no problem programming the video recorder to capture their favorite show. They have learned patterns of information storage that easily let them recall how such limited inputs can be used to do hundreds of functions. Most of the rest of us have learned to live with the useless, flashing 12:00 on the

VCR, rather than to try to fathom the new language of the single-button semaphore.[5]

MULTI-DIMENSIONALITY

We humans typically find *many* ways to index the same information. We might store away the concept of *tomato* in our minds with links to things like gardens, red things, round things, things that rot easily, things that make juice, Italian cooking, new world discoveries, or things that rhyme with "potato."

When we experience any new stimulus, we do so on a multi-dimensional basis. We remember the place, the temperature, our mood, the time of day, the smells and tastes and feel of the environment, and every other detail in the experience as a possible link to the new information that we are storing away in our brains.

One key problem of the information age is that the inputs we gather over electronic means lack most of the contextual and sensory information that helps us to index and sort the stimuli we

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[5] Once at NASA, I took part in a study with several astronauts and robotics designers as we tried to build the interface to the space station robotic systems. These tele-operated devices would be arriving onboard Space Station from manufacturers all over the world. Together, these robots would perform scores of different operations. We were trying to develop one common set of hand controllers that would move, rotate, grab, release, rigidize, go limp, pan, tilt, zoom, focus, illuminate, and do other functions. Most of these robots had numerous joints that would either work in concert, or would each need to be commanded separately. In each case, buttons and knobs on the hand controllers would be called upon to perform different functions at different times.

We found ourselves on the opposite side of the problem, now trying to force hundreds of functions into a limited number of switches and buttons that would be placed on the hand controllers themselves. One of the astronauts, the late Lacey Veach, coined the term: "nubology" to describe the science that we were trying to invent. Today, despite all our efforts, it still takes least a year to be declared proficient in the use of these controllers, and to effectively run the numerous operations of the space station robots.

get in other parts of our world. Even though we have daily teleconferences with our international partners and other space centers around the United States, we at the Johnson Space Center find that a significant fraction of our most productive work is done in those few days per year when our partners come to visit us or when we have the opportunity to travel to visit them. There is something about face-to-face contact and the ability to share the same environment that facilitates debate and agreement on all the topics we discuss. Why should this be true, when we are only debating mathematical and scientific concepts that are mostly abstract or cerebral? Somehow, it's the total stimulus of the immersion in a common situation that makes common understanding easier.

We'll go into this more in the next chapter, but this absence of sensory immersion is going to be with us for awhile, and will shape a lot of what we can and can't count on telecommunications to do for us.

THE CHANGING FACE OF EDUCATION

In ancient times it was possible for a child to learn all that was necessary to function in society by the time he or she reached adolescence. In feudal times the concept of childhood as a separate stage in human development was quite foreign to the educated minds of that era. Children were raised as if they were small adults, and they were expected to perform adult duties to the maximum extent of their physical capability. Children were routinely married in their early teens and death came at an early age.

Throughout the Renaissance and later the Industrial Revolution, the knowledge of mankind grew at a geometric rate. Our society has become far more complex, and now students must spend increasing numbers of years preparing to function in our new society. This has placed an unnatural stress on the youth of today, for we now ask—and even demand—that our children suppress the biological urge to mate and the adolescent imperative

to separate from family while we delay their entrance into adulthood. Human bodies were designed for a society that has been left behind by the advances of human intellect. This situation becomes more and more exacerbated by the astounding growth in our societal demands.

I think that there are many forces at work in modern society that will change the face of education more dramatically in *this* generation that we have seen in the past several hundred years. First of all is the problem of the rate at which society is increasing the body of human knowledge. Because the knowledge of mankind now multiplies *many* times during a single lifetime, it has long been recognized that continuing education is an essential part of most businesses and professions. Why would you delay entrance to the workforce if you're just going to get sent back to school (for pay) as soon as you get a job? The complexities of the modern workplace—especially in high-technology fields—have led to an increase in the number of students and businesses seeking to establish internships as a necessary part of grooming the student for the real world. The ancient practice of apprenticeship is coming back into vogue.

The sudden rise of the Internet as a tool that can accelerate and focus searches for information is the other key factor. Any student at any grade level now has access to the same body of information that supports researchers at the highest levels. This allows a motivated student to explore and to progress at much faster rates than society previously thought possible. The Montessori educational system emphasizes this ability to accelerate at the student's own pace, when he or she is ready to learn. The Internet puts that philosophy in play, even for students enrolled in a more traditional public school. Further, the Internet lowers the cost of delivering information, and provides a more flexible schedule of delivery. These features will trigger a whole new balance in the roles of distance learning, continuing education,

home schooling, peer counseling, gender and ethnic diversity, and other facets of the education process, far from their current norm.

APPRENTICESHIP

One feature that will drive the shape of education in the future is the *pace* of the nine stages of technological development as they cascade faster and faster from the moment of scientific discovery. Across the country, universities are establishing industrial parks and collaborative technology centers whose mission is to commercialize the university research. The line between academia and business is blurring. In the future, I foresee an even stronger link between universities and commercial partnerships.

For instance, Texas Tech University has an International Textile Research Institute that includes the capability to make small lots of customized fabrics, fibers and blends. It is important for the faculty and students to gain experience with the emerging fiber technology, just as it is crucial for the major textile companies to have access to innovative minds and inexpensive prototyping facilities. Indeed, there is a constant flux of industrial work channeled through this research department, and a constant flux of talented graduates who earn positions all over the world with the customers of the laboratory. I see more of this type of cooperative, apprentice-like participation in the future.

NASA encourages space grant consortia among universities in different regions of the country, wherein specific high-tech developments targeted at the agency's needs are funded within the university setting. There are thousands of similar examples. I see that this trend will blur the line between industrial and university research, thus blurring the line between industrial and academic endeavors as a whole.

THE COST IN TIME AND MONEY

Juan Enriquez has pointed out in his landmark book *As The Future Catches You* that in 1966 the cost of sending a child to private school or a year of college was approximately 537 work hours. In 2003 the cost had risen to nearly 1300 work hours—more than half the available work hours in a year. Notice that the amount of acquired human knowledge nearly tripled in that time, and so did the cost of acquiring that knowledge through conventional education. What is going to happen when we've doubled our knowledge in the next fifteen years, or quadrupled it in the lifetimes of our children? Will we all end up working the rest of our lives in order to pay the cost of our children's education? How long will they need to study to get up to speed?

Before the beginning of the universities, students learned the basics of agriculture, married, and were full members of society by their mid- to late teens. In the early universities, the student's degree was complete by age twenty. In modern times, the bachelor's degree is typically completed at age twenty-one, but advanced fields of study may keep the student from entering society until he or she has reached nearly age thirty. Meanwhile, the economic incentive to join the workforce is enormous. There is a small economic advantage to acquiring a master's degree beyond the bachelor's (and it is usually not a sound economic plan to get a Ph.D., which is why there are so few Americans getting them), but a majority of the master's degrees are awarded to part-time students who are already out in the workforce. They want to get settled at home and work as soon as possible, and then add education back into the mix. Faith Popcorn calls this phenomenon "Anchoring."[6]

BACK TO THE FARM

The urge to nest at home penetrates deep into the younger generation. I have become increasingly aware of the surge in home

[6] Faith Popcorn: *EVEolution*, page 1

schooling in recent years. There are probably as many reasons to home school a child as there are parents. I used to believe that the practice was done primarily for religious reasons, but increasingly I find parents who choose this route because the intimate setting can stimulate concentration, and because such a small setting virtually guarantees that the child will progress at a rate closely matched to his or her natural ability. This is particularly important for students at the extremes of the distribution of intellectual ability, where for the high achievers it is all too easy to "zone out" of a class that is too slowly paced, and for the low achievers it is difficult to make connections between ideas. New inputs to this latter group quickly become just noise.

One day I was giving a lecture to a group of home-schooled children at a museum. I was discussing the International Space Station, and used the opportunity to greet the children in many of the sixteen languages spoken by the participants in the project.[7] I was stunned when a blond-haired blue-eyed seven-year-old girl approached me after the seminar and began to converse in fluent Japanese. "I just thought it would be fun to learn!" she said. Imagine her sitting in a first-grade English class. (See Jane. See Jane daydream.)

Perhaps the brightest student I have ever met was home schooled in a tiny town on the north island of New Zealand. She is accomplished in aeronautics, art, athletics, and photography; winning several international competitions by the time she was fourteen.

Although there is a great potential that a home-schooled child will miss out on much of the necessary social interaction from a peer group, home schooling unquestionably enriches the diversity amongst students growing up in today's society. There are great

[7] I am conversant in English, French, and Russian, and I know a very little bit of Japanese, but I've had to ask where the bathroom is in eleven different languages so far!

risks, but also great potential benefits in parents taking a dominant role in their child's education.

NOT IN THE CURRICULUM

Over the past few centuries, there has been a progression away from Latin as the official language of science and technology. There was a great leap forward in the church (along with great social turmoil) when the Bible was translated into German, French, and English. Similarly, other information-rich fields such as the law and medicine have been brought within reach of the common citizen as a result of the steady conversion of sacred knowledge into common language. Similarly strong social upheavals are gradually building in response to this opening of the closed worlds of the doctor and the lawyer, just as there were upheavals when the world of the theologian was opened to the public.

The torrent of unfiltered information in today's world makes it all the more important for the student of tomorrow to embrace critical thinking as the most important skill. While we do not mourn the loss of Latin as a required subject, rhetoric and logic are becoming lost parts of the liberal arts, and must be resurrected in today's information age. No one wants to limit free speech, at least not at its source, but I truly hope that my stepdaughter builds enough of an internal filter to avoid ever saying something like, "I read an article that says all I have to do is eat grapefruit and I'll never have cancer."

THE CREATIVE CLASS

If you think about it, only a small percentage of the population is involved in the process of creating new technologies, new laws, and new medicines. These few people are shaping the way that all society will live in the future. In a high-technology society, this educated fraction is larger than in lesser-developed countries. In his book *The Rise of the Creative Class*, author Richard Florida examines modern American society. He identifies a group

he calls the creative class, consisting of approximately thirty-eight million adults who are actively involved in the design of new products and services.[8] Florida's creative class includes professionals in science, engineering, architecture, business, law, finance, and the health care fields.

Florida states that his creative class is involved not only in solving problems, but also in identifying the problems that we shall solve next. In that context, it is clear that they actually *shape* society as well as fix its ills. Note that most truly successful companies become successful by solving a problem that few people recognized in the first place. Who really understood in the early 1990s that the ability to search across the globe for arcane bits of information was a latent need of society, or that the solution of that unseen problem in the form of the World Wide Web would create instant financial empires that drive the world's economy? Bill Gates saw that the world needed an operating system for personal computers before anyone else on the planet knew what either of those were.

There is a somewhat fuzzy gray line that one draws at the boundary, but there is a philosophic distinction to be made between the vast majority of the population whose occupation is in some form of service versus that portion of the population that is involved in creating permanent change. I put lawyers in the first class, and engineers in the second. However, some engineers build old-style structures without innovating, and some lawyers create new legislation and direct landmark cases that forever change society. There is no simple way to cubbyhole people by their careers.

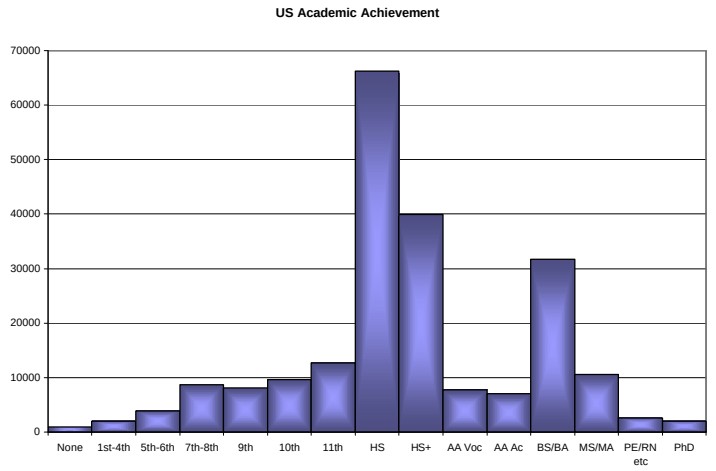
Typically, members of the creative class are college educated. This is not an absolute requirement: look at the likes of Bill Gates, Michael Dell, and the Wright brothers. However,

[8] Personally, I believe that Florida overestimates the number of people involved in creation of a new society, because he includes creators of such fleeting things as music and advertising in that group.

education of less than a four-year college degree is not common in the creative class). Look at what we pay for these educated minds and new ideas. Between the years 1979 and 1999, College graduates' incomes rose by 14%, while high-school graduates lost 12%, and those without a high-school education lost 27% in average real income. Even among college graduates, there is a significant difference between those who work in technological fields, and those who do not. Clearly, just within the past generation, modern society has started to create a higher sense of value around its high technology priests.

THE EDUCATION CURVE

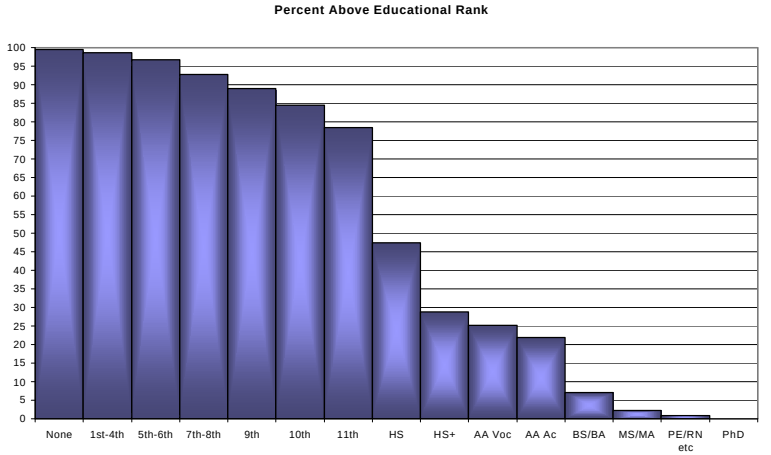
The current census of the US population shows the top level of academic achievement of all people over the age of 16. National statistics show a nearly a Gaussian (bell-shaped) curve revealing that the average educational achievement of adult Americans is only the completion of a high-school diploma. Half the population has less education than this and half the population has more. Look at the plot. Where will you find a doctor, a lawyer, a congressman, corporate executive, priest, or rabbi? It's clear where the leaders of society are.



The curve falls off rapidly in each direction, although there is a significant hump where a disproportionate fraction of higher educated individuals complete a bachelor's degree. Of course, if it weren't for dropouts like Bill Gates, Michael Dell, Orville and Wilbur Wright, Sir Trevor Baylis, and John Harrison, where would the world be now?[9]

Plotted the other way we find that only seven percent of the US population has more education than a bachelor's degree. Completion of a four-year college degree therefore puts a student in the elite group that will guide this nation. This group includes the businessmen, the lawmakers, the expert witnesses- all manner of professionals who shape current society.

An even smaller fraction continues on for the highest levels of academic achievement. These are the doctors, the lawyers, the university professors and other highly skilled professionals who solve our most critical needs, and who are our tiniest minority of academic achievers.



[9] Gates built Microsoft, Dell founded the computer company that bears his name, the Wrights invented the airplane, Baylis the clockwork radio, and Harrison the marine chronometer. None of them finished college before stunning the world with their inventions.

Although I hold a Ph.D., I've come to understand that high academic achievement is not necessary for most people, even if they are in the creative class. After the first one or two technology readiness levels, you need far more worker bees and fewer queens. The practices and skills that I developed as a doctoral student are vastly different from the skills that I use as an engineer within the space program. Only the payload sponsors and the research specialists who conduct the actual science onboard the station are involved in *research*. We engineers work in a world of standards, of quality control, of budget, of teamwork, of contracts, and of schedule to design and to build the astounding vehicle on which the research is carried out. We don't learn these practices in school. We learn them on the job. All previous academic exposure quickly becomes dormant, but not obsolete. Every now and then, we become absolutely dependent upon the information locked away in some engineer's head, known only because of previous academic work. That's why it pays to have as broad a set of backgrounds and academic exposures as possible on a team.

DIVERSITY

Statistics vary widely, but it is evident that while significant gains have been made by previously under-represented groups in academia and business, most minorities are still not represented in the creative class in proportion to white males, and this disparity is most dramatic in the technological disciplines. As Juan Enriquez points out, we are facing a crisis in ethnic diversity in our educational system. Although there is ethnic diversity in the US universities, most of it comes from foreign nationals who choose to get their education here. One-third of all the Ph.D.s awarded each year in America go to citizens of Asian nationality. A similarly large fraction of Ph.D.s goes to foreign nationals of all backgrounds, while the American minorities are receiving nearly no doctorates. One university research program with which I have regular contact has *no* American students in its graduate

department. Two percent of the Ph.D.s awarded each year in United States go to blacks, and one percent to Hispanics. Enriquez cautions that this is an *exceptionally* disturbing trend when you consider that the most common first name of children born each year in California is José.

Meanwhile, American women are at least going to college in greater numbers- in fact, freshman women now outnumber men. Unfortunately, those numbers aren't in the technology and science fields. Crystal's college is mostly female, since it is a school that focuses on business administration of the fashion industry. Cultural stereotypes are still prevalent, and their effect is more pervasive and subtle than you might first realize.

Dr. Elaine Seymour of Colorado State University has done a comprehensive study on the reasons why universities fail to retain the women and minorities who register in the techno-creative fields of science, mathematics, and engineering. She points out that there is a "gentrification" heritage in the scientific community that goes back to the very beginnings of Western scientific endeavor. This heritage includes the concept of religious (i.e., male) philosophers, gentleman scholars, and now a very competitive and selective business climate that reinforces longstanding male rites of initiation.

The prejudices and ingrained systematic biases in the practice of modern science and education are subtle but deep, even in elementary education. The landmark case of Brown vs. Topeka Board of Education was settled over fifty years ago. However, equality of education is still not reflected in current educational statistics despite focused legal and civic efforts for over two generations. If we're not making much headway after two generations of intensive effort, it is easy to see that we probably have a long way to go in those areas where we are perpetuating customs of which we are not even fully aware.

Dr. Seymour's work suggests that much of today's diversity problem is that our educational methods are still targeted

at the population that, until only a few generations ago, was the only group being groomed in western scientific thought. The problem, she asserts, is that equality for women and minorities will not necessarily flow from just opening the door to the traditional (read: white male) classroom, without accommodating the inherent differences in the diverse group that is joining the discussion.

Clearly, anyone who is ever been on a date will recognize that men and women see things differently. Maybe it's our levels of dopamine. (They don't call men "dopes" for nothing!) John Gray has made a substantial amount of money by exploring our differences in his book *Men Are from Mars, Women Are from Venus: A Practical Guide for Improving Communication and Getting What You Want in Your Relationships*. Formerly male universities have entered a new social relationship by accepting female students. Are they getting all they can out of that relationship, or are they just assuming that the coeds can simply mimic the men and do fine?

I try to be aware of my own biases. Of course, it is almost impossible to diagnose yourself. These biases are pervasive and insidious, and the memes associated with them camouflage themselves in our own brains as part of our "natural order of things." A few years ago, I was in Delaware giving a speech about the future of technology to over three thousand students. I had worked for months to try to find stimulating examples of where technology and society were going, and the students seemed to enjoy the speech as much as I did. However, several hours later one young lady who appeared to be on the verge of tears approached me. She asked me if I was aware that in my forty-minute speech about *her* future I had not given one example of any research being conducted by women. Dr. Seymour is right. We are all affected by cultural bias, and we need to be vigilant. We'll talk more about culture in Chapters 5 and 13.